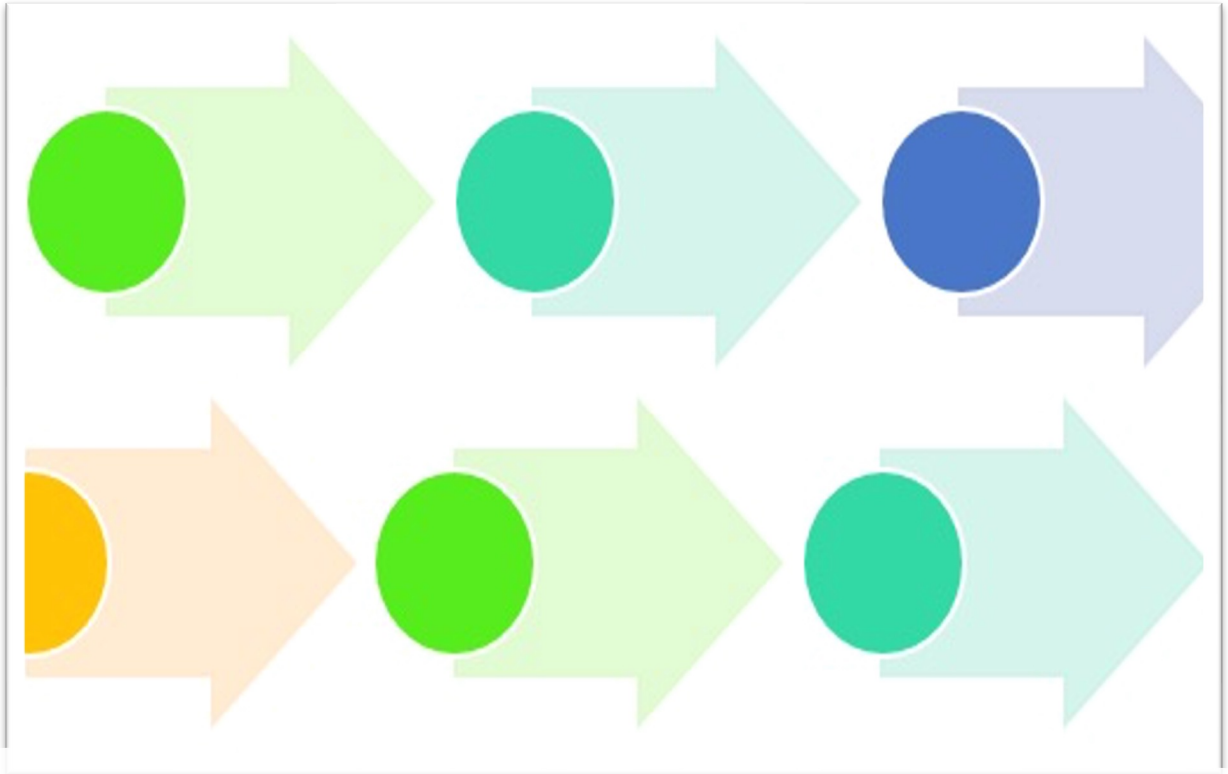

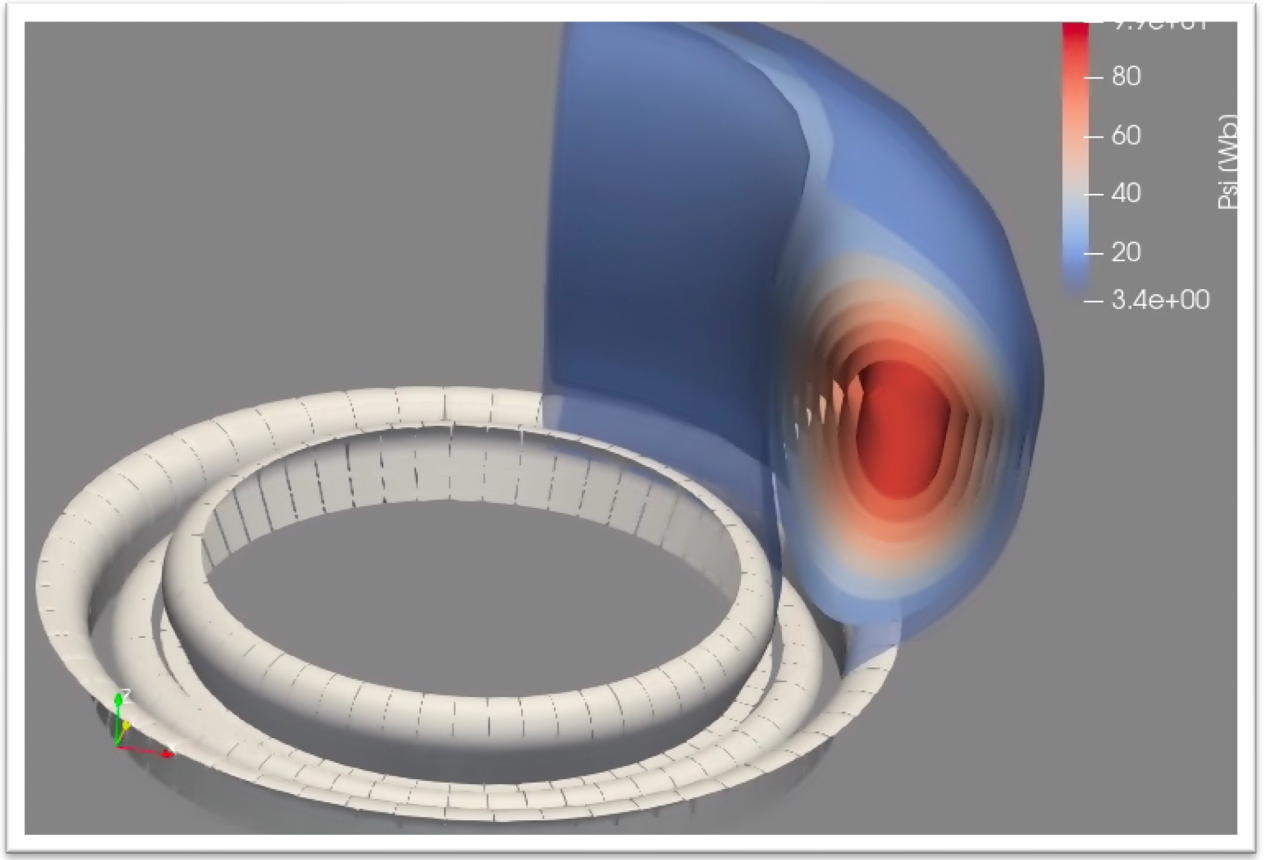

In-pulse analysis at ITER:

workflow managers and 3D visualization tools

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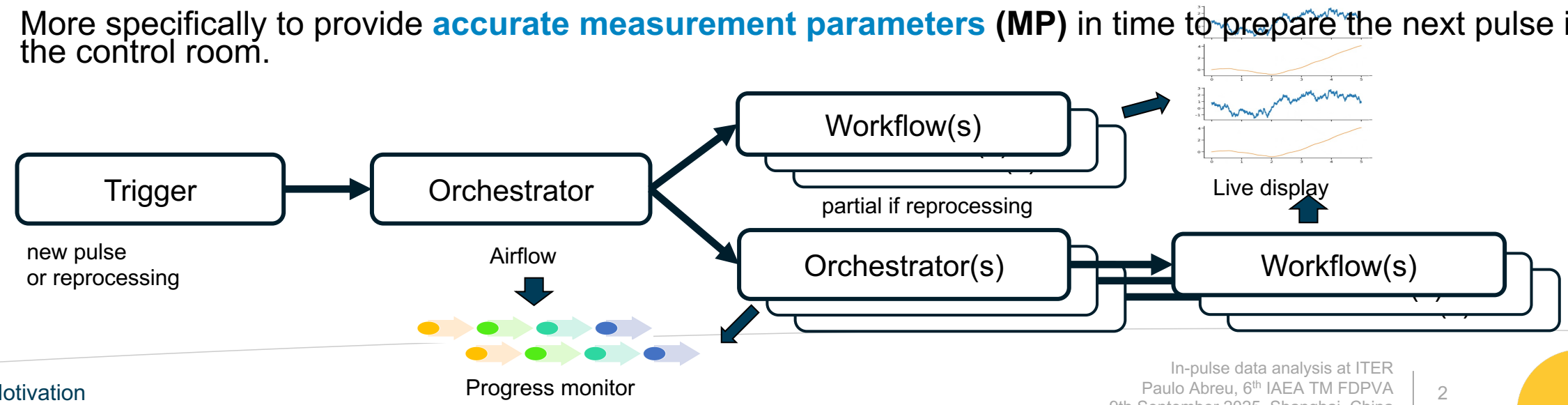
iter
china eu india japan korea russia usa

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

What is in-pulse data processing?

- A set of interdependent programs/actors that calculate **plasma parameters** from measurements.
- They use as **input** both the **raw data** from the diagnostics and **processed data** by other programs (hence the interdependence).
- The complete workflow(s) can be represented by a directed acyclic graph (**DAG**).
- The wider goal is to provide a consistent **interpretation of the plasma state** (with uncertainties) from the measurements **during** each pulse to guide the current experimental session.
- More specifically to provide **accurate measurement parameters** **(MP)** in time to prepare the next pulse in the control room.



