Introduction to the Integrated Modelling & Analysis Suite (IMAS)

S.D. Pinches

On behalf of Plasma Modelling & Analysis Section
and IMAS Contributors

ITER Organization

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

Outline

- Introduction
  - What is IMAS and what is it for?
  - IMAS infrastructure: Data Dictionary and Access Layer
  - Physics codes and creation of actors
- Preparations for ITER data processing and analysis
  - Creation of predictive simulations of scenarios
    - High-Fidelity Plasma Simulator
  - Synthetic diagnostic data from diagnostic forward models
  - Data processing and analysis
- Summary

ITER's Integrated Modelling & Analysis Suite

WHAT IS IMAS AND WHAT IS IT FOR?

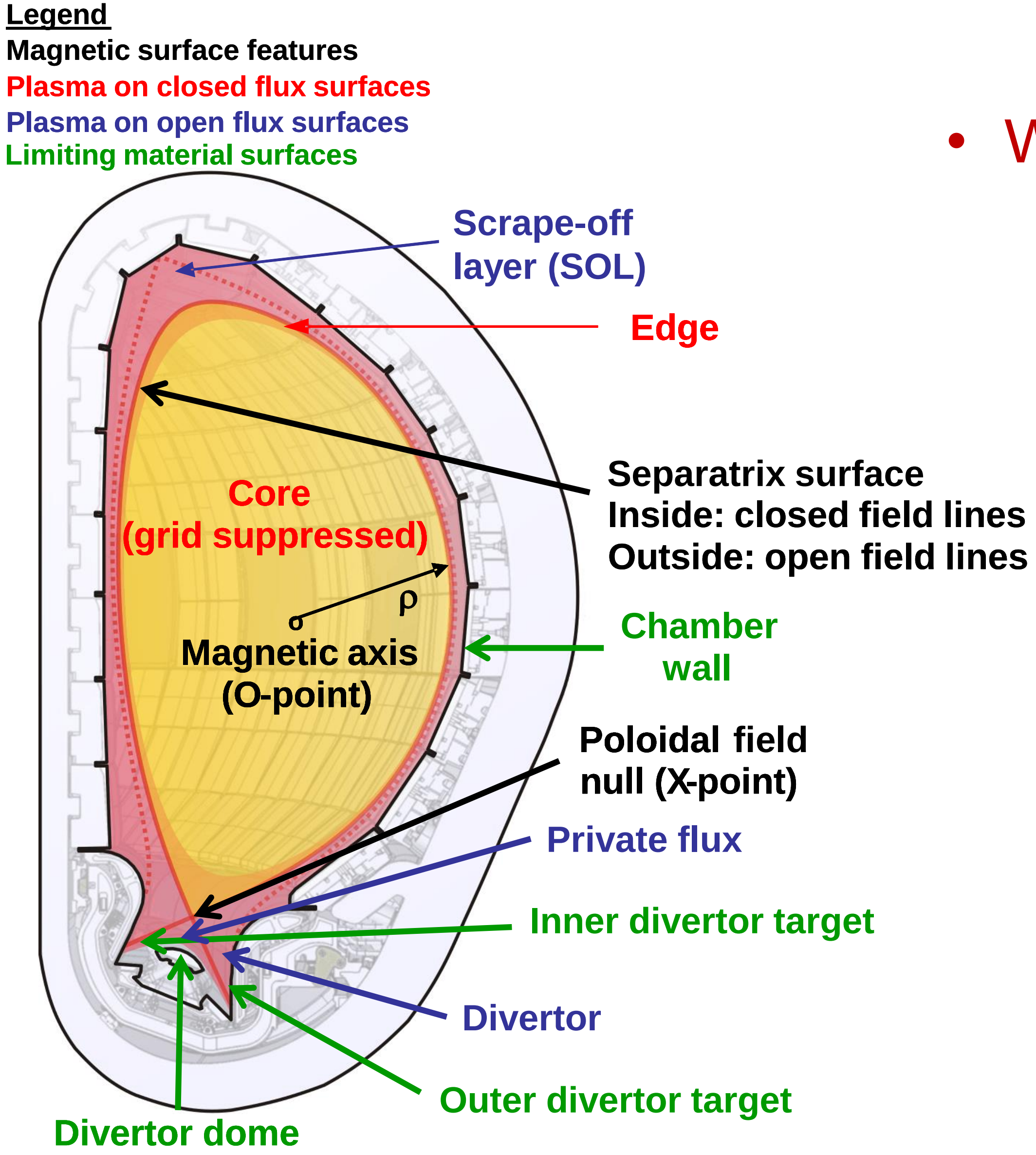
IMAS for beginners

- The Integrated Modelling & Analysis Suite (IMAS) is the collection of software that will be used for all physics modelling and analysis at ITER
- Uses a modular approach that builds around a standardized data representation that can describe both experimental and simulation data for any device
- Inclusion of machine description data allows development and validation of machine-generic components and workflows within ITER Members' programmes before application on ITER
  - Allows ITER Members to contribute to (and benefit from) developments including:
    - High Fidelity Plasma Simulator and its components
    - Data processing and analysis tools
- More information is available at https://imas.iter.org

Outline of ITER's IM and Analysis Needs

- Predictive workflows for simulations of ITER operation
  - Complete pulse from breakdown to termination
  - Respecting plant limitations (e.g. PF circuits)
  - Free-boundary magnetic equilibrium evolution including realistic plasma transport
    - With multiple impurities (W, Be, He, Ne, Ar, N,…)
  - Extensible to include the plasma edge, scrape-off layer (SOL) & plasma facing components (PFCs)
  - Modular inclusion of sources: heating & current drive (H&CD), fuelling (pellets & gas)
  - Description of transients: confinement (L-H), instabilities (e.g. MHD)
- Hierarchy of validated physics models and workflows of varying degrees of physics fidelity and computational performance
  - Scenario development and physics validation tools including interface with Plasma Control System Simulation Platform (PCSSP)

Physics Integration Challenges

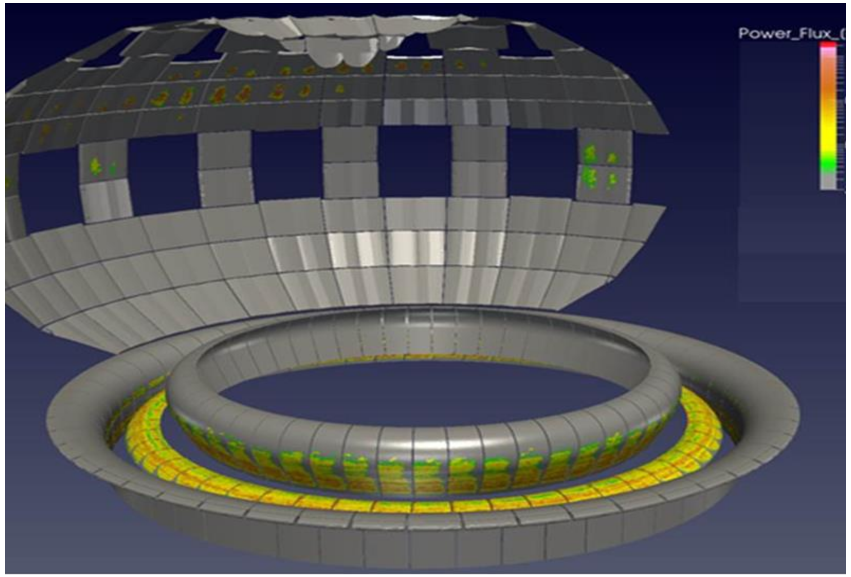


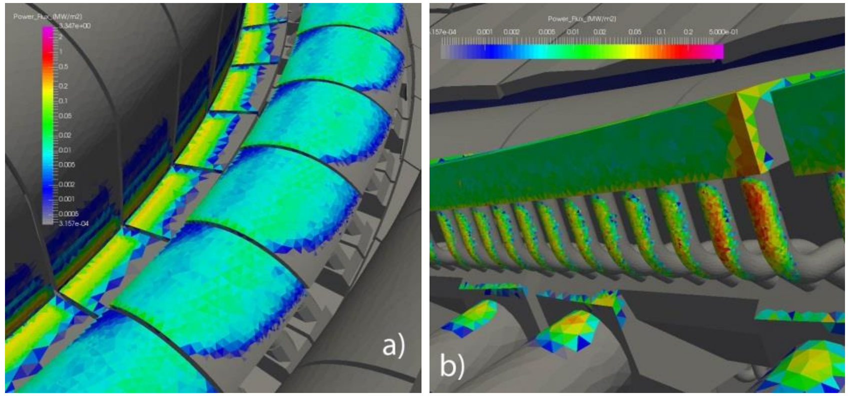
- Will ultimately require:
  - Coupling of all spatial plasma domains (core, edge, scrape-off layer & divertor)
  - Dynamic coupling of individual physics models relevant to each domain
  - Interaction between plasma and plasma facing components
  - Coupling of plasma with external circuits, heating & current drive, 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 ×50 over single core by using GPU to follow fast ions
    → ×200 using four GPU cards
- Exploit Machine Learning (ML) techniques
  - Speed-up transport models by $\times 10^7$

Beam ion power flux due to 3D fields from ELM coils, TF ripple and ferritic inserts



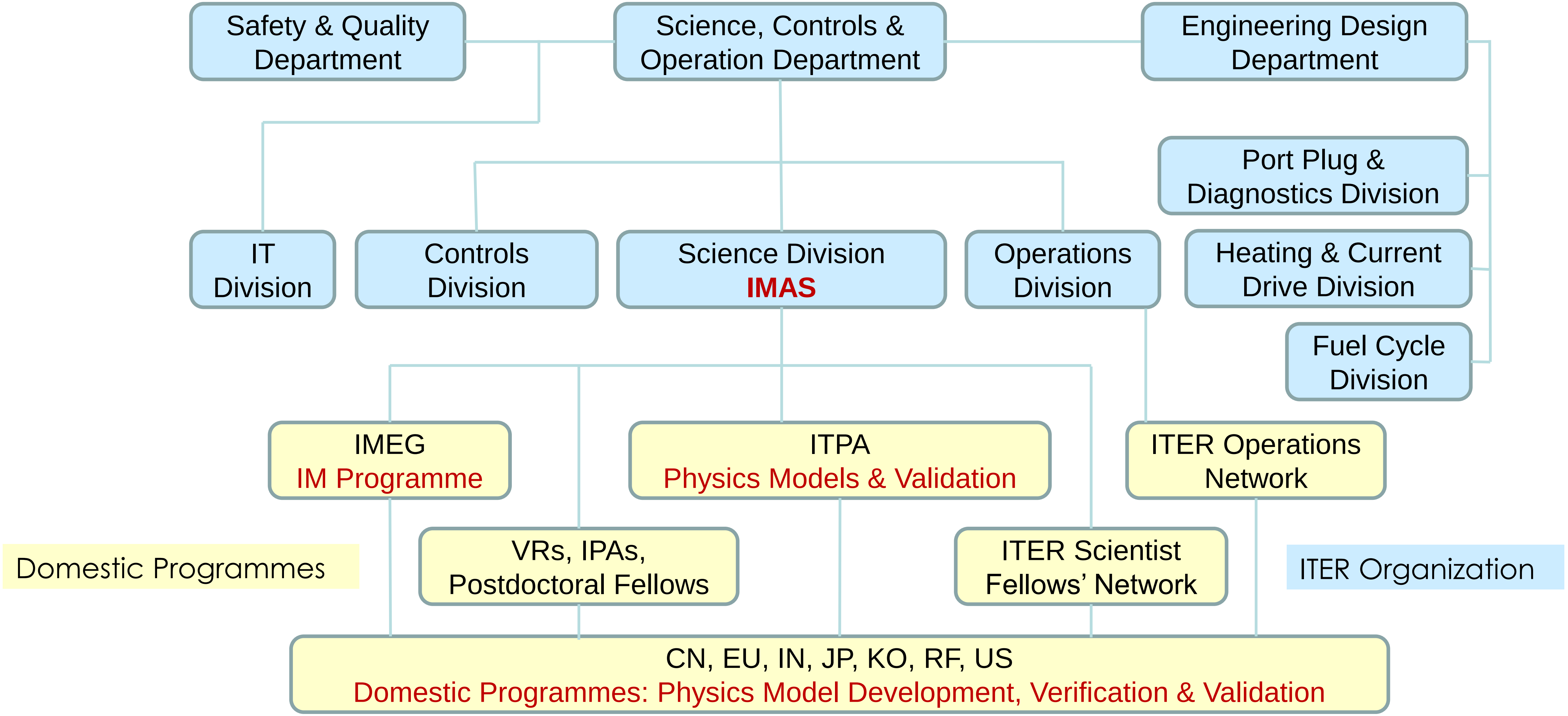


R. Akers *et al.*, LOCUST-GPU

Outline of ITER's IM and Analysis Needs

- Analysis, data processing and visualisation tools
  - Hierarchy of plasma reconstruction chains: magnetics-only equilibrium reconstruction → interpretive transport simulations
  - Inference capability to determine physics parameters and their uncertainties from raw measurements
    - Flow-down of diagnostic signals to meet Project Measurement Requirements
    - Diagnostic models (synthetic diagnostics) to support design and performance assessments
  - Data visualisation tools capable of supporting Operations (including Live Display) and Research
  - Tools to support data discovery and listing/filtering data by given criteria

