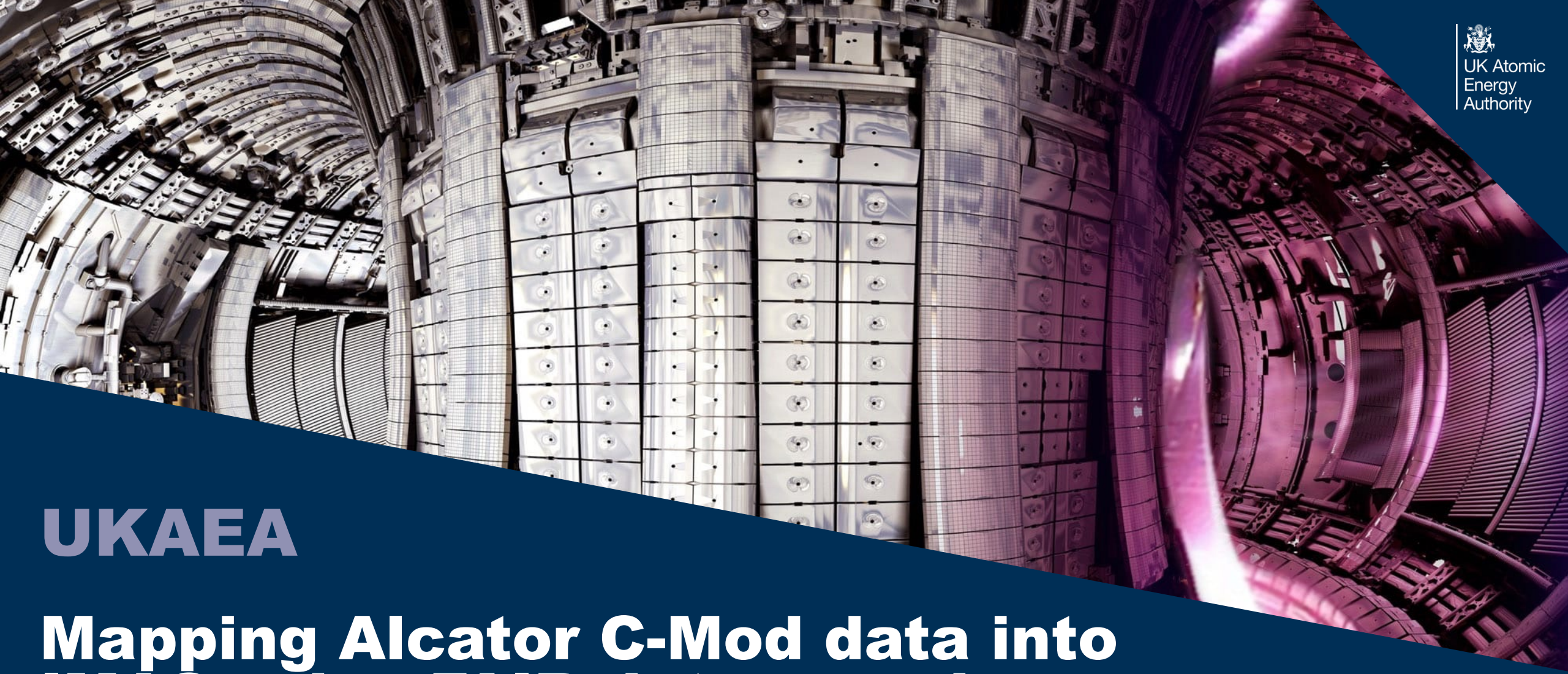

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Mapping Alcator C-Mod data into IMAS using FAIR data mappings