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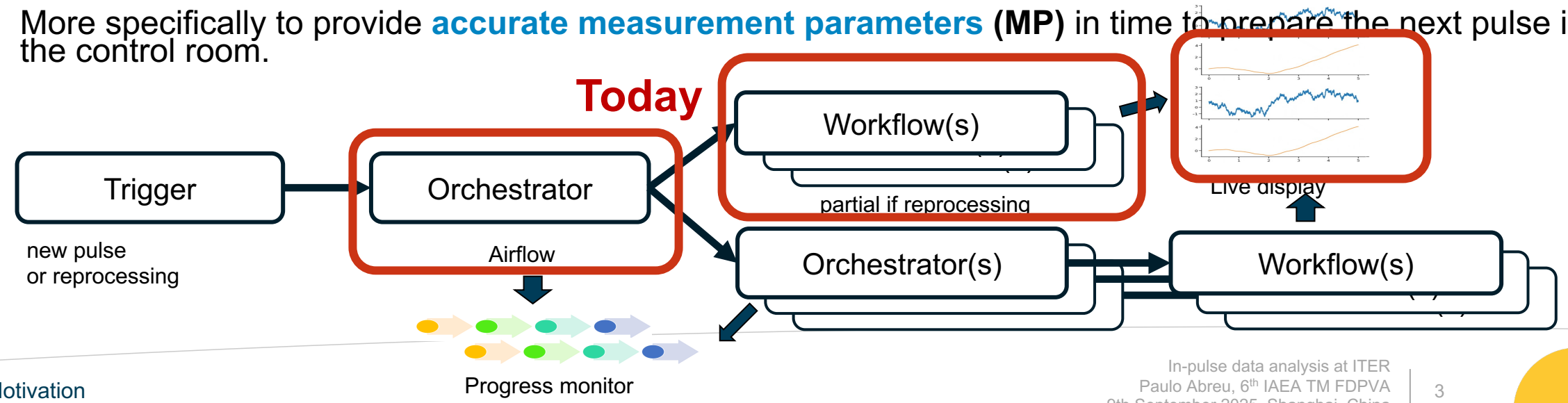


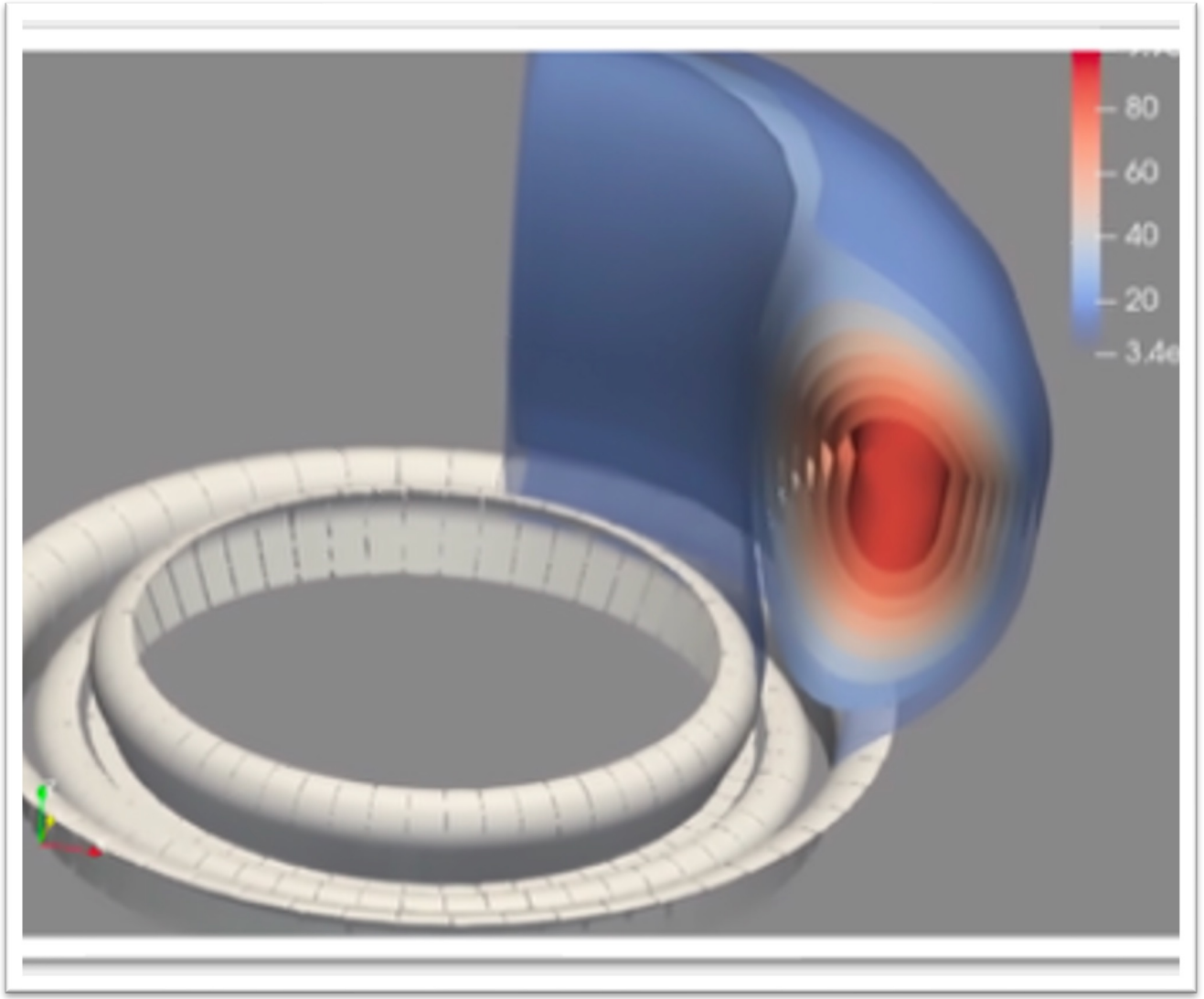
Overview

A. Motivation

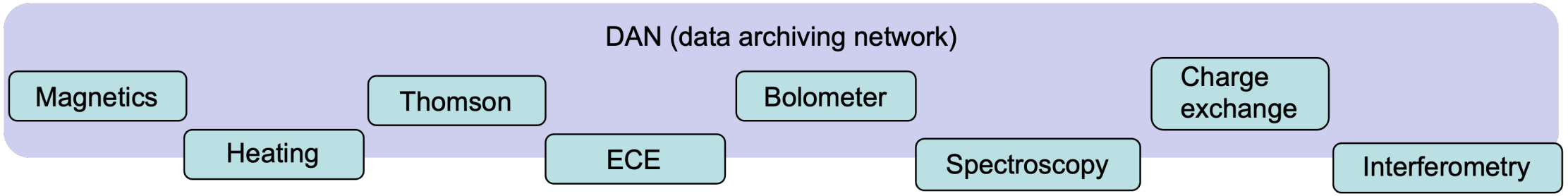
B. Workflow manager
   A. Airflow
   B. First application: equilibrium reconstruction
   C. Workflow framework

C. 3D visualization

D. Conclusions & future work



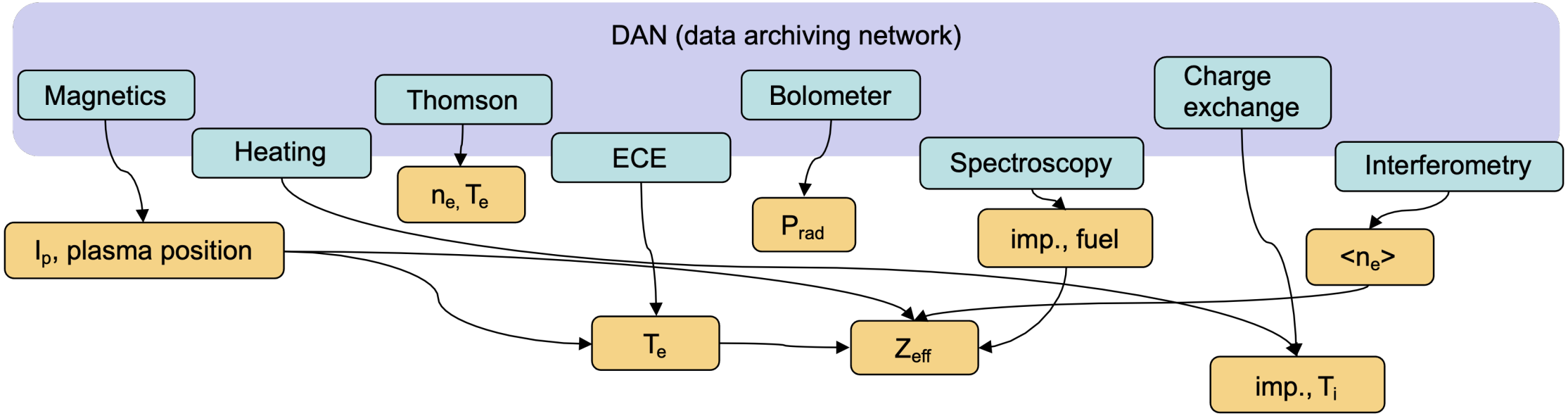
In-pulse analysis workflows: from diagnostics to physics



Labels: Diagnostics (~50)

Based on D. Dodt https://doi.org/10.1016/j.fusengdes.2012.11.015

In-pulse analysis workflows: from diagnostics to physics



Labels: Diagnostics (~50) Measurement parameters (~100)