Coordination with ITER Members



IMAS Framework: Data Model & Access Layer

INFRASTRUCTURE

Data Model

- Data Dictionary defines structuring and naming of data
  - Same data structures used for both experimental (all devices) and simulation data
  - Applicable to all devices (includes Machine Description data) – not restricted to ITER
  - Precise design rules ensure global homogeneity
  - Uses a tree structure (allows re-use of names)
  - Well-defined lifecycle procedures allow collaborative evolution of Data Model
- Interface Data Structures (IDSs)
  - Standardised entities for use between software components and storage
    - Examples include plant systems (*diagnostics, heating systems*) and physics concepts (*equilibrium, core plasma profiles*)
  - Contains traceability (provenance) and self-description information
  - Supports modularity and facilitates interchange of components from contributors

IMAS Data Model (3.34.0)

See talks by Shaun de Witt, Marcin Plociennik, Michal Owsiak, & Pär Strand today and Friday

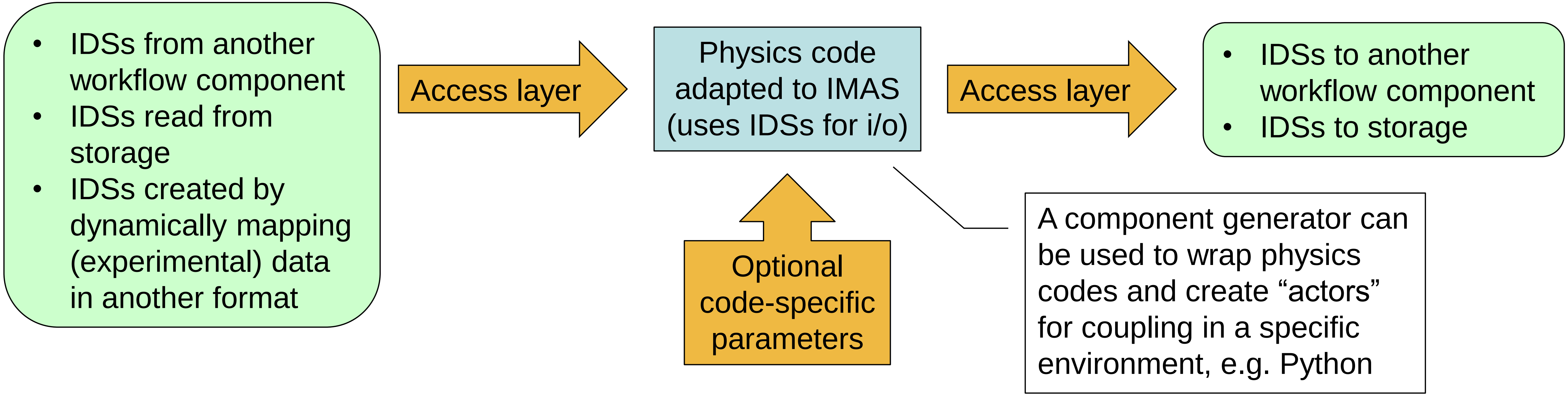
Heating systems | Diagnostics

amns_data	disruption	iron_core	reflectometer_profile
barometry	distribution_sources	langmuir_probes	refractometer
bolometer	distributions	lh_antennas	sawteeth
bremsstrahlung_visible	divertors	magnetics	soft_x_rays
calorimetry	ec_launchers	mhd	spectrometer_mass
camera_ir	ece	mhd_linear	spectrometer_uv
camera_visible	edge_profiles	mse	spectrometer_visible
charge_exchange	edge_sources	nbi	spectrometer_x_ray_crystal
coils_non_axisymmetric	edge_transport	neutron_diagnostic	summary
controllers	em_coupling	ntms	temporary
core_instant_changes	equilibrium	pellets	thomson_scattering
core_profiles	gas_injection	pf_active	tf
core_sources	gas_pumping	pf_passive	transport_solver_numerics
core_transport	gyrokinetics	polarimeter	turbulence
cyrostat	hard_x_rays	pulse_schedule	wall
dataset_description	ic_antennas	radiation	waves
dataset_fair	interferometer	real_time_data	workflow

Extension of Data Dictionary mainly through application to new Use Cases and user feedback. For more details, see links from https://imas.iter.org.

Using Interface Data Structures (IDS) to couple codes

- The IMAS Access Layer is used to retrieve/store data and also makes coupling codes using IDSs straightforward, even if they are written in different languages
  - Automated definition of data structures for all supported languages
  - Fortran, C++, Python, Java, MATLAB
- This is the basis upon which modular workflows such as plasma simulators and data processing chains are created

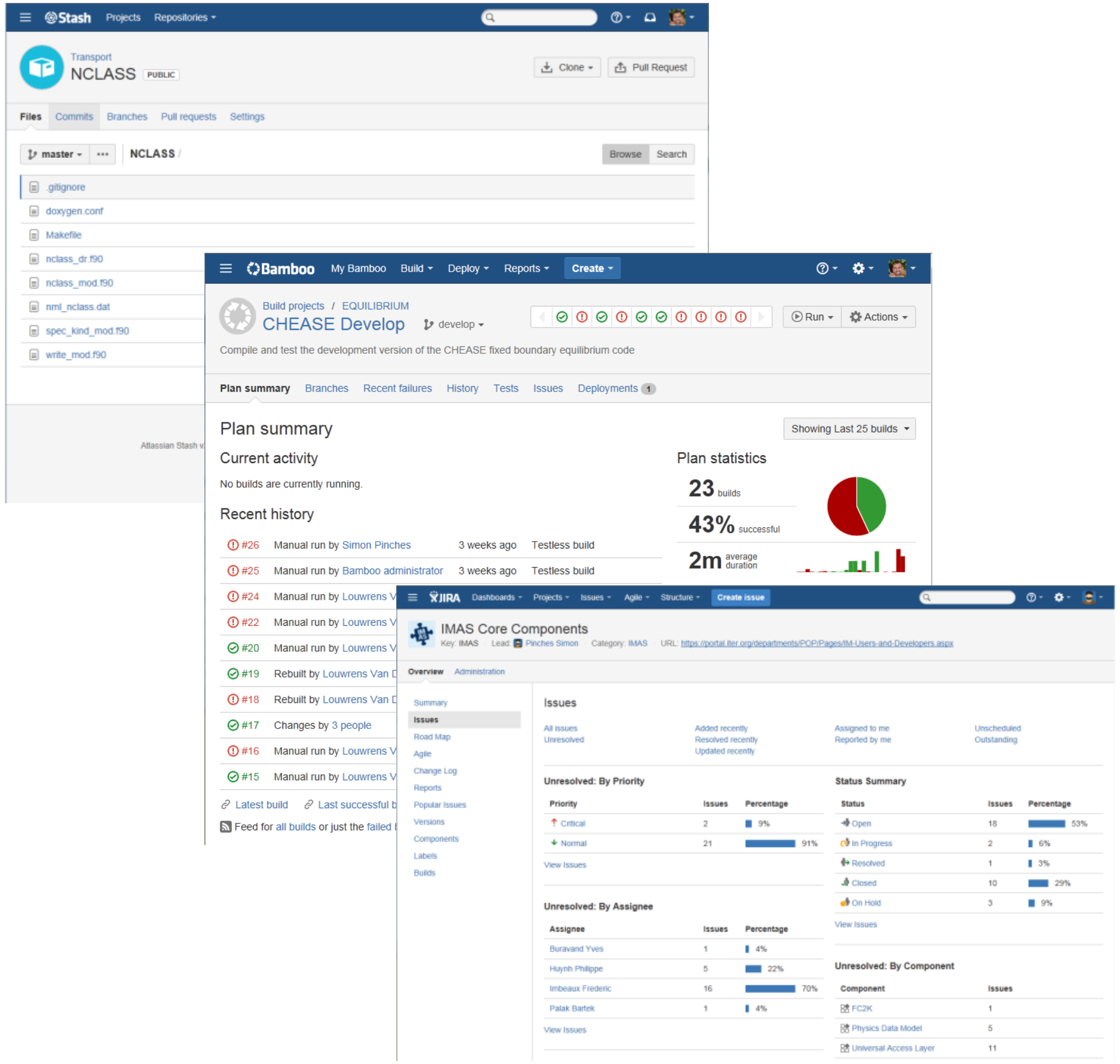


Data for Validating IMAS Components and Workflows

- Validation is an important element of IMAS development
- Validation needs data
- Data is only available on existing machines
  - IMAS needs to connect to existing (as well as future) data
- Existing experimental data stored in wide variety of formats
  - ITER DAN data will be stored as HDF5
- IMAS needs to be able to read different storage formats and map into IDSs
  - Data owners write (UDA) plug-ins to read their data formats and map into Data Model
  - On-going voluntary activity with Members
- Mapping device-specific data into Data Model needs managing
  - Data Model allowed to evolve (latest release is v3.34.0)
  - Plug-in based technology demonstrated to manage mapping (e.g. by shot ranges)

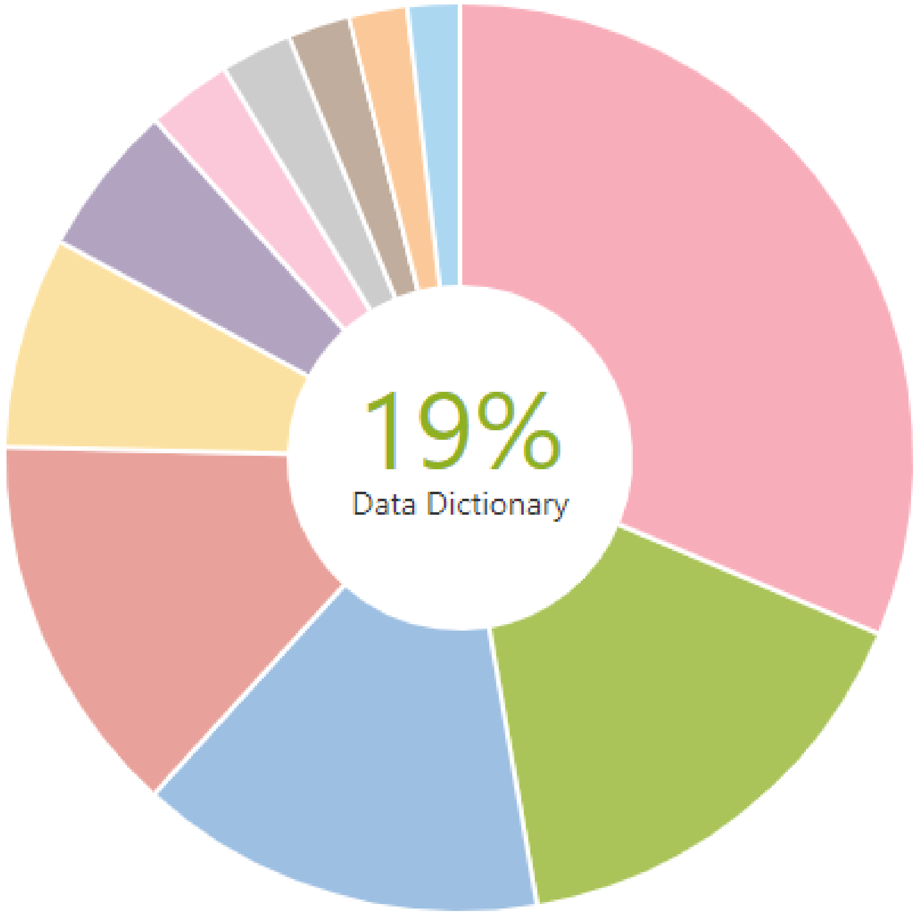
IMAS Software Management Tools

- Issue Tracking (JIRA)
  - Integrated across management tools
  - ~4000 issues categorised across ~100 components
  - Issues are associated with components and are auto-assigned to the relevant ROs
- Distributed Revision Control (Git)
  - 70+ repositories grouped across 17 projects
  - Branch-based access control
- Automatic building, unit & regression testing, and deployment (CI/CD server)
  - Continuous Integration to support agile development
  - Changes pushed to ITER repositories trigger automatic builds and testing to prevent regression (deny Pull Requests to merge changes)
  - Branch-based testing



Majority of open issues relate to AL and DD

https://jira.iter.org



Components
Total Issues: **726**

Data Dictionary	138
UAL	125
JOREK	118
UDA	65
Database	47
User	26
HAGIS	22
Documentation	19
DINA	18
Tools	16
Other...	271

- Issues are associated with IMAS components (infrastructure or physics) and are automatically assigned to individuals ROs
  - Anyone (IO and collaborators) can watch any issue and configure filters to receive automatic notifications

IMAS Releases

- https://jira.iter.org → IMAS Project → Releases

Jira   Dashboards   Projects   Issues   Boards   WorklogPRO   Insight   Create   Search