J. Hollocombe (UKAEA), A. Parker (UKAEA)

IAEA workshop, Sao Paulo, Brazil, 17th July 2024

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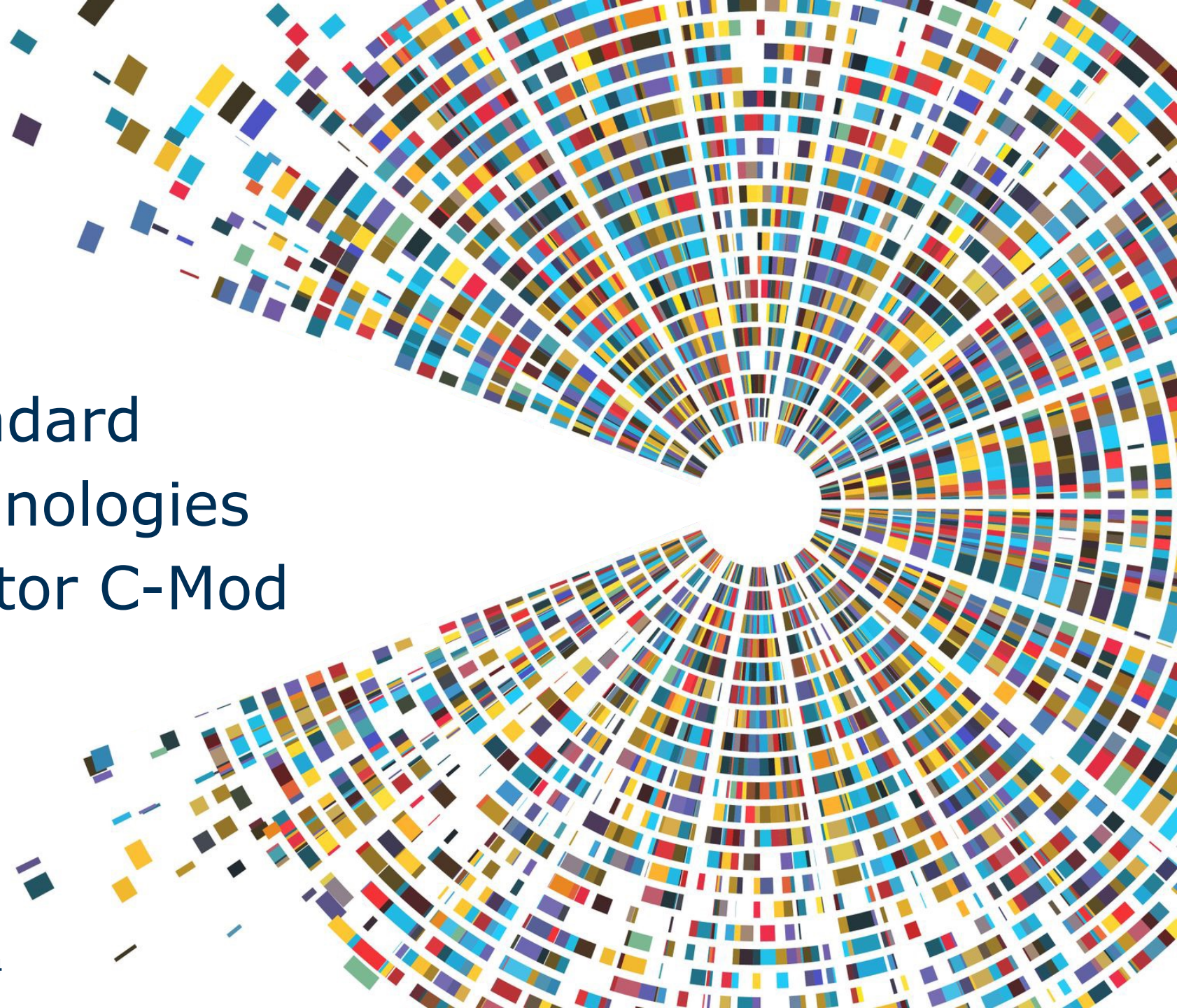

1. Motivation
2. Mapping Standard
3. Mapping Technologies
4. Mapping Alcator C-Mod
5. Future Work

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1. Motivation

Motivation

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Data

- Lots of existing experimental data – untapped resource
- Common data model exists in IMAS data dictionary