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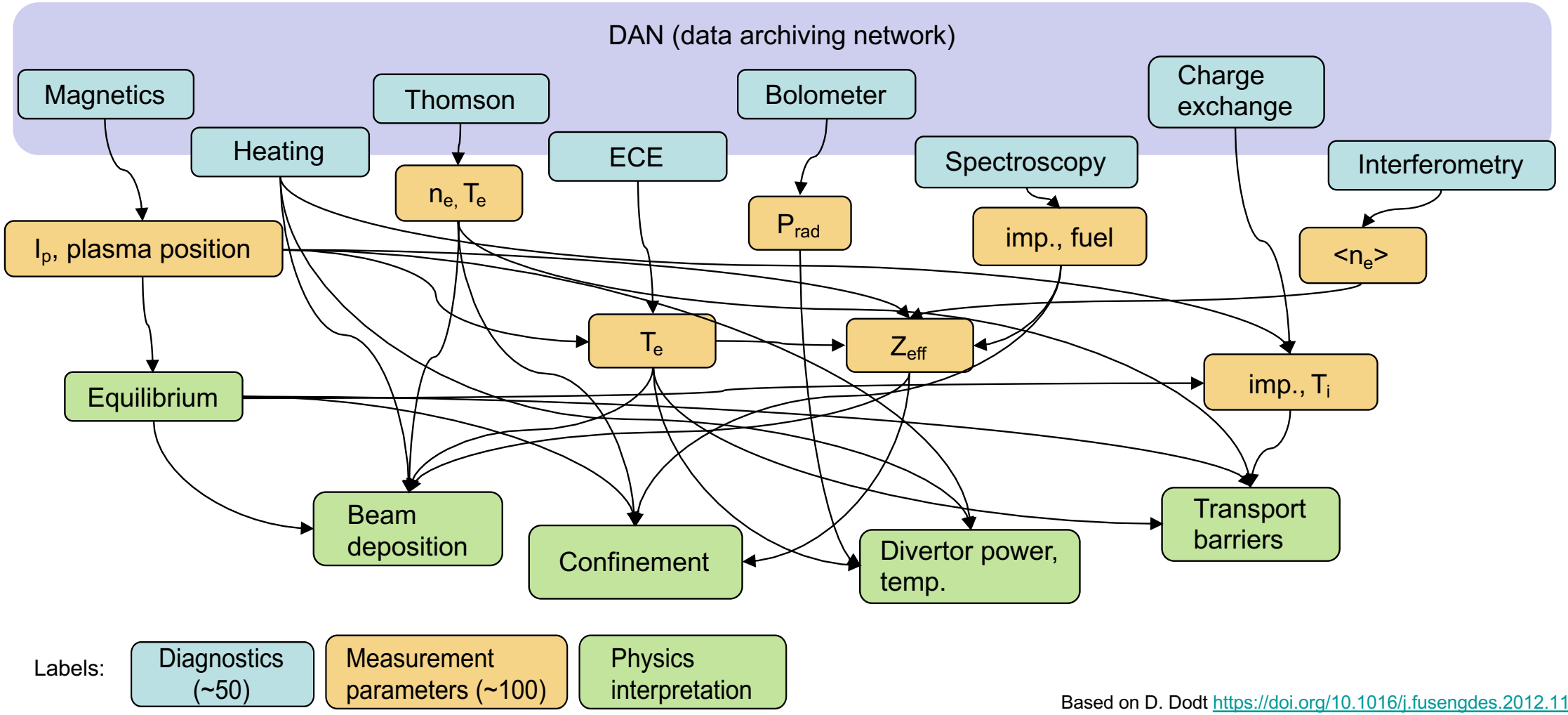
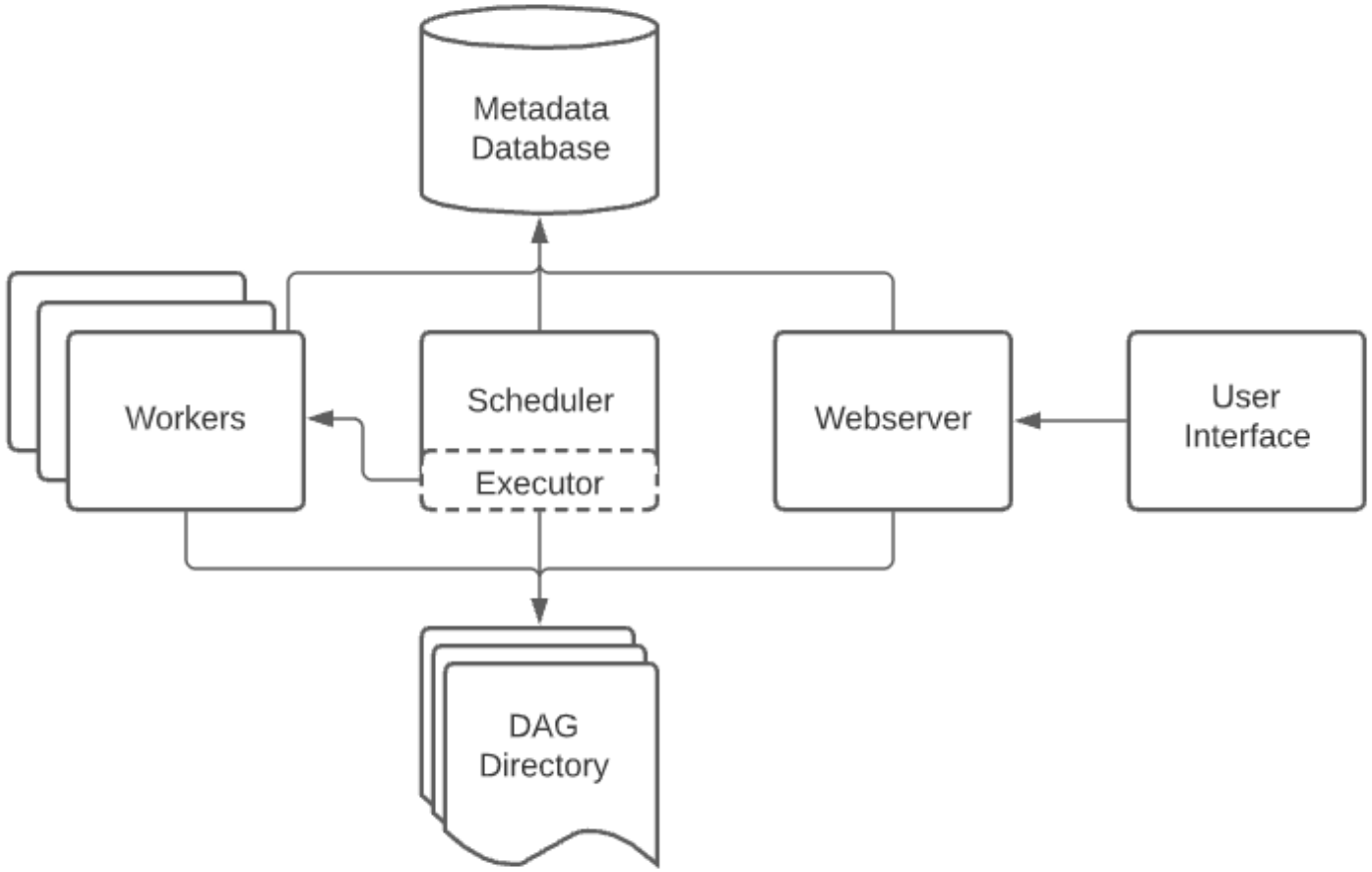
In-pulse analysis workflows: from diagnostics to physics



Based on D. Dodt https://doi.org/10.1016/j.fusengdes.2012.11.015

Apache Airflow as the workflow manager

- Open source
- Python
- DAG
- Web and CL interfaces
- Scalable (built-in task parallelism)
- Operators can have introspection into actors:
  - Fault detection
  - Restart
  - Replace



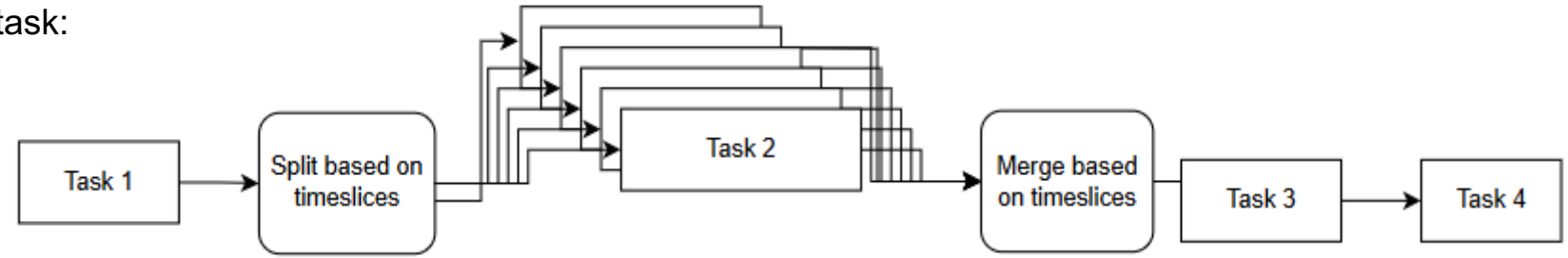
Airflow features at a glance

1. **Retry Mechanism:**
   - Automatically retries failed tasks to enhance reliability.
2. **Configuring Task Scheduling:**
   - Inbuild scheduling with Airflow.
   - External scheduling.
3. **Parallel Execution:**
   - **Parallelism:** Maximum number of tasks running across all DAGs.
   - **Concurrency:** Maximum tasks allowed for a single DAG.
4. **Task Dependencies:**
   - Specify execution order explicitly.