Releases

Manage Versions

QUICK FILTERS: Released   Unreleased   Archived

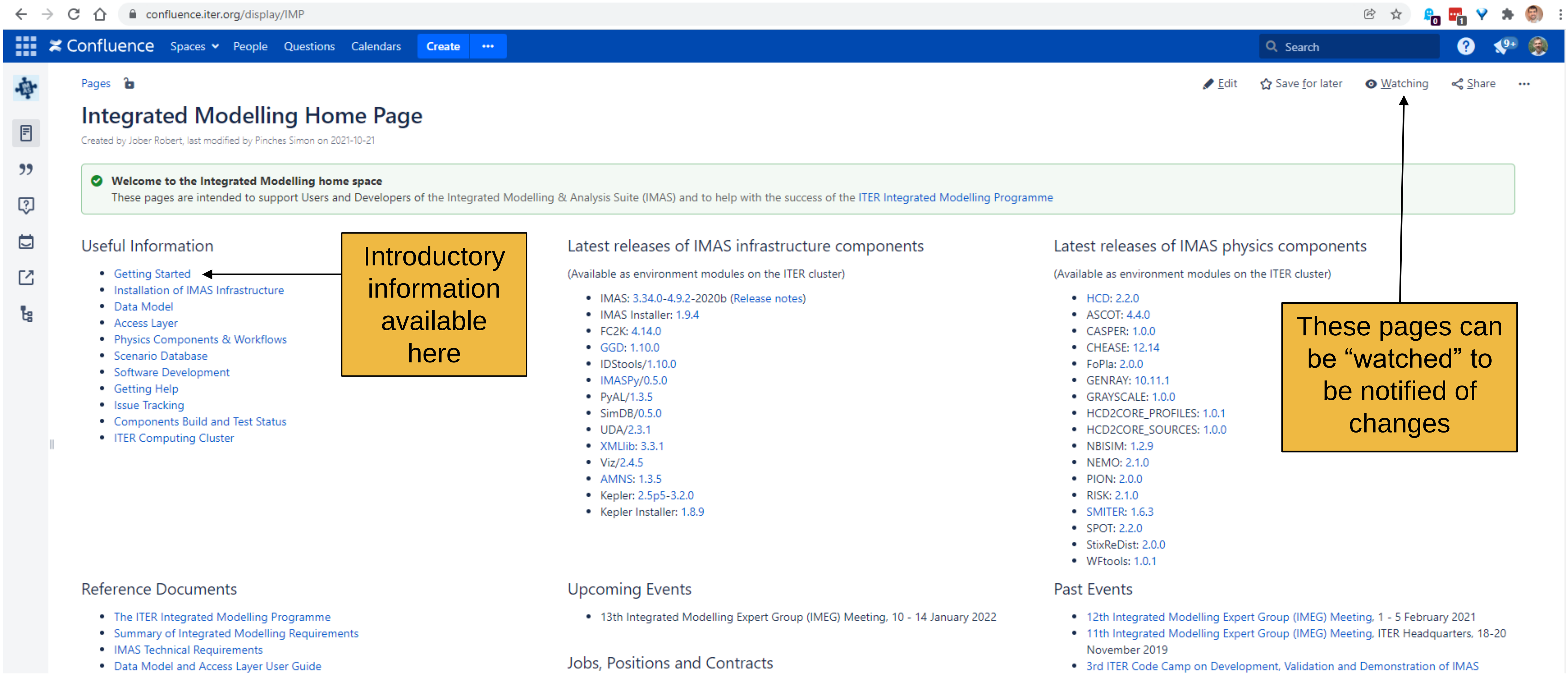
Merge versions

Version name | Start date (optional) | Release date (optional) | Description (optional) | Add

Version	Status	Progress	Start date	Release date	Description	Actions
4.0.0	UNRELEASED				Next major release of Data Dictionary	...
3.34.0	RELEASED		07/Jun/21	19/Oct/21	Extension of the CORE_PROFILES IDS with volume averaged densities and temperatures; Add a geometry_content identifier in the GGD; Restructuring of the SPECTROMETER_X_RAY_CRYSTAL IDS; Modification of the GAS_INJECTION IDS; Renaming of the SDN IDS into REAL_TIME_DATA IDS; Modification of the source/provenance information in all IDSs (new provenance structure and source becomes obsolescent in ids_properties); Renaming of neutron_fluxes into neutron_rates in the SUMMARY IDS. New WORKFLOW IDS (replaces the NUMERICS IDS)	...
3.33.0	RELEASED		07/May/21	30/Jul/21	Refactoring of the REFRACTOMETER IDS. Adding new distances and strike points for separatrices in the EQUILIBRIUM IDS. Extensions to the EDGE_PROFILES and DIVERTORS IDS and MAGNETICS IDSs for edge currents and related shunt measurements. Extension of the WALL IDS. Add a latency node to all diagnostic and actuator IDSs. Extensions to the THOMSON_SCATTERING, CAMERA_IR, EQUILIBRIUM and LANGMUIR_PROBES IDSs with an outboard midplane radial coordinate.	...
3.32.1	RELEASED	No issues	17/Mar/21	01/May/21	Add a geometry matrix to the SPECTROMETER_VISIBLE IDS; Clarification of the definition of coil current versus turns_with_sign in the PF_ACTIVE IDSs, and of the oblique angles in PF_ACTIVE and PF_PASSIVE IDSs; Increase max size of unit_source AoS and remove superfluous index nodes in the NEUTRON_DIAGNOSTIC IDS; Addition in the REFLECTOMETER_PROFILE IDS; Add Gaussian beam and polarizer structures to the ECE IDS	...
3.32.0	RELEASED		21/Jan/21	19/Mar/21	Extension of CORE_PROFILES, EQUILIBRIUM, PF_ACTIVE and SUMMARY ; Improvement of definitions and documentation ; New structure for geometry of secondary separatrix in EQUILIBRIUM ; Update of DISTRIBUTIONS and DISTRIBUTION_SOURCES ; Increase maximum number of channels in BOLOMETER ; Increase maximum number of occurrences of MHD_LINEAR ; Indicate some limitations are specific to MDS+ backend ; Modifications to LH_ANTENNAS and IC_ANTENNAS ; Fix units in DIVERTORS ; Update GYROKINETICS (including introducing complex types)	...
3.31.0	RELEASED		13/Oct/20	19/Jan/21	Refactoring of reciprocating probe part of LANGMUIR_PROBES IDS and extension of embedded probes structure; Extension to DISTRIBUTIONS IDS; New REFRACTOMETER IDS; Addition of gaps to EQUILIBRIUM IDS; Extension of SUMMARY IDS; Extension of DISRUPTION IDS; Modification of CALORIMETRY IDS; Addition in CORE_SOURCES IDS; New DIVERTORS IDS; Additions to WALL IDS; Extension to NEUTRON_DIAGNOSTIC IDS; Additions and clarifications of PELLETS IDS; New GAS_PUMPING IDS	...
3.30.0	RELEASED		27/Jul/20	29/Sep/20	Extension to the MHD_LINEAR IDS. Increase maximum number of ec_launchers.launcher and waves.coherent_wave. Extend SPECTROMETER_VISIBLE to include polarized light characteristics. Add list of libraries to the code structure and allow for implicit declaration of trivial grid_subsets for the GGD. Improvement of the MAGNETICS IDS. Modification of LANGMUIR_PROBES IDS. Increase the maximum number of occurrences of the MHD_LINEAR IDS. Addition of code parameters for each transport model to the EDGE_TRANSPORT IDS. Extension of the DATASET_DESCRIPTION IDS. New DATASET_FAIR IDS.	...
3.29.0	RELEASED		08/Apr/20	23/Jul/20	New SPECTROMETER_UV and SPECTROMETER_MASS IDSs; Increase number of channels in THOMSON_SCATTERING IDS Remove confusing periodicity nodes in COILS_NON_AXISYMMETRIC IDS Extension of PF_ACTIVE, LANGMUIR_PROBES, LH_ANTENNAS and MHD_LINEAR IDSs; Additions to SUMMARY IDS; Addition of surface to the CORE_* IDSs' radial grid; Correction of units Spelling corrections	...

IMAS Documentation

- More information can be found on the IMAS pages here: https://imas.iter.org



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Integrated Modelling Home Page

Created by Jober Robert, last modified by Pinches Simon on 2021-10-21

Welcome to the Integrated Modelling home space

These pages are intended to support Users and Developers of the Integrated Modelling & Analysis Suite (IMAS) and to help with the success of the ITER Integrated Modelling Programme

Useful Information

- Getting Started
- Installation of IMAS Infrastructure
- Data Model
- Access Layer
- Physics Components & Workflows
- Scenario Database
- Software Development
- Getting Help
- Issue Tracking
- Components Build and Test Status
- ITER Computing Cluster

Latest releases of IMAS infrastructure components

(Available as environment modules on the ITER cluster)

- IMAS: 3.34.0-4.9.2-2020b (Release notes)
- IMAS Installer: 1.9.4
- FC2K: 4.14.0
- GGD: 1.10.0
- IDStools/1.10.0
- IMASPy/0.5.0
- PyAL/1.3.5
- SimDB/0.5.0
- UDA/2.3.1
- XMLlib: 3.3.1
- Viz/2.4.5
- AMNS: 1.3.5
- Kepler: 2.5p5-3.2.0
- Kepler Installer: 1.8.9

Latest releases of IMAS physics components

(Available as environment modules on the ITER cluster)

- HCD: 2.2.0
- ASCOT: 4.4.0
- CASPER: 1.0.0
- CHEASE: 12.14
- FoPla: 2.0.0
- GENRAY: 10.11.1
- GRAYSCALE: 1.0.0
- HCD2CORE_PROFILES: 1.0.1
- HCD2CORE_SOURCES: 1.0.0
- NBISIM: 1.2.9
- NEMO: 2.1.0
- PION: 2.0.0
- RISK: 2.1.0
- SMITER: 1.6.3
- SPOT: 2.2.0
- StixReDist: 2.0.0
- WFtools: 1.0.1

Reference Documents

- The ITER Integrated Modelling Programme
- Summary of Integrated Modelling Requirements
- IMAS Technical Requirements
- Data Model and Access Layer User Guide

Upcoming Events

- 13th Integrated Modelling Expert Group (IMEG) Meeting, 10 - 14 January 2022

Jobs, Positions and Contracts

Past Events

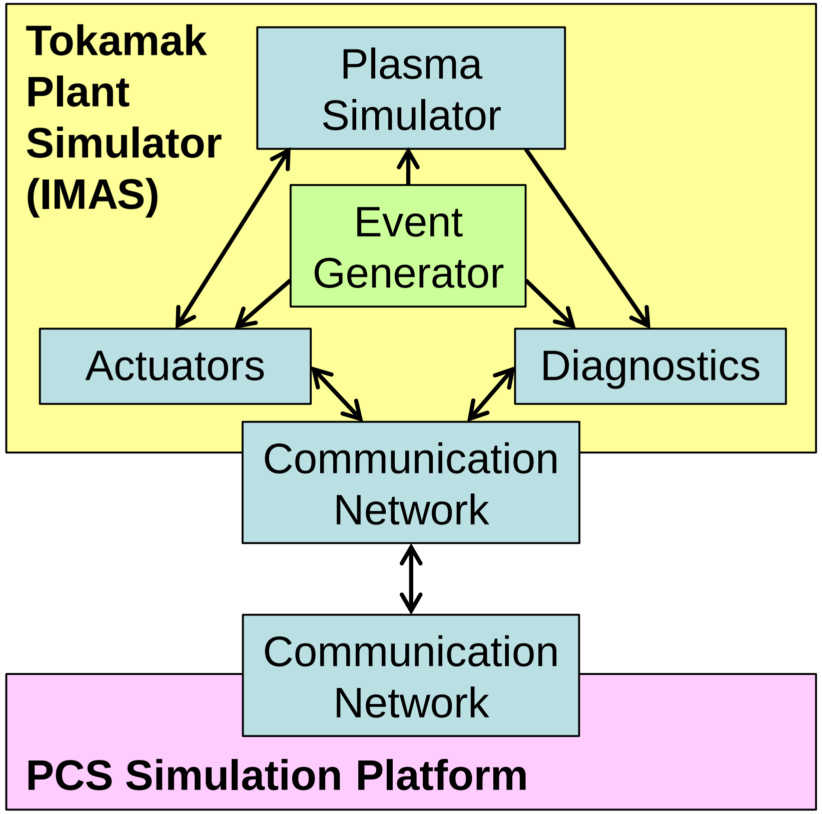
- 12th Integrated Modelling Expert Group (IMEG) Meeting, 1 - 5 February 2021
- 11th Integrated Modelling Expert Group (IMEG) Meeting, ITER Headquarters, 18-20 November 2019
- 3rd ITER Code Camp on Development, Validation and Demonstration of IMAS

Supporting ITER design activities and performance assessments

HIGH-FIDELITY PLASMA SIMULATOR

IMAS Plasma Simulator

- One of the principle deliverables from the IMAS programme is a plasma simulator to support physics validation of plasma scenarios
- Co-simulations of Plasma Simulator and Plasma Control System Simulation Platform (PCSSP)
  - Basis for physics validation
  - Develop control strategies from plasma initiation to burn control
  - Refine response to events
    - L-H transition
    - Power supply interruption
    - Diagnostic degradation / failure