Mappings

- Many ways of mapping the data – technologies & representation
- Off-line vs on-line mapping – different trade-offs
- Only want to write these mappings once – people's time is precious
- Interoperable/sharable mappings would allow common tools to be developed

Create a Mapping Standard

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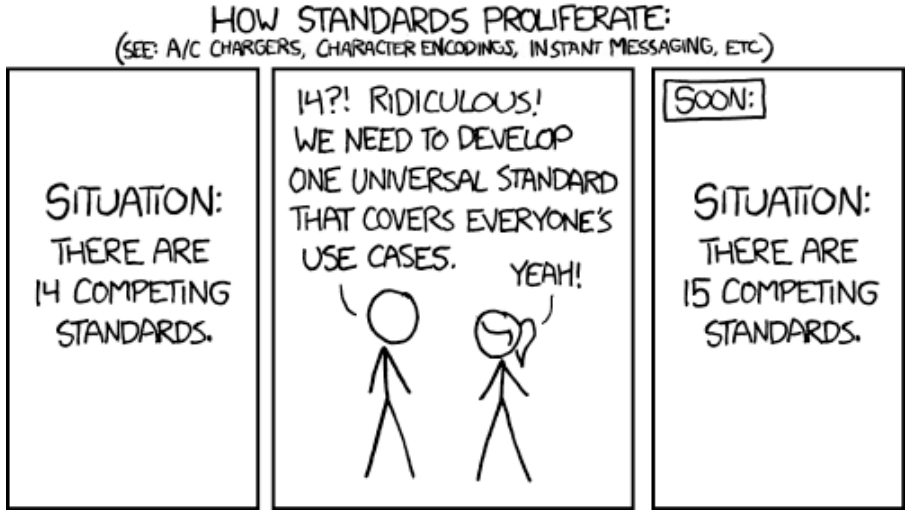
- Create a mapping standard like the Common Workflow Language† for workflows
- Using a standard human maintainable format – able to be updated and maintained by non-software engineers
- Ability to run validity checks – in development and CI
- Should allow for description fields to be added to mapping to enable self-documentation
- Encode as much as possible in the mapping but being pragmatic

† https://www.commonwl.org/



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2. Mapping Standard (TokaMap)

TokaMap mapping syntax

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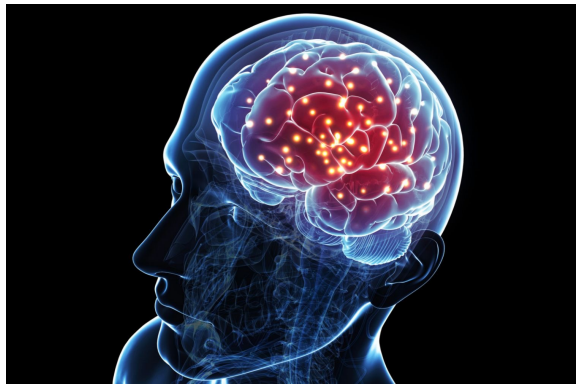
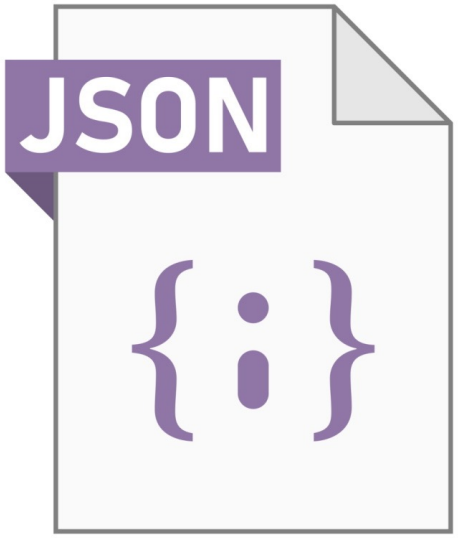
- Devised a JSON based mapping syntax
- Designed to be flexible, template-able and extensible
- Can be used to populate an IDS on request using the UDA IMAS plugin or used in a mapping tool such as pytokamap to generate the mapped data off-line
- Capture all that precious machine knowledge