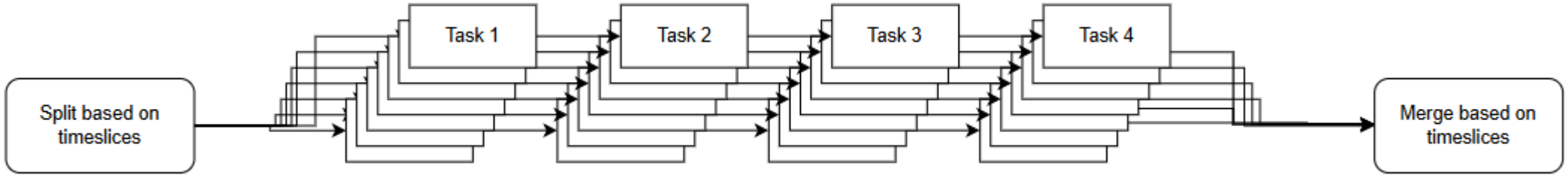
```python
# Define default_args for the DAG
default_args = {
    'owner': 'airflow',                        # Task owner
    'depends_on_past': False,                  # Don't wait for previous runs
    'email_on_failure': False,                 # Disable email alerts on failure
    'email_on_retry': False,                   # Disable email alerts on retry
    'retries': 3,                              # Retry up to 3 times
    'retry_delay': timedelta(minutes=5),       # Wait 5 minutes between retries
}

# Initialize the DAG
with DAG(
    dag_id = 'print_time_dag',                   # Unique DAG ID
    default_args = default_args,                 # Apply default arguments
    description = 'A DAG with key configurations to print the current time',
    schedule_interval='@hourly',               # Runs every hour
    max_active_runs = 10,                        # Limit concurrent runs of this DAG
) as dag:

    # Define the task functions
    def print_time():
        print(f"Current Time: {datetime.now()}")

    def end_message():
        print("Workflow Completed Successfully!")

    # Task 1: Print the current time
    print_time_task = PythonOperator(
        task_id='print_time',                  # Task name
        python_callable=print_time,            # Callable function
    )
    # Task 2: Print an end message
    end_message_task = PythonOperator(
        task_id='end_message',                 # Task name
        python_callable=end_message,           # Callable function
    )
    # Define task sequence flow
    print_time_task >> end_message_task      # Task 1 must finish before Task 2
```

Simple parallelization per time slice

- Most in-pulse actors process single time slices.
- We can process time slcies in batches / ranges with simple parallelism
  - Per actor / task:



  - Or per workflow:

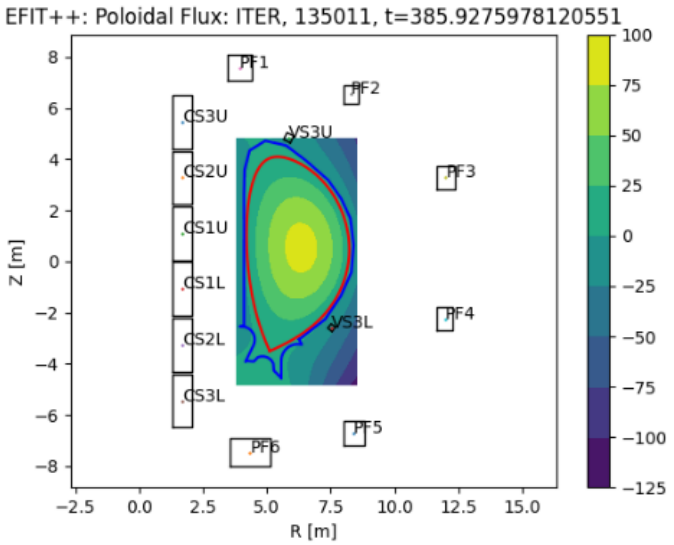


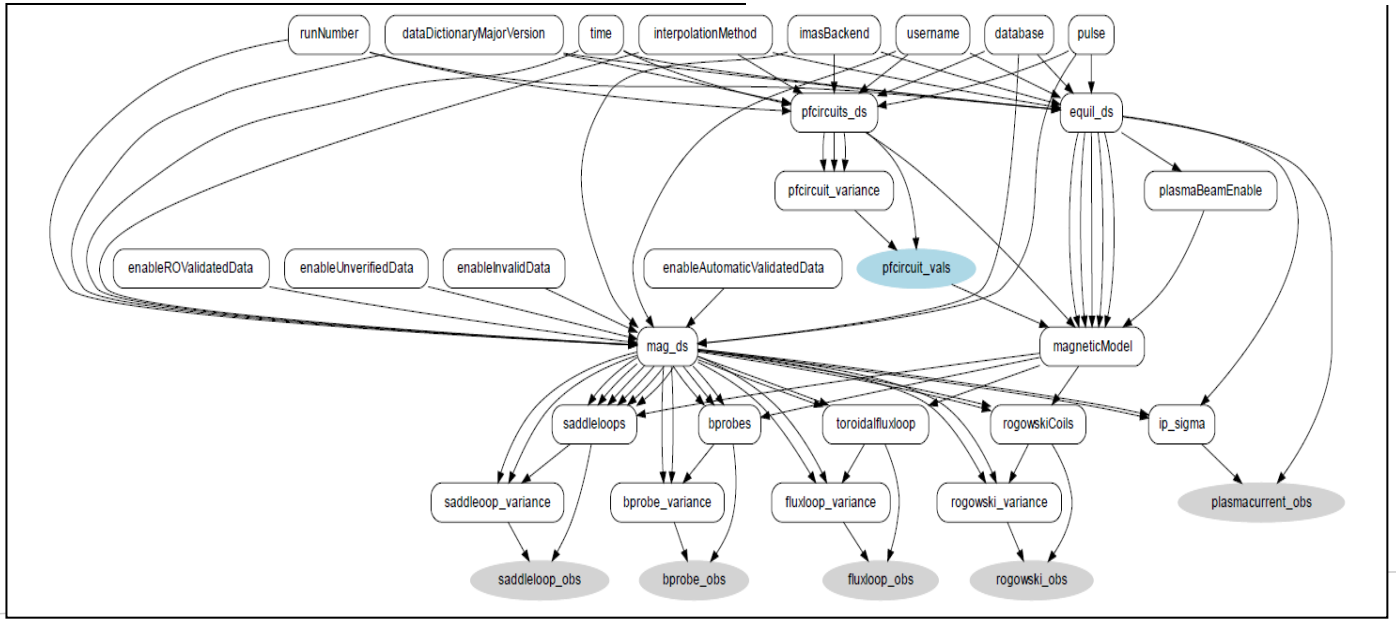
First application: equilibrium reconstruction with synthetic magnetics constraints

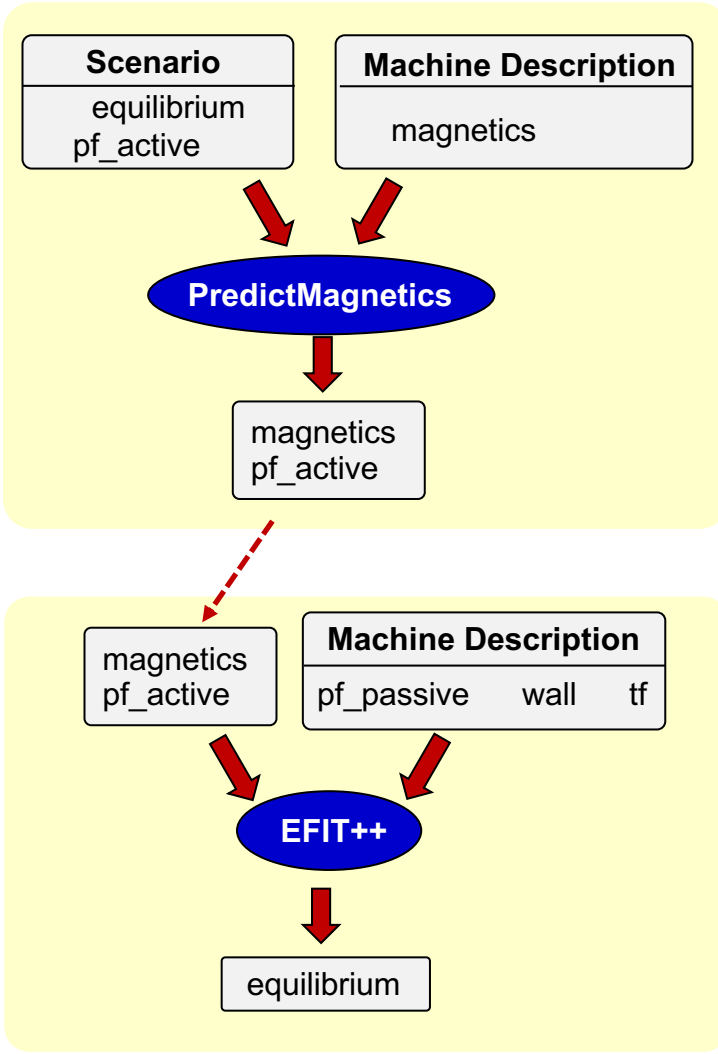
- **Magnetics Actor**
  - **Magnetics_prep** – Reads machine/diagnostic specific data.
  - **Magnetics** – Synthetic diagnostic modelling for magnetics measurements.
- **Equilibrium Actor**
  - **Equilibrium_prep** – Reads machine/diagnostic specific data for the equilibrium reconstruction.
  - **Equilibrium** –Actor used to reconstruct plasma equilibrium.
- **Machine agnostic**: diagnostic/machine specificities are parameters to the actors.
- **Code agnostic**: actors exchange data in IDS format, easily replaceable by other actors with the same inputs and outputs.
- In this particular exercise:
  - predictMagnetics (from the Minerva framework, L. Appel, UKAEA)
  - EFIT++ (L. Appel, UKAEA)

First application: equilibrium reconstruction with synthetic magnetics constraints