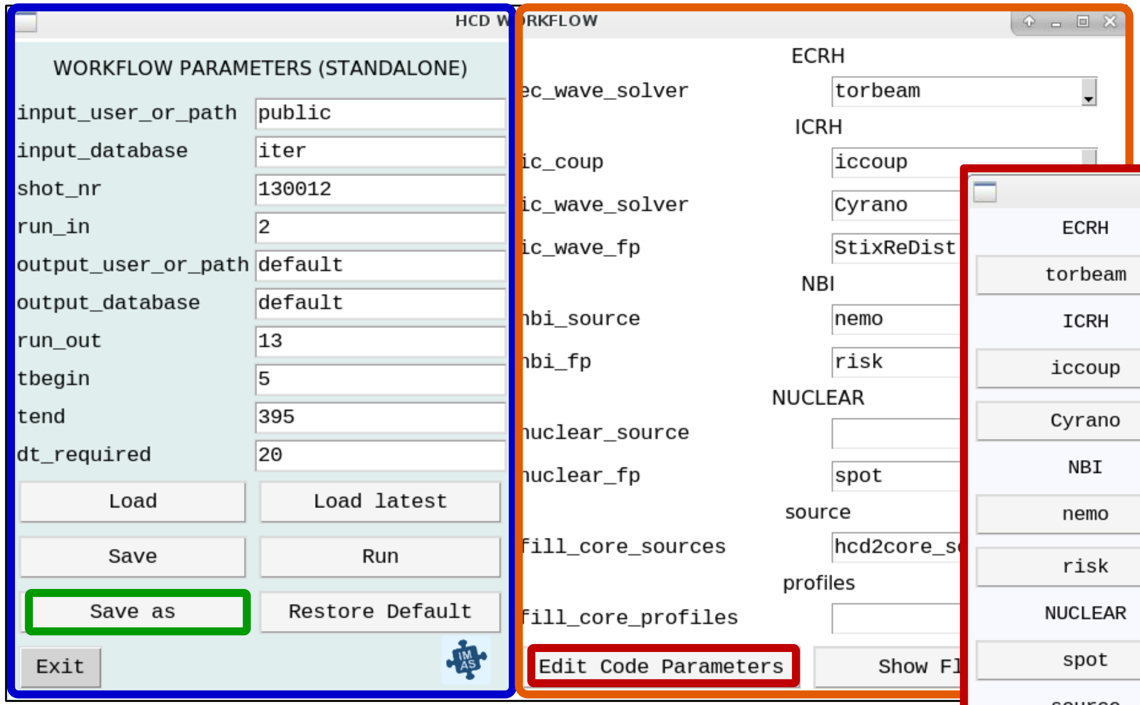


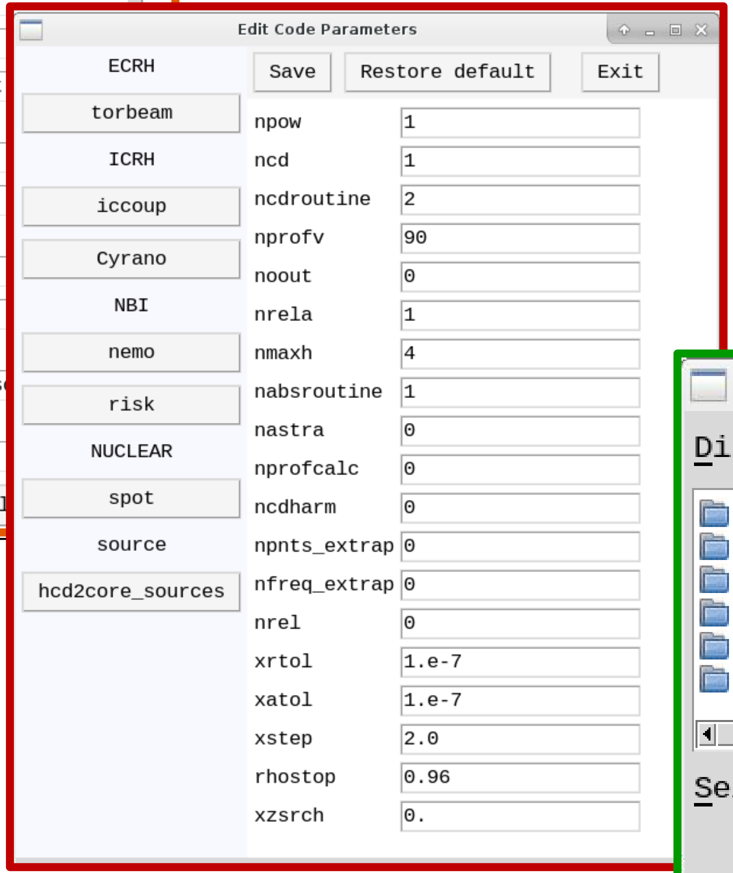
Ingredients of High-Fidelity Plasma Simulator

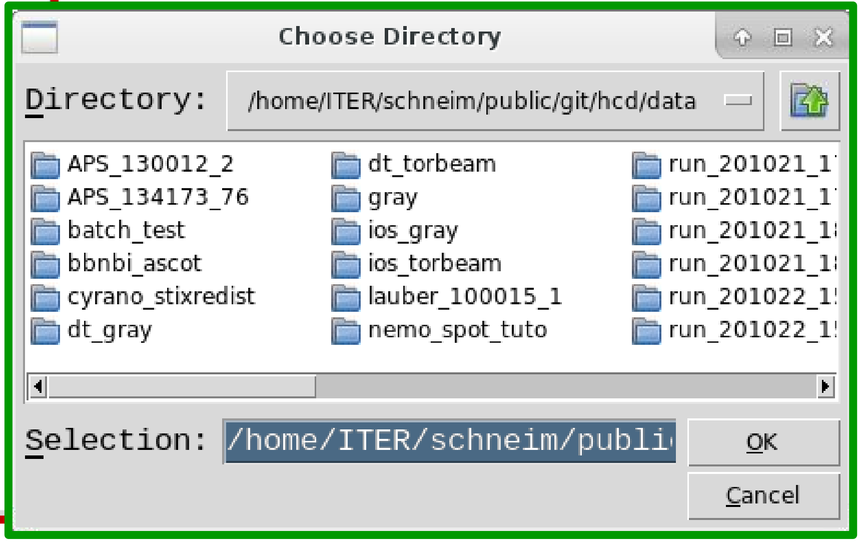
- IO doesn't have resources to develop a full plasma simulator from scratch
- Many existing plasma simulators with a long history of refinement and exploitation have been used by the IO to support the ITER design and the development of the ITER Research Plan, including
  - ASTRA, CORSICA, DINA, JINTRAC, TRANSP,…
- Following initial efforts to align on-going voluntary efforts with IMAS, we now focus upon integrating and refactoring the following key components
  - JINTRAC for core-edge coupled transport simulations (particles and energy)
  - DINA for evolution of magnetic equilibrium and poloidal field (PF) circuit
- In addition, IO staff and interns have developed a Heating & Current Drive (H&CD) workflow to describe (synergistically) all the ITER plasma heating systems and provide the source terms for a HFPS transport solver

GUI to configure the H&CD workflow

GUI dynamically built from code-specific parameters files (xml validated through xsd files)





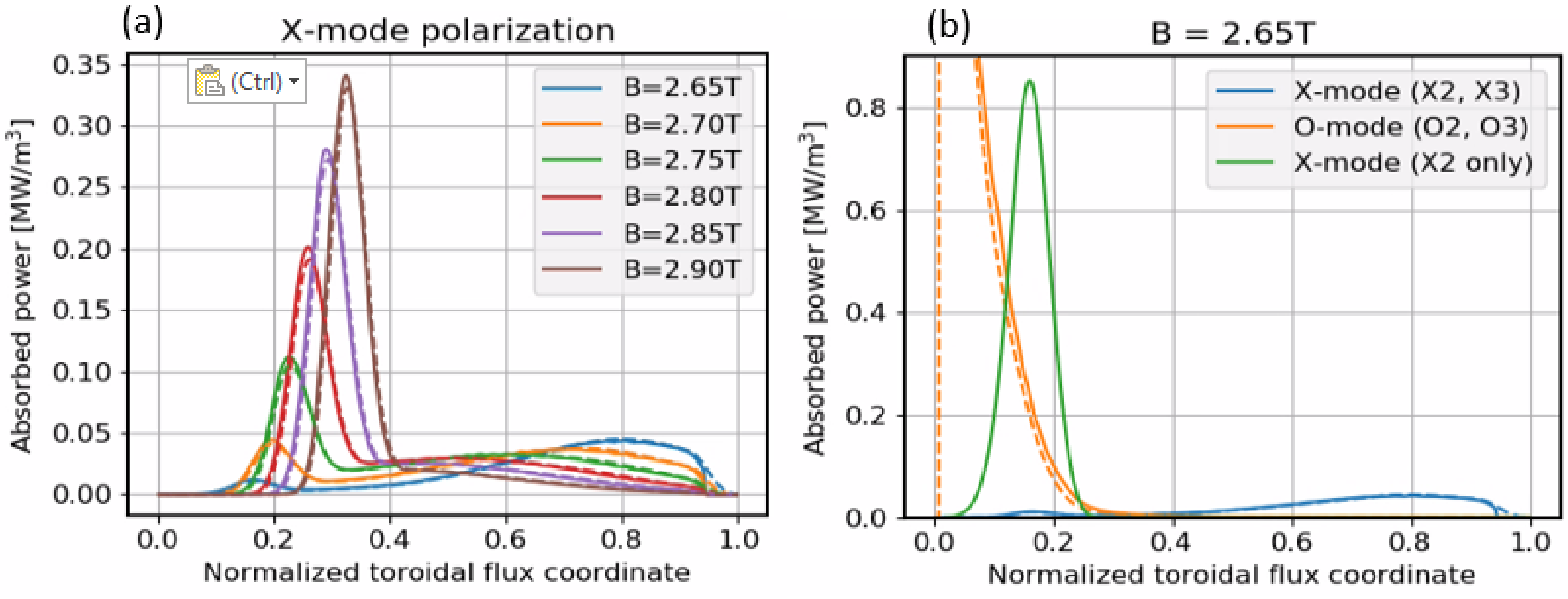


- Choice of H&CD codes for each source
- Configuration of code parameters for each code

- Workflow and code-specific configuration stored in a specific configuration folder

- Possibility to configure a time loop for standalone H&CD execution on an existing scenario

Study of ECH absorption profiles in 2.65 T / 7.5 MA scenarios

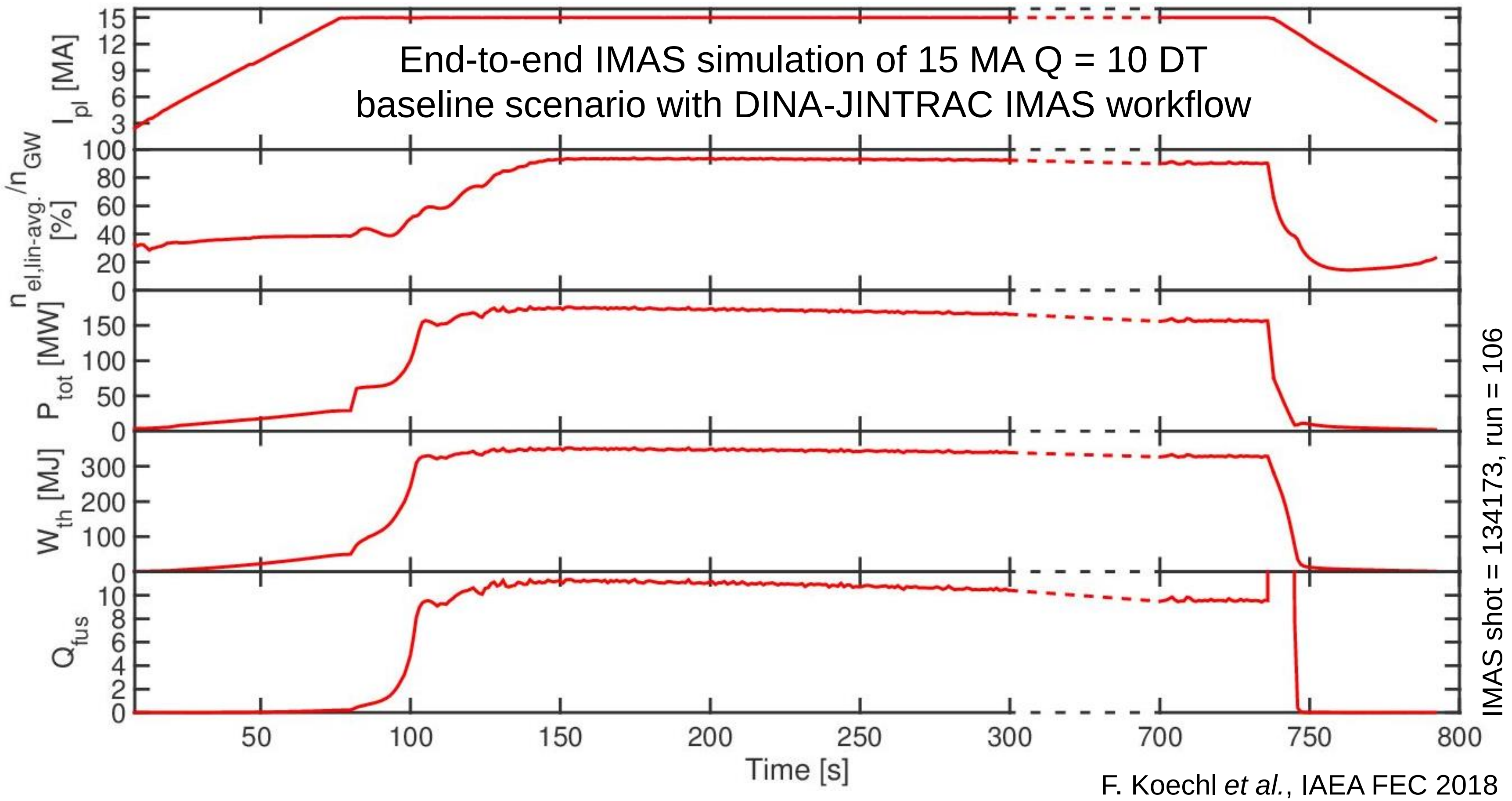


- Switching between TORBEAM and GRAY in the H&CD GUI is only one click!
- Since both codes use IDSs, exactly the same input/output is required/provided
- Excellent agreement between TORBEAM (solid) and GRAY (dashed)
  → IMAS platform is well-suited to supporting Verification and Validation

First integrated physics assessment of baseline DT scenario

- Free-boundary equilibrium code DINA and the JINTRAC suite of codes adapted to IMAS and used to simulate the 15 MA / 5.3 T DT Q=10 ITER baseline scenario

- For first time, scenario assessed for its entire evolution from early ramp-up phase (from X-point formation) until late ramp-down phase (to X-point-limiter transition) by means of integrated simulations including core, edge, and SOL transport with time-dependent free-boundary plasma geometry and pedestal pressure determined by continuous self-consistent edge MHD stability analysis



F. Koechl *et al.*, IAEA FEC 2018

Storing Plasma Simulations

- Plasma simulations are stored in an IMAS Scenario Database which now contains >750 ITER scenario simulations of various fidelities
- Data is represented as sets of Interface Data Structures (IDSs)
- This is the single source through which all physics simulation data is now made available
  - E.g. To support on-going project design activities including development of diagnostic models (synthetic diagnostics)
- New SimDB tool for improved management of datasets and remote data discovery and retrieval

  → See talk by J Hollocombe today

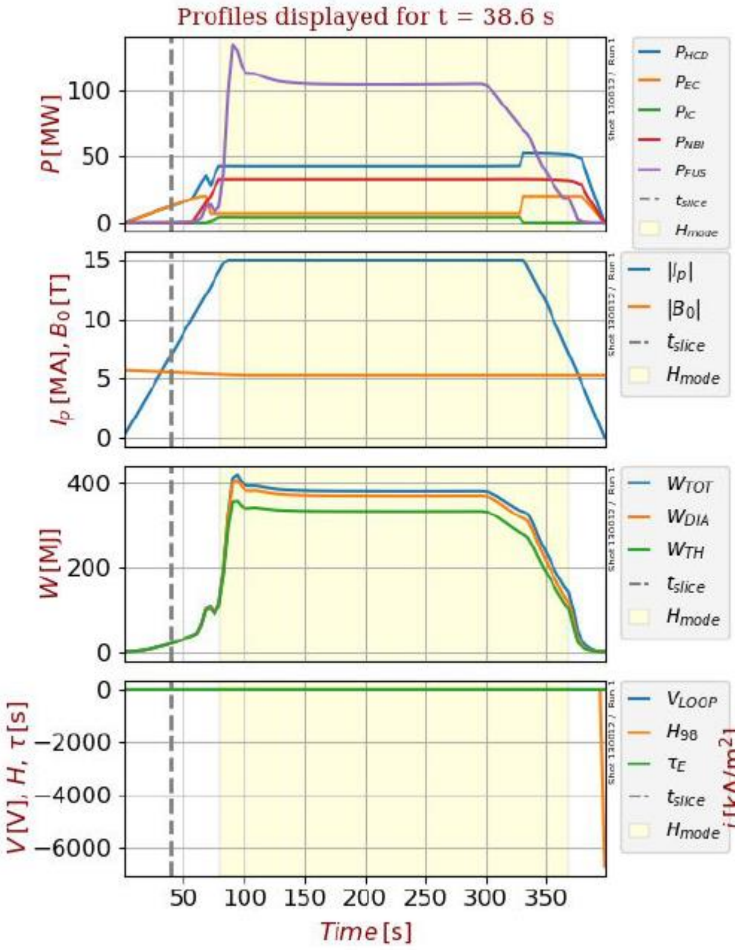
More than 750 active scenarios in IMAS scenario DB

```
----> Default call equivalent to:
      scenario_summary -c shot,run,database,ref_name,ip,b0,fuelling,confinement,workflow
```

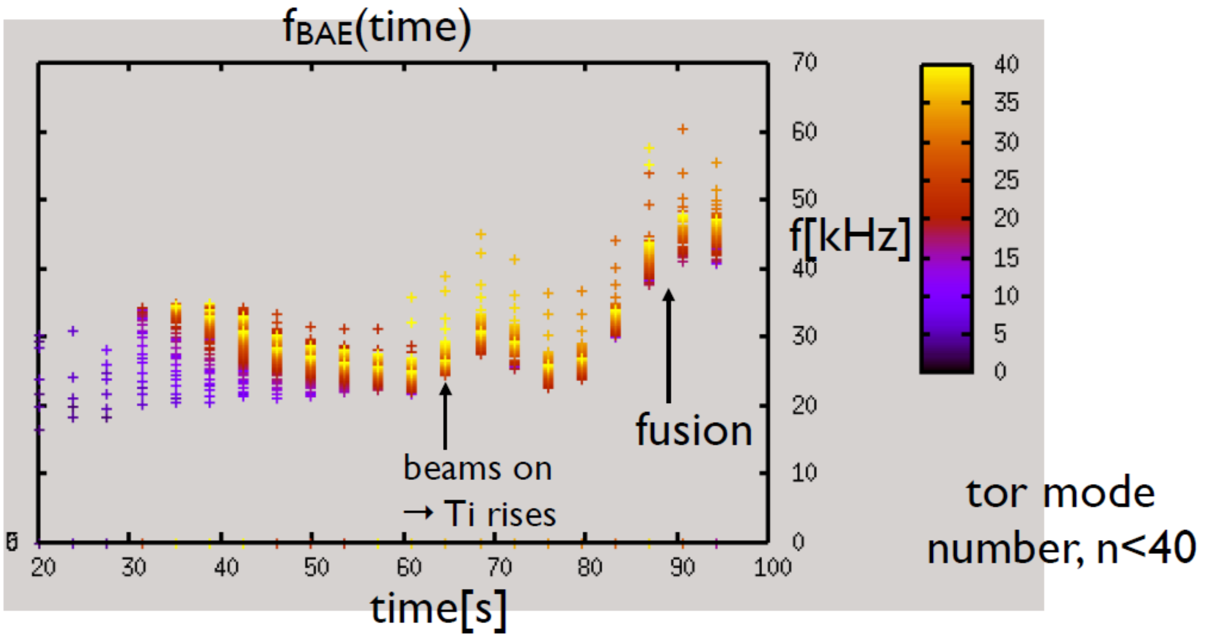
Pulse	Run	Database	Reference	Ip[MA]	B0[T]	Fuelling	Confinement	Workflow
100001	2	ITER	ITER-full-field-H	-15.0	-5.3	H	L-mode	METIS
100002	1	ITER	ITER-half-field-H	-7.5	-2.65	H	L-mode	METIS
100003	1	ITER	ITER-third-field-H	-5.0	-1.8	H	L-H-L	METIS
100007	1	ITER	ITER-intermediate-3T-H	-8.5	-3.0	H	L-H-L	METIS
100008	1	ITER	ITER-intermediate-3.3T-H	-9.5	-3.3	H	L-H-L	METIS
100009	1	ITER	ITER-intermediate-4.5T-H	-12.5	-4.5	H	L-mode	METIS
100013	1	ITER	ITER-PFPO1-1.8T-H	-5.0	-1.8	H	L-H-L	METIS
100014	2	ITER	ITER-PFPO2-1.8T-H-0.5*n_GW-NBI_530keV_9.4MW	-5.0	-1.8	H	L-H-L	METIS
100015	1	ITER	ITER-PFPO2-1.8T-H-0.9*n_GW-NBI_745keV_22.3MW	-5.0	-1.8	H	L-H-L	METIS
100501	3	ITER	ITER-nonactive-H	-7.5	-2.65	H	L-H-L	CORSICA
100502	3	ITER	ITER-nonactive-H	-7.5	-2.65	H	L-H dithering	CORSICA
100503	3	ITER	ITER-nonactive-H	-7.5	-2.65	H	L	CORSICA
100504	3	ITER	ITER-nonactive-H	-9.6	-3.25	H	L	CORSICA
100505	3	ITER	ITER-nonactive-H	-12.7	-4.7	H	L	CORSICA
100506	3	ITER	ITER-nonactive-H	-15.0	-5.3	H	L	CORSICA
100507	3	ITER	ITER-nonactive-H	-5.0	-1.77	H	L-H-L	CORSICA
101000	50	ITER	PFPO-2 tf=tE,2NBI,highTped,postST	-7.5	-2.65	H	H-mode	ASTRA
101001	50	ITER	PFPO-2 tf=tE,2NBI,highTped,preST	-7.5	-2.65	H	H-mode	ASTRA
101002	50	ITER	PFPO-2 tf=tE,2NBI,lowTped,postST	-7.5	-2.65	H	H-mode	ASTRA
101003	50	ITER	PFPO-2 tf=tE,2NBI,lowTped,preST	-7.5	-2.65	H	H-mode	ASTRA
101004	60	ITER	PFPO-2 tf=2tE,2NBI	-7.5	-2.65	H	H-mode	ASTRA
101005	60	ITER	PFPO-2 tf=tE,2NBI	-7.5	-2.65	H	H-mode	ASTRA
101006	60	ITER	PFPO-2 tf=0.5tE,2NBI	-7.5	-2.65	H	H-mode	ASTRA
101007	40	ITER	PFPO-2 H-5MA-20EC-10NBI Pr=0.3(tF/tE=2)	-5.0	-1.8	H	H-mode	ASTRA
101007	41	ITER	PFPO-2 H-5MA-20EC-10NBI Pr=0.3(tF/tE=1)	-5.0	-1.8	H	H-mode	ASTRA
101007	42	ITER	PFPO-2 H-5MA-20EC-10NBI Pr=0.3(tF/tE=0.65)	-5.0	-1.8	H	H-mode	ASTRA
101008	40	ITER	PFPO-1 iterH08.HOHFSBMI	-5.0	-1.8	H	Ohmic	ASTRA
104001	1	ITER	Militello Asp et al IAEA 2016 TH/P2-23 paper Figur	-15.0	-5.16	H	L-mode	JINTRAC mkimas
104001	2	ITER	Militello Asp et al IAEA 2016 TH/P2-23 paper Figur	-15.0	-5.3	H	L-mode	JINTRAC mkimas
104010	1	ITER	OPE1057 - Three ion ICRH scheme first attempt	-8.8	-3.13	H	H-mode	JETTO mkimas
104100	1	iter	Easp F4E-GRT502 H 10MA 20MW L-mode	-10.0	-5.23	H	L-mode	JINTRAC mkimas
104100	2	iter	Easp F4E-GRT502 H 15MA 20MW L-mode	-15.0	-5.16	H	L-mode	JINTRAC mkimas
104101	1	iter	F4E-GRT502 derived H 9.5MA 4.5T 20MW L-mode	-9.5	-4.5	H	L-mode	JINTRAC mkimas
104102	12	ITER	Vasilli H 5.0MA 1.8T L-H transition	-5.0	-1.8	H	L-mode	JINTRAC mkimas + spider-inverse
104102	22	ITER	Vasilli H 5.0MA 1.8T L-H transition	-5.0	-1.8	H	L-H	JINTRAC mkimas + spider-inverse
104102	32	ITER	Vasilli H 5.0MA 1.8T L-H transition	-5.0	-1.8	H	L-H	JINTRAC mkimas + spider-inverse
104102	42	ITER	Vasilli H 5.0MA 1.8T L-H transition	-5.0	-1.8	H	H-mode	JINTRAC mkimas + spider-inverse
104103	12	ITER	Luca H 7.5MA 2.65T Ne rich L-H transition	-7.5	-2.58	H	L-mode	JINTRAC mkimas + spider-inverse
104103	22	ITER	Luca H 7.5MA 2.65T Ne rich L-H transition	-7.5	-2.58	H	L-H transition	JINTRAC mkimas + spider-inverse
104103	32	ITER	Luca H 7.5MA 2.65T Ne rich L-H transition	-7.5	-2.58	H	L-H transition	JINTRAC mkimas + spider-inverse
104103	42	ITER	Luca H 7.5MA 2.65T Ne rich L-H transition	-7.5	-2.58	H	H-mode	JINTRAC mkimas + spider-inverse
104104	12	ITER	Emmi H 7.5MA 2.65T with He, L-H transition	-7.5	-2.65	H	L-mode	JINTRAC mkimas + spider-inverse
104104	22	ITER	Emmi H 7.5MA 2.65T with He, L-H transition	-7.5	-2.65	H	L-H transition	JINTRAC mkimas + spider-inverse
104104	32	ITER	Emmi H 7.5MA 2.65T with He, L-H transition	-7.5	-2.65	H	H-mode	JINTRAC mkimas + spider-inverse
104105	12	ITER	Emmi H 7.5MA 2.65T with He, L-H transition	-15.0	-5.3	H	L-mode	JINTRAC mkimas + spider-inverse
105001	4	ITER	15MA H-DINA2017-01	-14.97	-5.3	H	Ohmic	DINA
105002	4	ITER	15MA H-DINA2018-04	-14.97	-5.3	H	Ohmic	DINA
105003	4	ITER	10MA H-DINA2018-03	-10.08	-5.3	H	Ohmic	DINA
105004	4	ITER	7.5MA H-DINA2016-01	-7.52	-2.65	H	L-mode	DINA