- 55.A* magnetic diagnostics
- PredictMagnetics by L. Appel within the Minerva framework
- EFIT++ actor





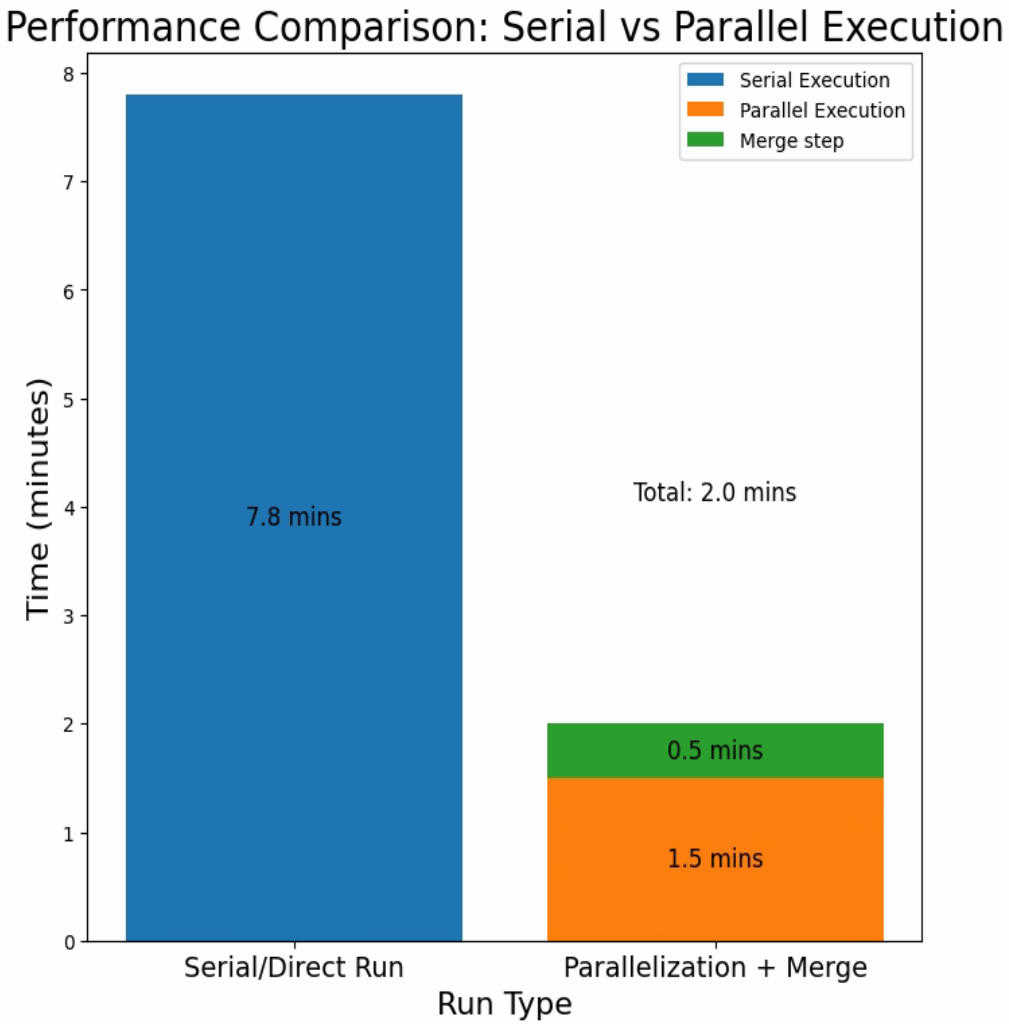


M. Schneider @ ITPA TG Diag 2022

Workflow manager: equilibrium reconstruction

First application: simple parallelism

- **Workflow info:** the **Magnetics Actor** for IMAS **Pulse 105027**, consisting of **614 timeslices.**
- **Serial Execution:**
  - Total execution time: **7.8 minutes**.
  - Tasks were executed sequentially without concurrency.
- **Parallel Execution + Merge:**
  - Average execution time of **5 parallel runs** : 1.5 minutes.
  - Merge operation of the runs : 0.5 minutes.
  - Total execution time reduced to **2.0 minutes** (1.5 + 0.5 minutes).
- **Conclusion:**
  - Even with the **overhead of the merge step,** the average execution time of the parallel runs combined is significantly faster than the serial/direct run.

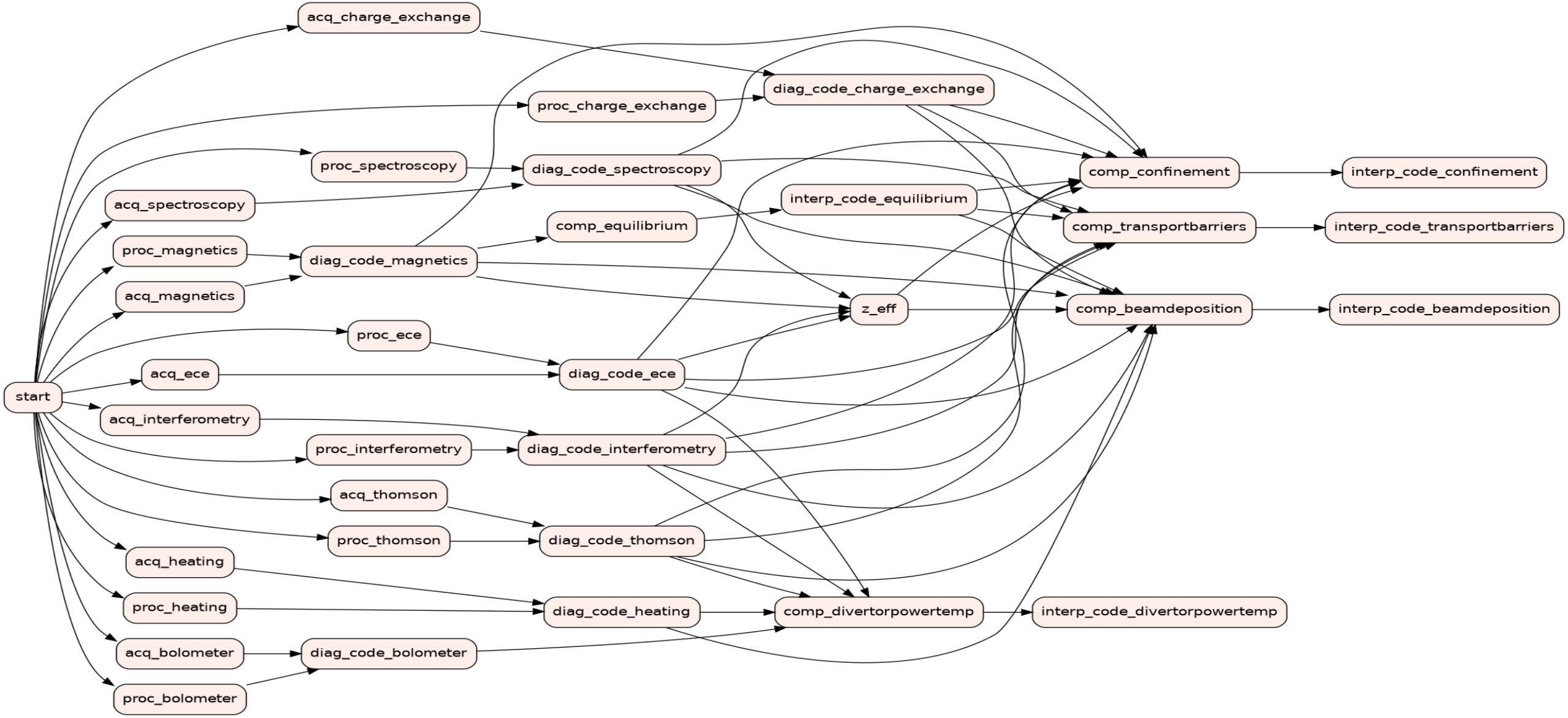


In-pulse Workflow Framework

Developed a **mock in-pulse processing workflow** to simulate a complete plasma analysis workflow during a pulse.