Redistribution of fast ions by instabilities

- LIGKA/HAGIS Python workflow to assess fast particle stability in ITER scenarios
  - Used fast particle distributions calculated by H&CD workflow (shown above)



Frequencies of predicted Beta-induced Alfvén Eigenmodes (fast particle instabilities) during ITER pulse

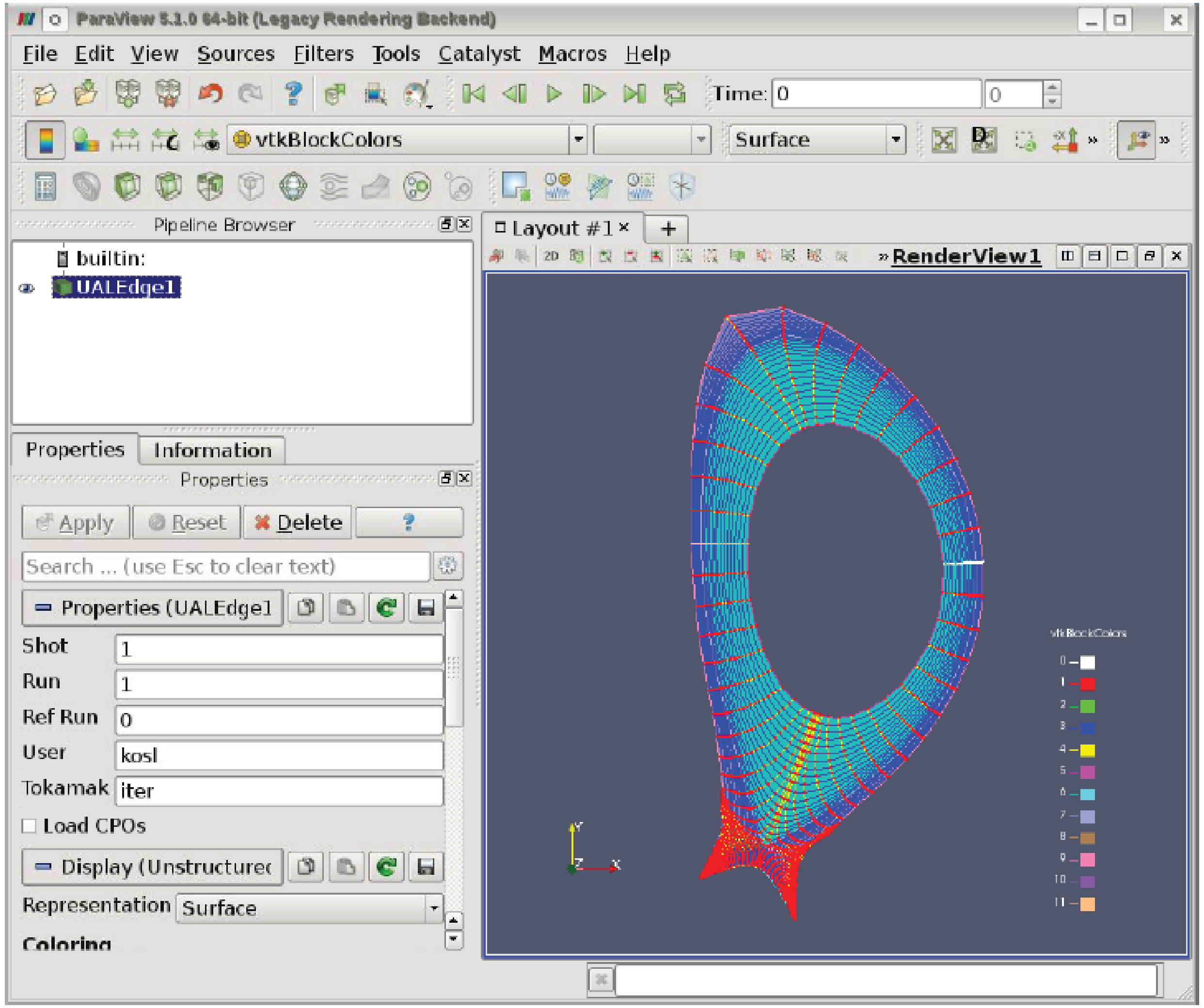


Transport of fast ions by instabilities changes evolution of plasma profiles → work underway to incorporate these effects in plasma scenario simulations (ITPA/ISFN)

See talk by Alin Popa on Friday

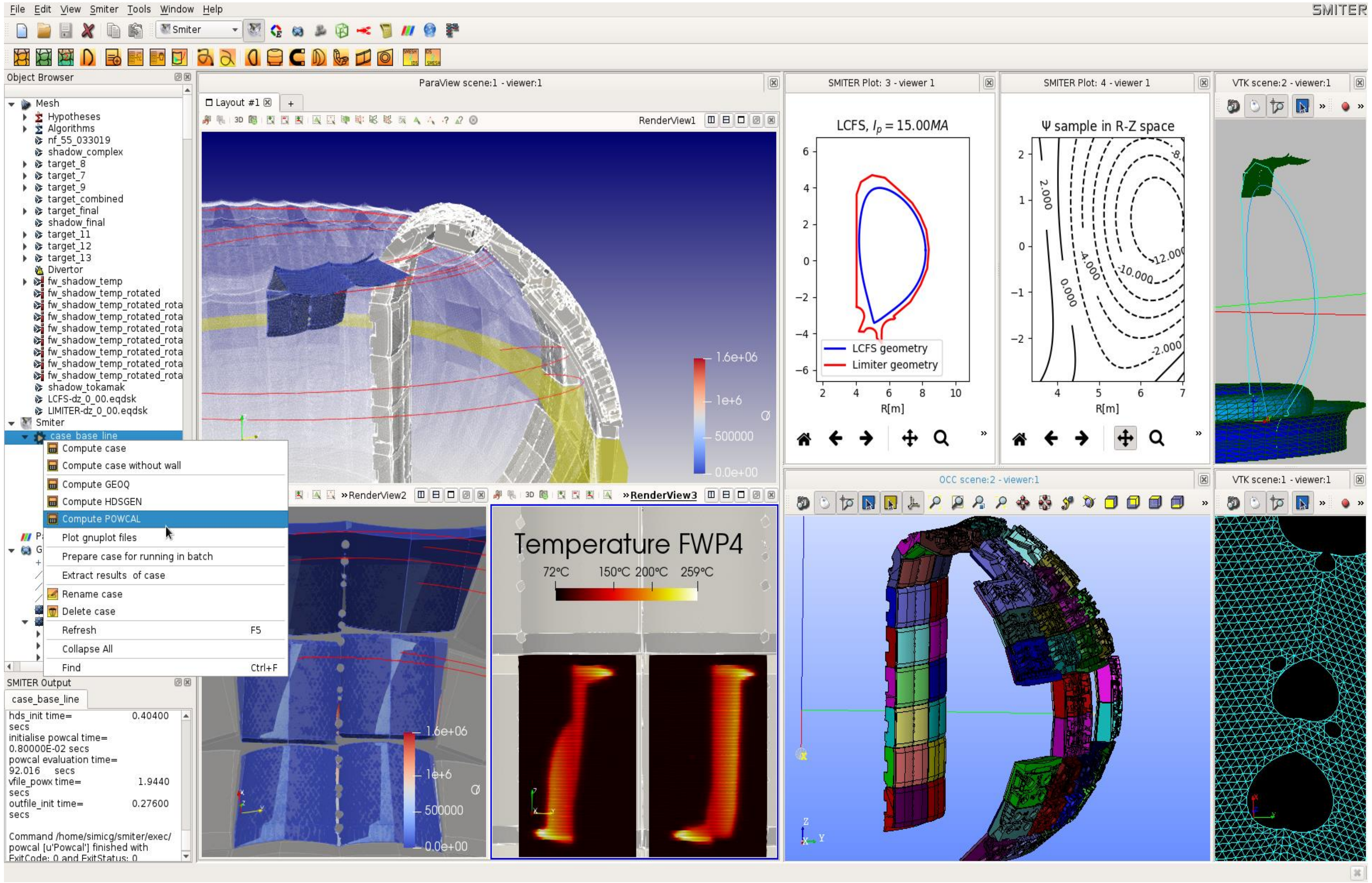
SOLPS-ITER

- SOLPS-ITER is ITER’s standard edge physics code
  - Now adapted to archive its data in the form of edge_profiles, edge_sources, edge_transport, and radiation IDSs and use AMNS for A&M rates in B2.5 fluid species
- Now ~500 edge/SOL ITER cases in IMAS database (including all SOLPS4.3 cases)
- New SOLPS-GUI developed to help launch and monitor runs, archive and analyse results in detail
- DivGeo divertor geometry utility can now read/write WALL IDSs



SMITER magnetic field-line tracing code

- SMITER addresses a variety of use cases:
  - Power deposition mapping onto first wall and divertor PFCs
  - Input to control algorithms and production of synthetic surface temperatures for diagnostic design
- Can read/write and manipulate WALL and EQUILIBRIUM IDSs
  - Makes extensive use of the IMAS Generalised Grid Description



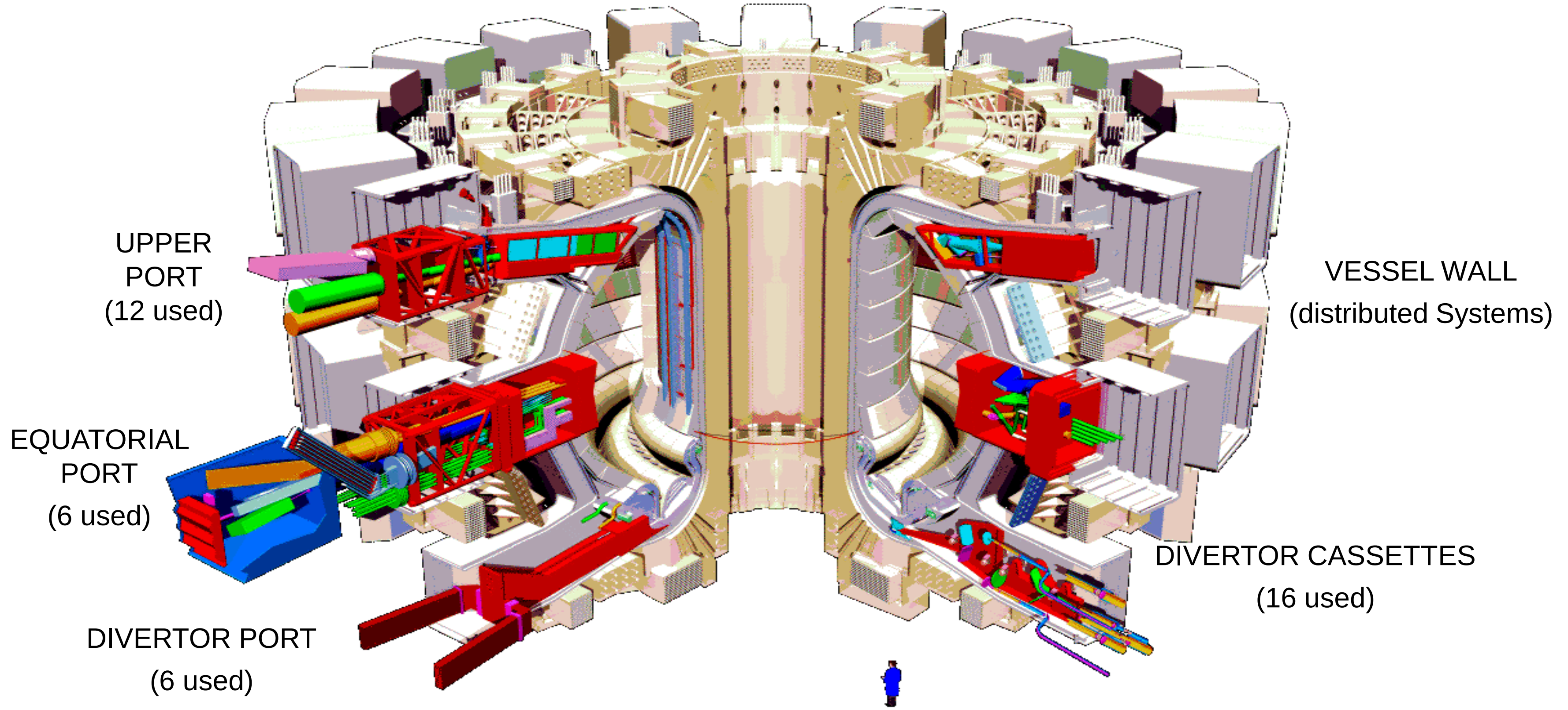
L. Kos *et al*., 30th Symposium of Fusion Technology, (2018) Preparing for ITER experimental data