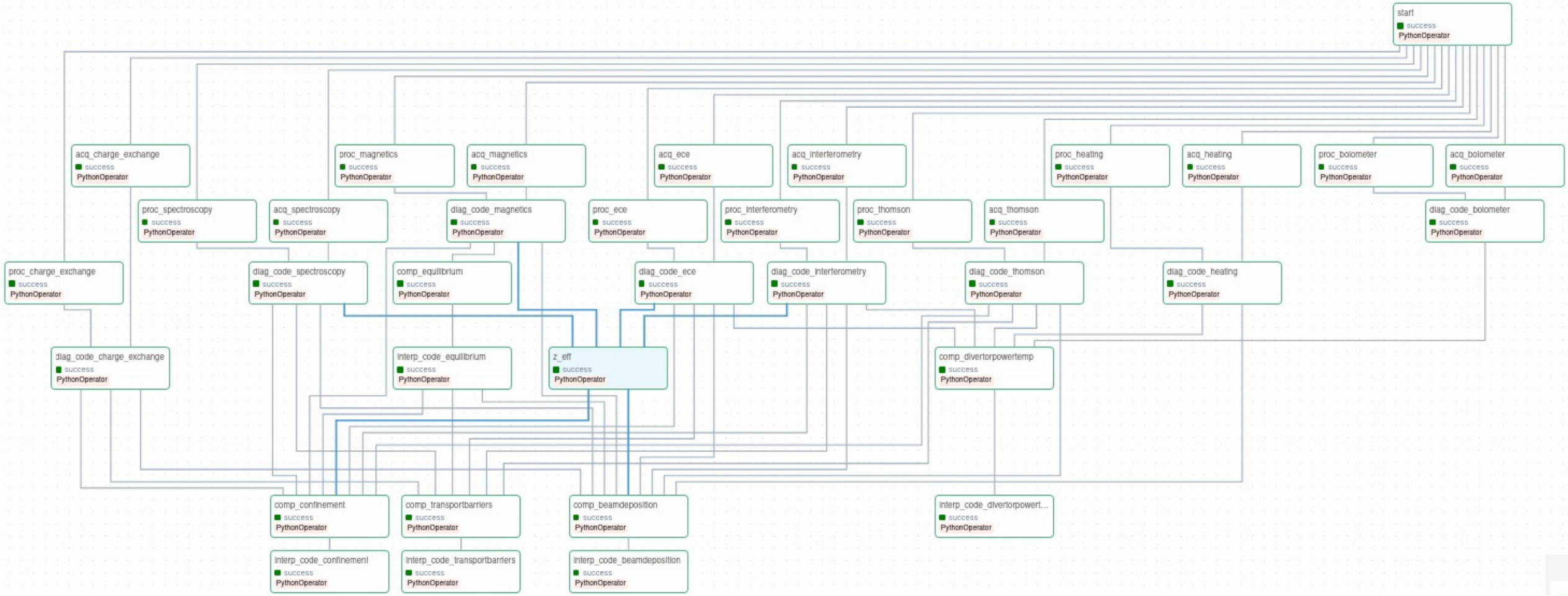
- The workflow serves as a **blueprint** for future integration of real physics-based codes in ITER's real-time processing pipeline.
- All computational steps currently use **placeholder actors**, designed to be replaced with validated physics modules in future iterations.
- This **framework** establishes a baseline architecture for modular, scalable in-pulse workflows spanning multiple diagnostics and control loops.

In-pulse Workflow Simulation



Workflow manager: framework

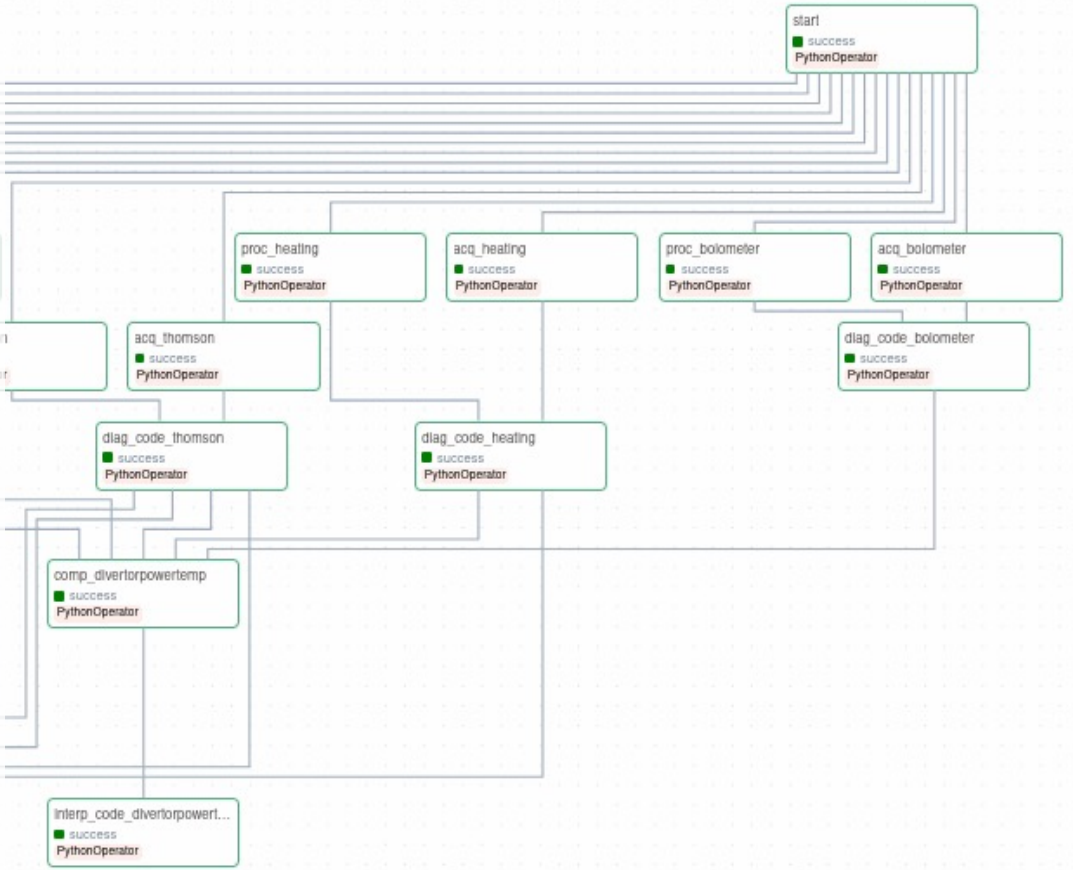
In-pulse Workflow Simulation in Airflow



Workflow manager: framework

In-pulse Workflow Simulation in Airflow

- **Failure detection**: detects failures and supports resolution through **retry logic**, **fallback paths**, and execution monitoring.
- **Failure resolution**: includes alternative placeholder codes that can be triggered dynamically if a primary actor fails enabling **fault tolerance**.
- The architecture supports **horizontal scaling**, where multiple timeslices can be processed concurrently as they arrive.
- It also enables **vertical scaling**, allowing additional dependent tasks (e.g., diagnostics, post-processing) to be added without disrupting existing workflows.
- The orchestration setup is **modular** and **extensible**, allowing increased complexity and integration over time without changing the core design.



Workflow Simulation: in-pulse and reprocessing

1. **In-Pulse Workflow** (Simulated):

   Mimics online timeslice-by-timeslice processing during an active pulse. Tasks triggered sequentially as new timeslices arrive.

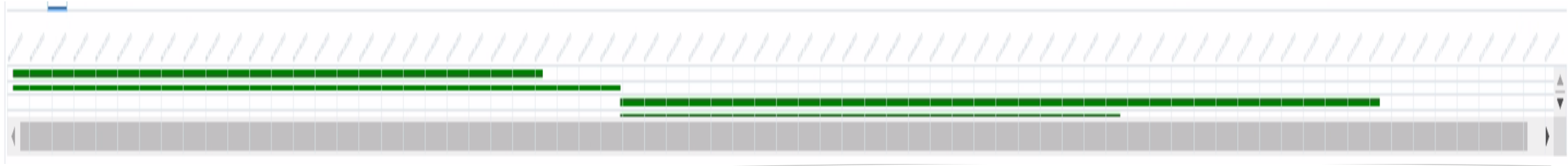
2. **Reprocessing Workflow** (Simulated):

- Executes after pulse completion using full data availability. Represents a traditional, serial processing pipeline.
- Both workflows use identical placeholder actors and input conditions, isolating orchestration behaviour for easier comparison.
- Each actor had randomized processing times, generated deterministically using the component's name as a seed.

Workflow Simulation: in-pulse and reprocessing

In-pulse:

Reprocessing:



Data visualization and exploration

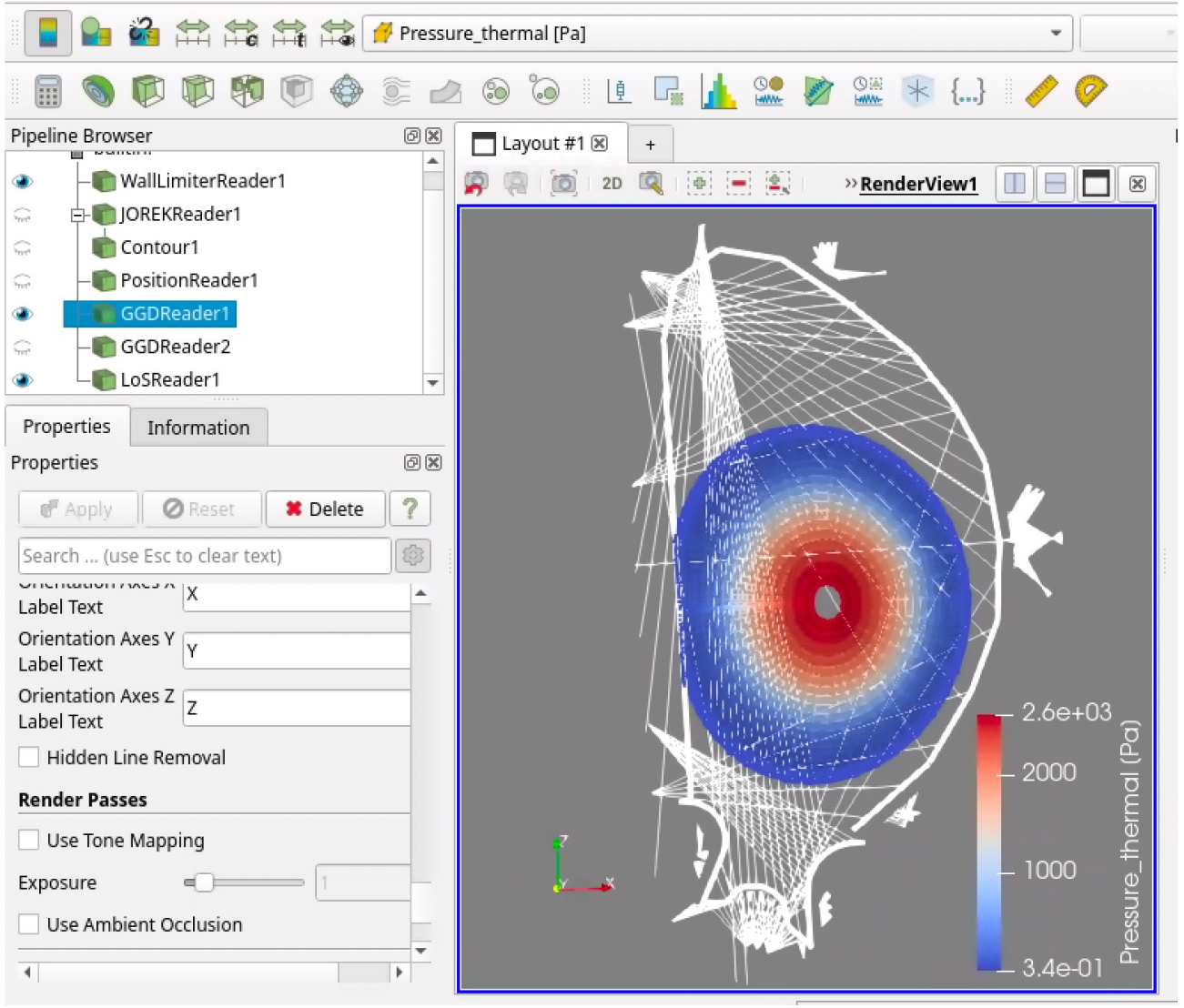
- Data is useless without insight.
- There is an ongoing development of ITER plotting library (L. Abadie):
  - iplot ecosystem and MINT
  - DAN, SDN, IMAS, …
  - 1D and 2D
  - control room display and user desktop
- 3D scientific data exploration tool was missing:

  Kitware Paraview

  +

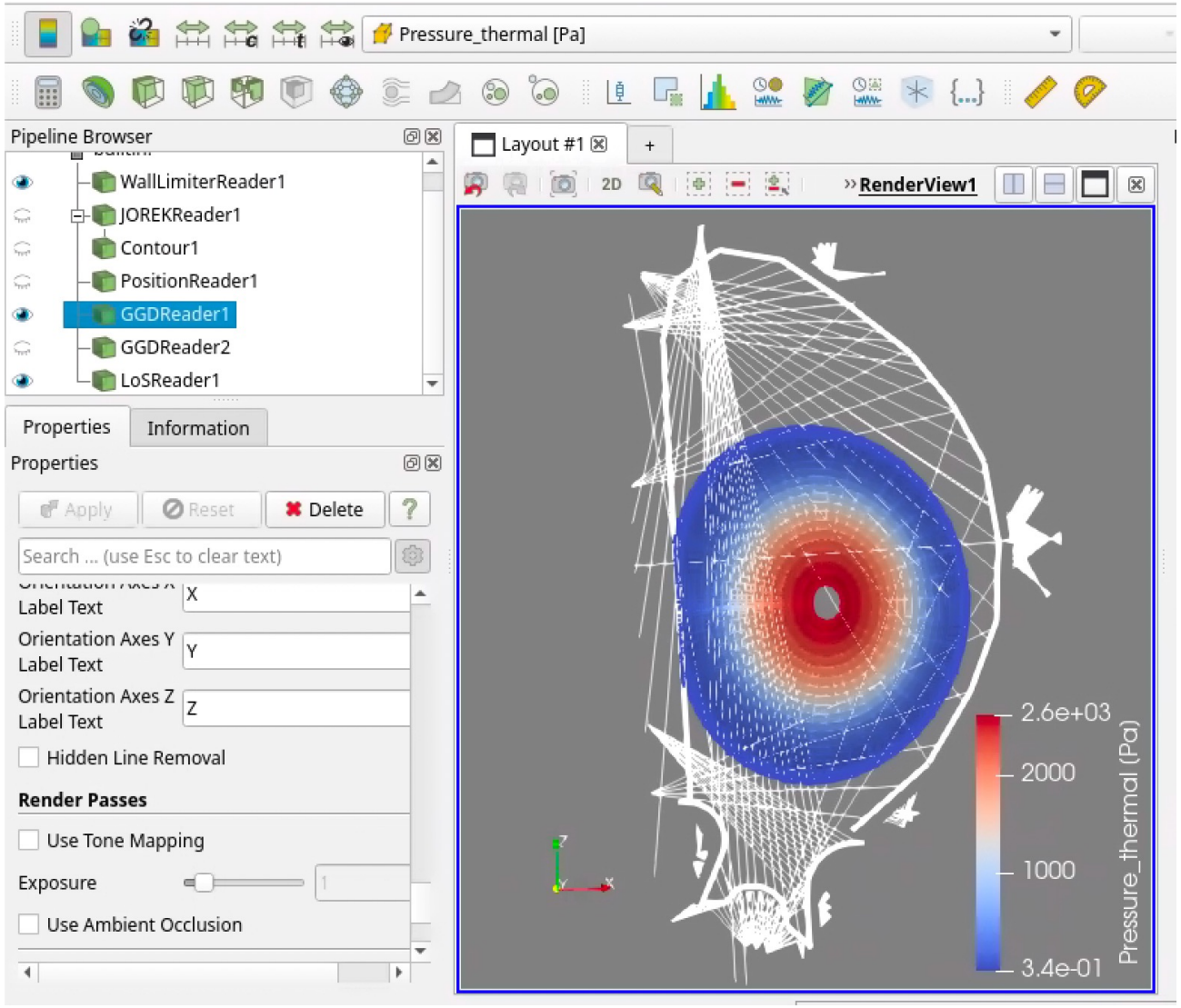
  IMAS plugin

SOLPS + Limiter + ECE LOS



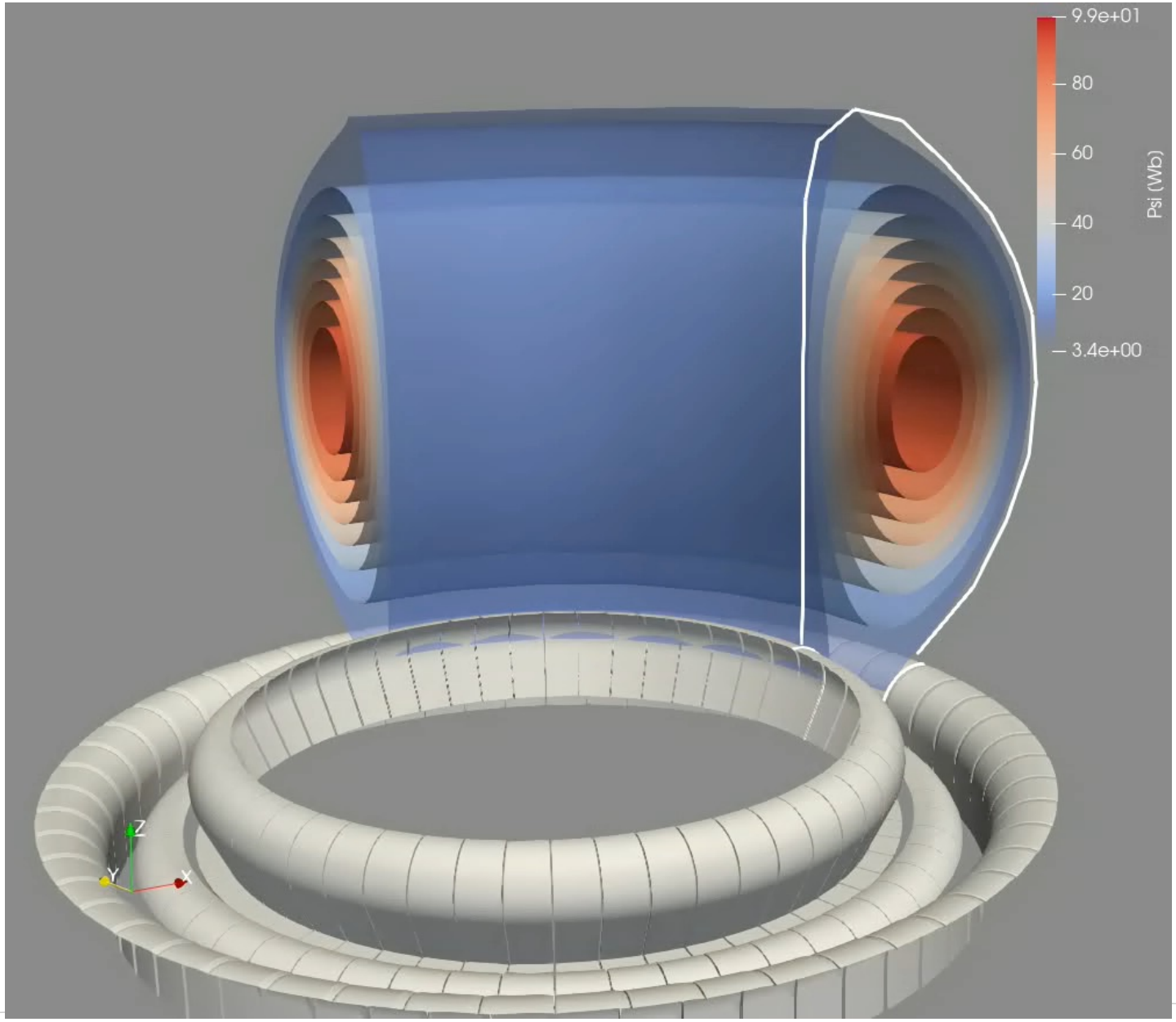
Data visualization and exploration

- See IMAS-Paraview manual and example.
- Open source on github
- GUI and CLI (export to VTK)
- GGD data (2D and 3D)
- JOREK
- 1D profile data:
  - Integrate 1D core with 2D edge
- Machine/diagnostic description data:
  - Divertor
  - Wall
  - LoS
  - Magnetic sensors
  - …