DATA PROCESSING & ANALYSIS

Processing of data must be efficient: ITER will generate Big Data

ITER will have around 50 major diagnostic systems

- For machine protection, control and physics studies
- Data volumes expected to reach up to 2.2 PB of raw data per day



ITER will produce Big Data: Volume Estimates

- In DT phase, ITER will operate for 16 out of 24 months
  - 2 years × 52 weeks × 16 / 24 = 69 weeks every 2 years
- Operation consists of 2 shifts for 12 / 14 days
  - 12 / 14 × 69 = 59 weeks of data producing days every 2 years
- Typically day expected to produce up to ~2.2 PB of raw data
  - 2.2 PB × 59 × 7 / 2 = 0.45 EB / year of raw data
  - Data processing and analysis will further increase volume, although this is not expected to be significant
  - Largest fraction of data is expected to be camera data

Automated Processing of Data

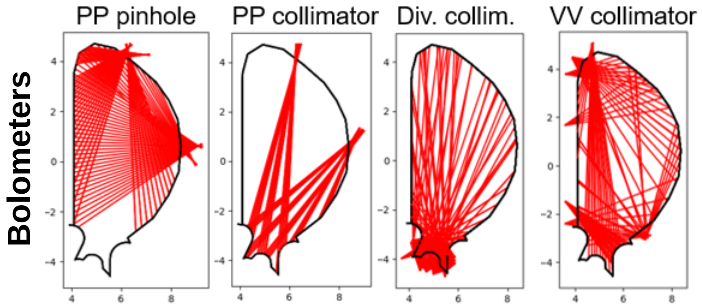
- Envisaged that many data processing chains will run concurrently (on dedicated hardware) as soon as their input raw data dependencies (in form of IDSs) are satisfied during a pulse
  - Whilst some simple linear chains will have modest computational requirements, more complex statistical (Bayesian) inference chains may consume significant resources
  - Since these latter chains are envisaged to be highly parallelizable, computational capabilities should ensure delivery of processed data does not impact inter-shot time or delay next pulse

    →Scalable parallel computing infrastructure
  - Close collaboration with devices which can map and serve raw data and matching Machine Description data → allows development and validation of workflows now
  - First example/near-term target: magnetics-only equilibria

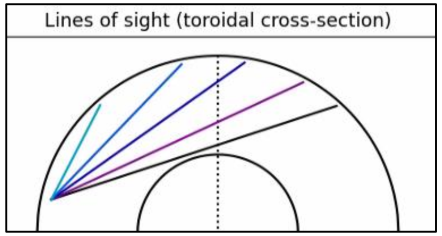
IMAS Machine Description database

- Machine Description available for H&CD systems, many diagnostics, wall, magnetics and coils

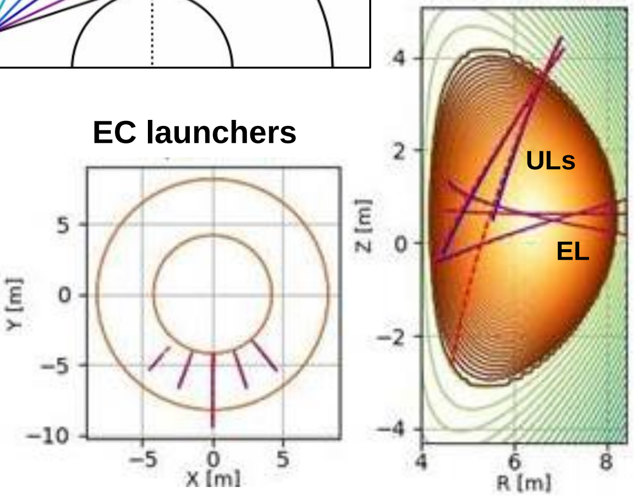
```
[pinches@sdcc-login03 ~]$ md_summary
----> Default call equivalent to:
      md_summary -c pbs,ids,description
-----------------------------------------------------------------------------------------------------------------------------------------------
PBS            IDS                          DESCRIPTION                                                                        SHOT/RUN
-----------------------------------------------------------------------------------------------------------------------------------------------
PBS-11         pf_active                    PF/CS Coil System, TF busbars (equivalent) and Virtual Coils                       111001/3
PBS-11         tf                           TF Coil System                                                                     111002/1
PBS-11         coils_non_axisymmetric       Ex-Vessel Coils (EVC) Systems (CC)                                                 111003/1
PBS-15         coils_non_axisymmetric       In-Vessel Coils (IVC) Systems (ELM)                                                115001/1
PBS-15         coils_non_axisymmetric       In-Vessel Coils (IVC) Systems (ELM periodic)                                       115002/1
PBS-15         coils_non_axisymmetric       In-Vessel Coils (IVC) Systems (VS)                                                 115003/1
PBS-15         pf_passive                   Vacuum Vessel (VV), Triangular Support (TS) and Divertor Inboard Rails (DIR) from IDM  115004/1
PBS-15         pf_passive                   Vacuum Vessel (VV), Triangular Support (TS) and Divertor Inboard Rails (DIR) from DINA 115005/2
PBS-55.D1      bolometer                    PP pinholes and collim., Div. collim., VV collim. (550 channels)                   150401/2
PBS-55.E5      spectrometer_x_ray_crystal   Core X-Ray Spectrometer (XRCS)                                                     150505/2
PBS-55.EC      spectrometer_visible         Charge Exchange Recombination Spectroscopy (CXRS) Edge                             150512/2
PBS-55.E1      spectrometer_visible         Charge Exchange Recombination Spectroscopy (CXRS) Core                             150501/2
PBS-55.EF      spectrometer_visible         Charge Exchange Recombination Spectroscopy (CXRS) Pedestal                         150515/2
PBS-52         ec_launchers                 Electron Cyclotron (EC) launchers                                                  120000/1
PBS-55.F1      ece                          Electron Cyclotron Emission (ECE) - Radial O-mode                                  150601/1
PBS-55.F1      ece                          Electron Cyclotron Emission (ECE) - Radial X-mode                                  150601/2
PBS-55.F1      ece                          Electron Cyclotron Emission (ECE) - Oblique O-mode                                 150601/3
PBS-55.F1      ece                          Electron Cyclotron Emission (ECE) - Oblique X-mode                                 150601/4
PBS-51         ic_antennas                  Ion Cyclotron (IC) antennas                                                        110000/1
PBS-55.C5      interferometer               Toroidal Interfero-Polarimeter (TIP)                                               150305/1
PBS-55.FA      interferometer               Density Interfero-Polarimeter (DIP)                                                150610/1
PBS-55.A*      magnetics                    AD,AE,AF,AH,AI,A3,A4,A5,A6,AA,AB,AJ,AL,A9,AC,AG,AP magnetic systems                150100/3
PBS-53         nbi                          Heating Neutral Beams (HNB) - H beams 870 keV - off-off                            130000/1201
PBS-53         nbi                          Heating Neutral Beams (HNB) - H beams 870 keV - off-on                             130000/1301
PBS-53         nbi                          Heating Neutral Beams (HNB) - H beams 870 keV - on-on                              130000/1501
PBS-53         nbi                          Heating Neutral Beams (HNB) - D beams 1 MeV - off-off                              130000/2201
PBS-53         nbi                          Heating Neutral Beams (HNB) - D beams 1 MeV - off-on                               130000/2301
PBS-53         nbi                          Heating Neutral Beams (HNB) - D beams 1 MeV - on-on                                130000/2501
PBS-53         nbi                          Diagnostic Neutral Beam (DNB) - on-axis                                            130000/3201
PBS-53         nbi                          Diagnostic Neutral Beam (DNB) - off-axis                                           130000/3101
PBS-55.C6      polarimeter                  Poloidal Polarimeter (POP)                                                         150306/1
PBS-55.F9.40   refractometer                Sub-system refractometer of HFS reflectometer                                      150609/401
PBS-55.E6      spectrometer_visible         Visible Spectroscopy Reference System (VSRS)                                       150506/2
PBS-16         wall                         First wall and divertor geometry for PFPO and FPO phases                           116000/2
PBS-16.FC      wall                         First Plasma Protection Components (FPPC)                                          116612/1
PBS-16         pf_passive                   Blanket Module Panel (BMP)                                                         116001/1
-----------------------------------------------------------------------------------------------------------------------------------------------
```



Toroidal Interfero-Polarimeter



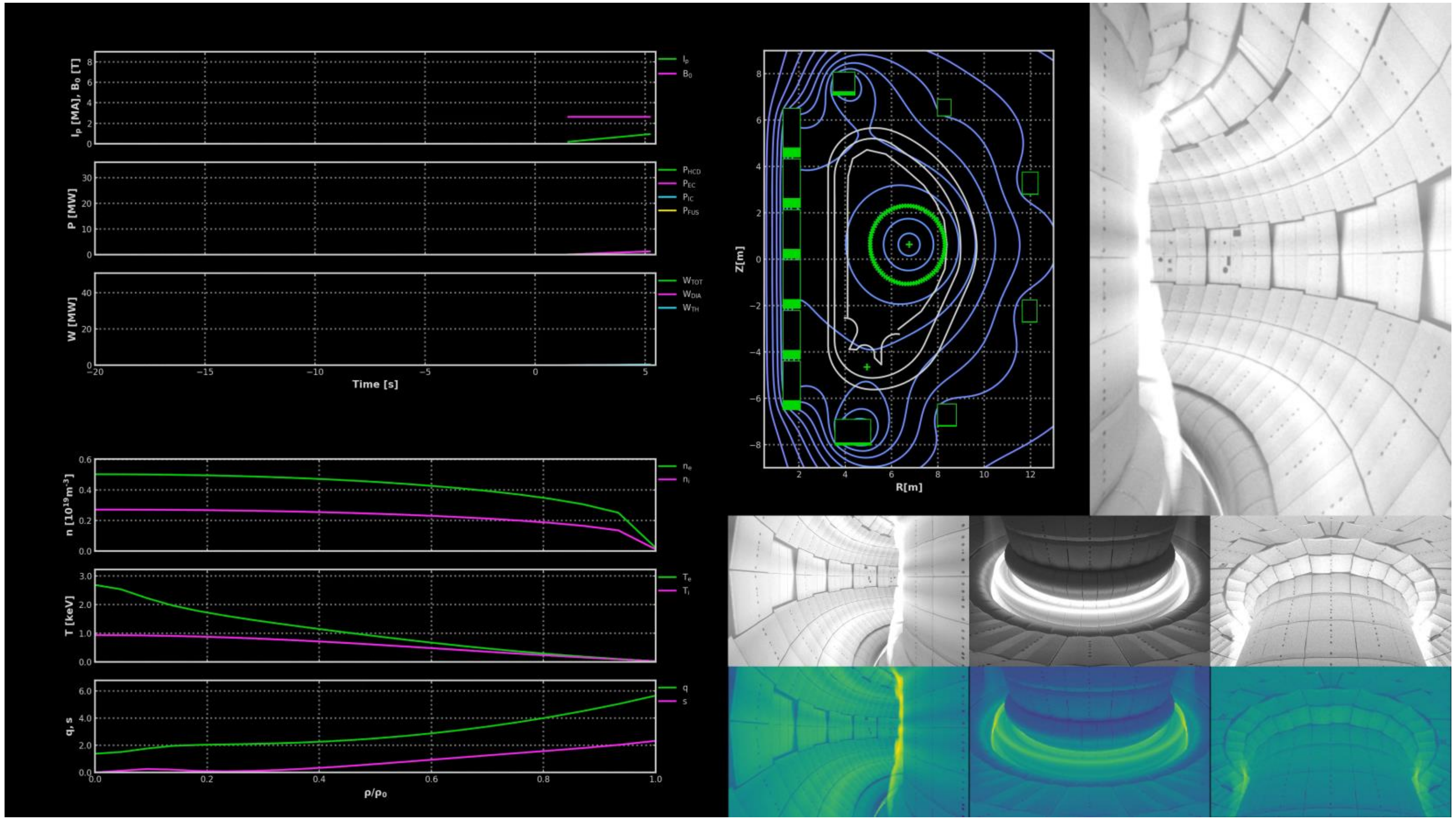
EC launchers



- The MD database provides the geometry of the plant systems to be used as input of simulation codes

Live Display as in Control Room

- Simulation of 7.5 MA / 2.65 T He4 plasma in ITER PFPO



Example control-room Live Display calculated using ITER scenario database and showing plasma equilibrium, waveforms and profiles (based on JINTRAC simulation, shot=110005; run=1), together with synthetic views from the Wide Angle Viewing System (WAVS) (based on shot=122264, run=1).