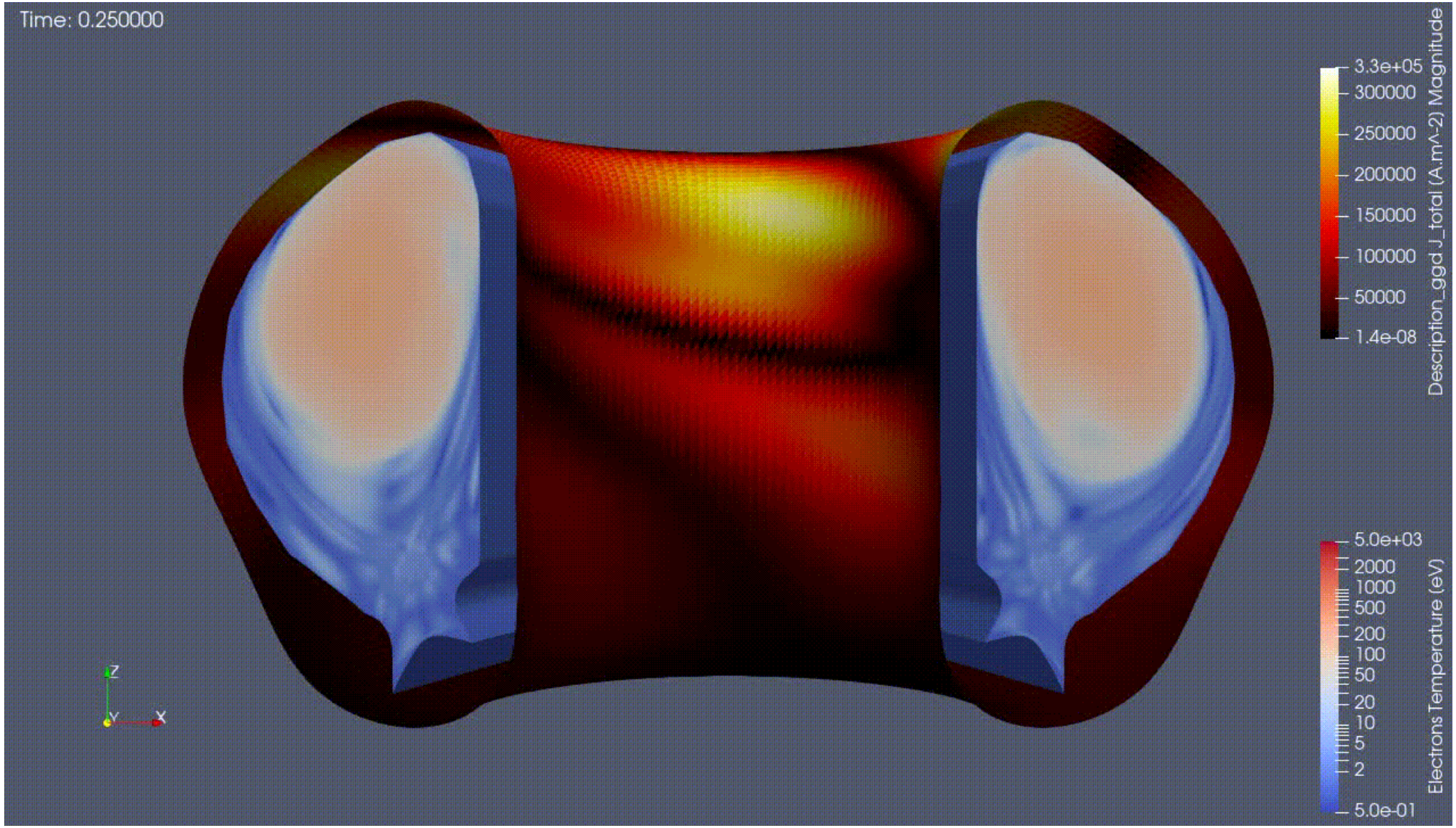
Example:

- JOREK data (psi)
- Divertor
- Limiter



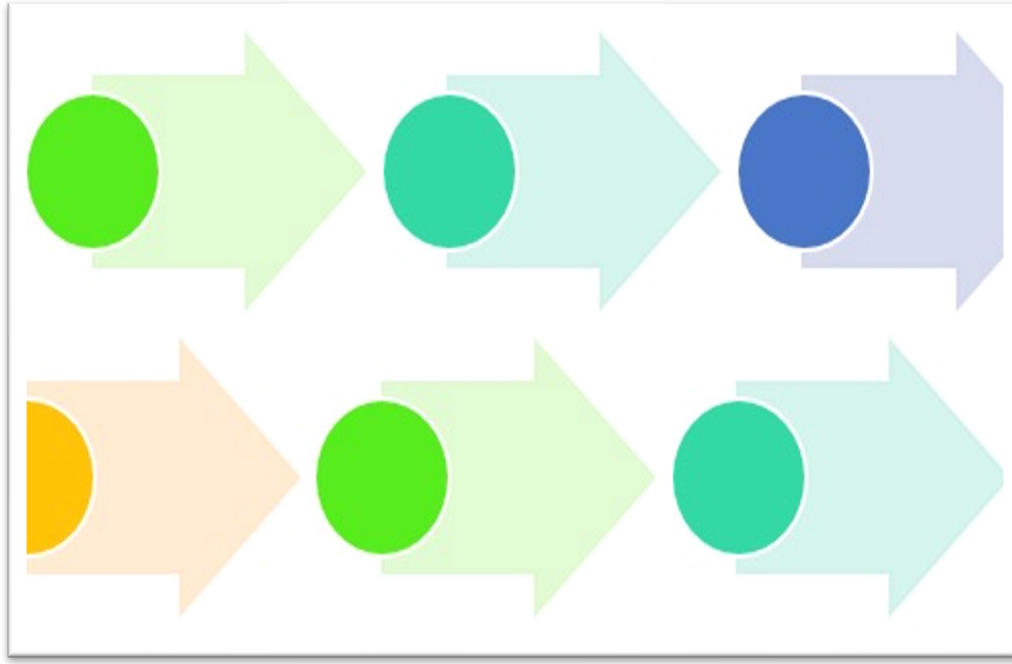
Example:

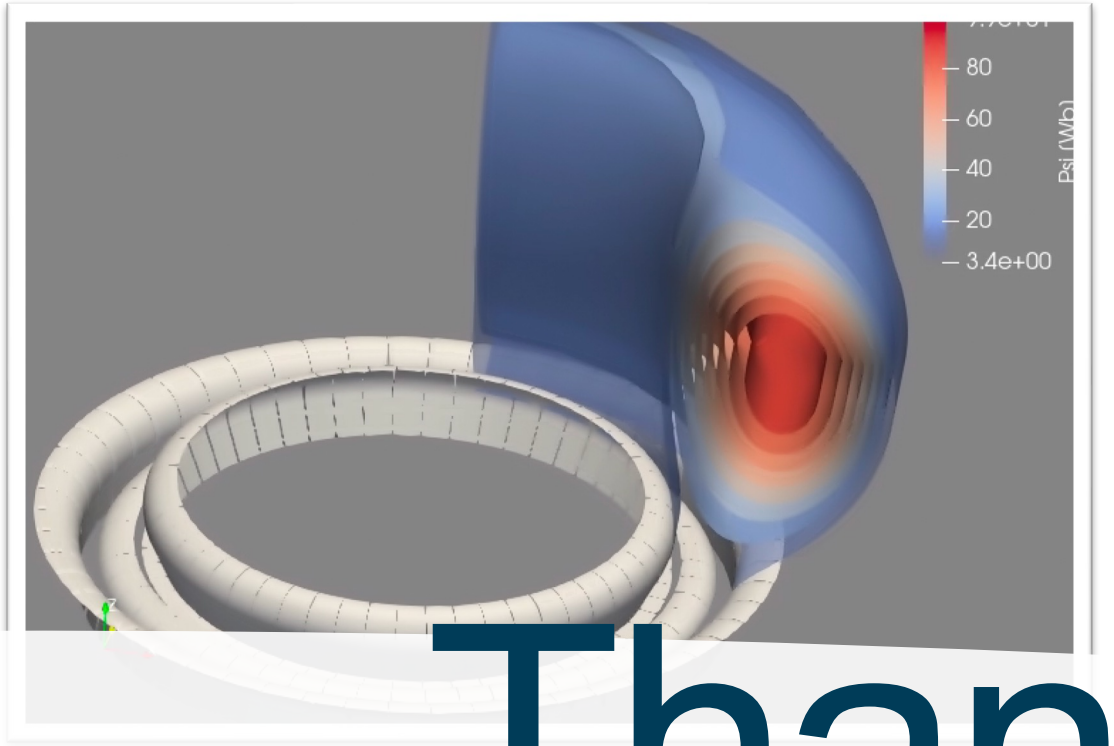
- JOREK data
- Animation of the electron temperature and wall currents.
- Data provided by J. Artola.



Future work

- Workflows:
  - Realistic **input data**:
    - Use **synthetic diagnostic models** as input to the workflows (see presentation from S. Pinches).
    - Use **mapped experimental data** from other devices.
  - Integrate with **MUSCLE3** (persistent actor framework):
    - Work by F. Poli based on the ETS-PAF
    - H&CD workflow by M. Schneider
- 3D visualization: further improvements based on user request





Thank you!

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workflow managers and 3D visualization tools

Paulo Abreu, ITER Organization
Sixth IAEA Technical Meeting on Fusion Data Processing, Validation and Analysis
September 2025, Shanghai, China

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