Example use of an IMAS synthetic diagnostic

- This example is based on the DIP_TIP_POP model developed by Anna Medvedeva (Monaco Postdoctoral Fellow at ITER) that is used here to simulate the Toroidal Interfero-Polarimeter (TIP) diagnostic
  - The example is run on the ITER SDCC cluster

```
module load IMAS
git clone ssh://git@git.iter.org/diag/tip.git
mkdir -p ~/public/PYTHON_ACTORS
cd tip
./extract_actor
export PYTHONPATH=~/public/PYTHON_ACTORS/dip_tip:$PYTHONPATH
mkdir -p ~/public/imasdb/iter/3/0
```

Example (Python) script

```python
import os, imas
from imas.imasdef import MDSPLUS_BACKEND,CLOSEST_SAMPLE
from dip_tip.wrapper import dip_tip_actor as dip_tip

# SCENARIO AND MD INPUT DATA, LOCAL OUTPUT DATA
shot_scen, run_scen, user_scen, database_scen = 134174, 117, 'public',          'iter'
shot_md,   run_md,   user_md,   database_md   = 150305, 1,   'public',          'ITER_MD'
shot_out,  run_out,  user_out,  database_out  = 134174, 118,  os.getenv('USER'), 'iter'

# OPEN SCENARIO DATA
scenario = imas.DBEntry(MDSPLUS_BACKEND,database_scen,shot_scen,run_scen,user_scen)
scenario.open()

# OPEN AND READ MACHINE DESCRIPTION DATA
mach_descr = imas.DBEntry(MDSPLUS_BACKEND,database_md,shot_md,run_md,user_md)
mach_descr.open()
interferometer_md = mach_descr.get('interferometer')

# CREATE LOCAL OUTPUT DATAFILE
output = imas.DBEntry(MDSPLUS_BACKEND,database_out,shot_out,run_out,user_out)
output.create()

# TIME ARRAY
time_array = scenario.partial_get(ids_name='equilibrium',data_path='time')
ntime = len(time_array)

# START TIME LOOP
first_time_slice = 1
for itime in range(ntime):

    # TIME PASSING BY
    print('Time = %5.2f' % time_array[itime],'s, itime = ',itime,'/',ntime)

    # GET EQUILIBRIUM AND CORE_PROFILES FOR CURRENT TIME SLICE
    equilibrium_scen   = scenario.get_slice('equilibrium',  time_array[itime],CLOSEST_SAMPLE)
    core_profiles_scen = scenario.get_slice('core_profiles',time_array[itime],CLOSEST_SAMPLE)

    # RUN THE SYNTHETIC DIAGNOSTIC
    interferometer_out = dip_tip(equilibrium_scen,core_profiles_scen,interferometer_md,'parameters.xml')

    # SAVE OUTPUT TO LOCAL DATABASE
    if first_time_slice == 1:
        output.put(interferometer_out) # !!! FOR STATIC DATA TO BE SAVED
    else:
        output.put_slice(interferometer_out)

    first_time_slice = 0

scenario.close()
mach_desc.close()
output.close()

print('Done.')
```

Specify database entries for reading plasma scenario, machine description data, and storing output

Open scenario database, read machine description data, and create output database entry

Read equilibrium and core_profiles IDSs

Run synthetic diagnostic

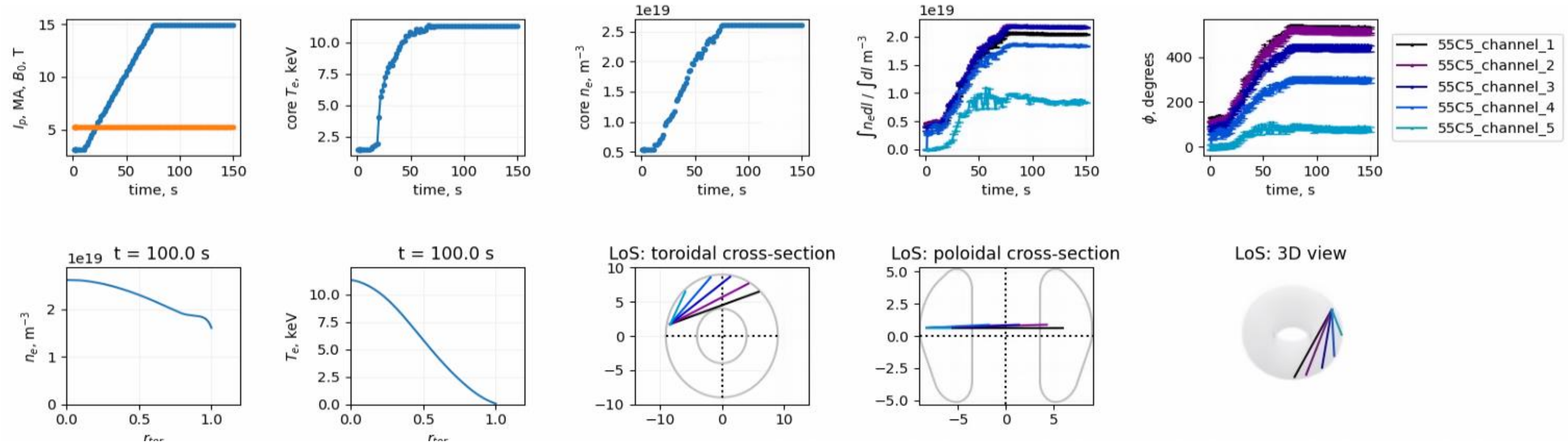
Save output

Loop over time slices

Visualizing synthetic TIP data

- The output can be visualized using the interplot.py script within the tip repository:

```
python interplot.py -s 134174 -req 117 -rd 118 -db iter -ueq public -ud pinches-t 100
```



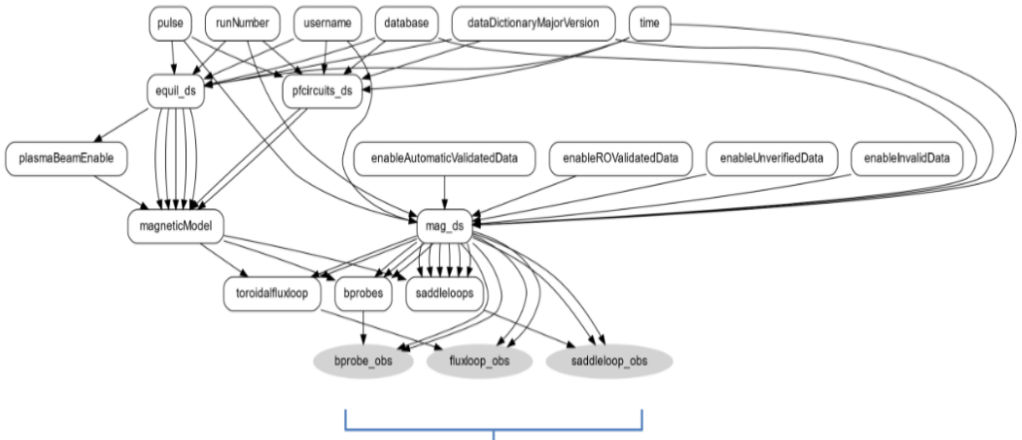
Data Analysis and Interpretation Platform

- Call for initial development launched following discussions with ITPA Topical Group on Diagnostics and IAEA Technical Meeting on Fusion Data Processing, Validation and Analysis (driven by IMEG)
  - ITPA Diagnostics provide voluntary support for development, evaluation and testing;
- Minerva being evaluated for rigorous interpretation and analysis of experimental data and for a community of users (IO staff & externals) to gain experience with its use and application
  - Interpret data from individual diagnostics;
  - Unified methodology for integrating data from multiple diagnostics to obtain improved results with derived uncertainties;
  - Support generation of realistic synthetic diagnostic data to assess performance of diagnostics and develop data interpretation techniques;
  - Estimate hardware requirements to support running automated interpretation workflows that combine a realistically achievable combination of diagnostics during ITER's PFPO and FPO phases;

Synthetic diagnostics in Minerva

- Initial focus on diagnostics models for First Plasma and PFPO operation
- Associated Machine Description data (being populated):
  - Magnetic coils, flux loops, Rogowski loops:
    - input = magnetics, pf_active, pf_passive, equilibrium
    - output = magnetics
  - VSRS, H-alpha:
    - spectrometer_visible
  - interferometry:
    - interferometer
  - X-ray spectrometer (edge/core/survey):
    - x_ray_crystal_spectrometer

- Model to compute toroidal flux loops, saddle loops and pickup probes.
  - Both pf currents and plasma current included



Declarative model for magnetics

"obs" nodes contain both the measured, and computed signals

- Early application:
  - Assessment of diagnostic coverage for early detection of L-H transition in PFPO-2
    → See talk by Anna Medvedeva on Friday

Integrated Data Analysis

- Growing list of synthetic diagnostics developed for or adapted to IMAS
  - ~20 models
- Start of development of IDA workflows for combining signals
  - See talk by Rainer Fischer on combining ECE, TS and interferometry on Friday

Diagnostic (+ITER PBS identifier)	Contacts	Source Code Repository	Dependencies	In IMAS	Regression Tests	Documentation	Demonstration input data	Applications: Design, Physics, Control
Calculates the generic light spectrum for all visible spectrometers and cameras.	Multi-authors. Current main developer: @Shabashov Aleksei IO contact: @De Bock Maarten	CASPER	CHERAB	yes	no	In the future to come.		D/P
Charge Exchange Recombination Spectroscopy, for Core / Edge / Pedestal 55.E1 / 55.EC / 55.EF	Author: Alexey Shabashov IO contact: @De Bock Maarten	CXRS	CHERAB	yes	no	Presentation: 3U2DBZ Report by Maxim Bykov based on old material (Matlab): X3NAVL		D/P
H-alpha and Visible Spectroscopy 55.E2	Author: @Khusnutdinov Radmir IO contact: @De Bock Maarten	H-alpha	CHERAB	yes	no	Report: 2N57XR		D/P
Divertor Impurity Monitor (DIM) 55.E4	Author: @Natsume Hiroki IO contact: @De Bock Maarten	DIM	CHERAB	yes	no	Presentation: 2C7R9M To be published in Plasma and Fusion Research: 3Z47PC		D/P
Visible Spectroscopy Reference System (VSRS) 55.E6	Author: Bart van den Boorn IO contact: @De Bock Maarten	VSRS	CHERAB	yes	no	Report: 3AKPSV Presentation: 3TY5AU	134000/60/public/ITER 122264/2/public/ITER	D/P
• 55.C5: Toroidal Interferometer Polarimeter (TIP) • 55.FA: Density Interfero-Polarimeter (DIP) • 55.C6: Poloidal Polarimeter (POP)	Author, IO contact: @Medvedeva Anna	DIP_TIP_POP	-	yes	no	Described in the following presentation: IMEG 2020-21 - Development of Synthetic Diagnostics for ITER	100002/1/public/ITER	D/P/C

SUMMARY

The ITER Integrated Modelling Programme

- Imposes a standard for FAIR fusion data and provides associated management tools
  - *See talks by Jonathan Hollocombe, Shaun de Witt, Michael Oswiak, Pär Strand, and Marcin Plociennik*
- Software using such data is device-generic since Machine Description metadata is part of the standard
  - Allows development, validation and application on today's devices in preparation for ITER operation
  - Many languages and environments supported: C++, Fortran, Python, Java, MATLAB,…
- High-Fidelity Plasma Simulator based upon DINA-JINTRAC in development
  - Loose iterative coupling already successfully demonstrated; H&CD workflow models sources
  - Simulations of ITER stored in IMAS scenario database and available as input to synthetic diagnostics
- Workflows describing additional physics developed for integration with HFPS
  - E.g. Energetic particle stability and transport → *See talk by Alin Popa*
- Development of diagnostic models to generate synthetic signals and preparation of analysis workflows
  - Also used to support diagnostic design and development of control algorithms
    → *See talks by Mireille Schneider, Anna Medvedeva, Valentina Nikolaeva, Andrea Pavone, Severin Denk, Andreas Dinklage, Rainer Fischer, Didier Vezinet, Andreas Langenberg and Jorge Morales*
- IMAS is being built to meet the needs of ITER but is ready to support today's devices!

Collaboration with the ITER Organization is always welcome

- Voluntary contributions and collaborations
  - Visiting Researchers, ITER Scientist Fellows, ITPA
  - Feel free to contact me about opportunities, Simon.Pinches@iter.org
- Internships
  - Advert for 2022 to appear in early December including development of synthetic diagnostics, see https://www.iter.org/jobs/internships
- Postdoctoral positions
  - Monaco Postdoctoral Fellowships and new ITER postdoctoral positions including proposals in area of integrated modelling, data processing & analysis
  - Next recruitment round starts in January 2022, see https://www.iter.org/Monaco2022
- Staff positions
  - 2 x staff positions in area of integrated modelling, data processing & analysis
  - To be advertised Spring – Summer 2022, see https://www.iter.org/jobs