IMAS mappings

```
Data dictionary
- amns_data
- b_field_non_axisymmetric
- barometry
- …
- waves
- workflow
```

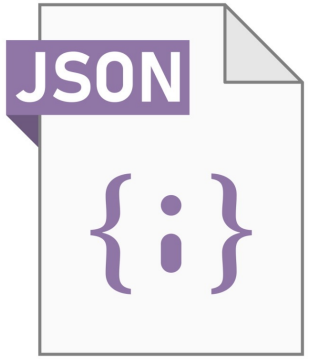
magnetics/mappings.json

Nested structures

Data fields

Array of structures

```
magnetics IDS
- ids_properties
    - comment
    - field
    - …
- flux_loop(N)
    - name
    - flux/data(:)
    - …
- …
```




```
“flux_loop[3]/flux/data” : {
    “MAP_TYPE”: “…”
}
```

Mapping Files: Directory Structure

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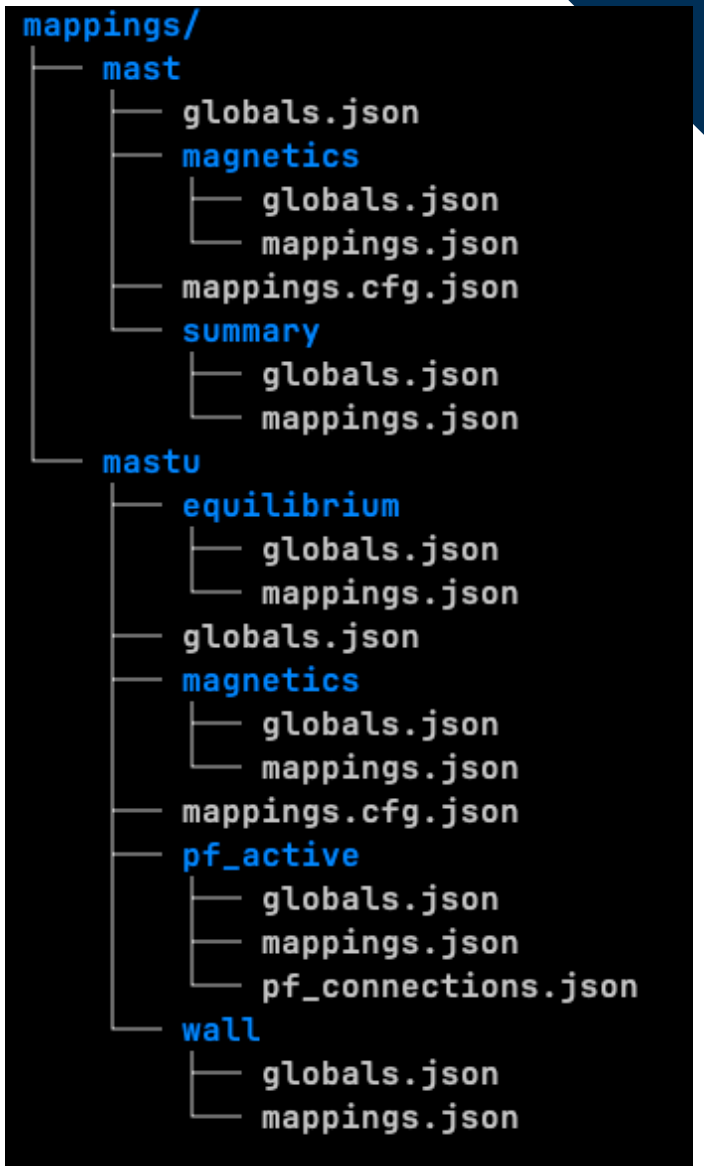
- Inside mappings directory we have a folder for each machine
- Top level “globals.json” contains common data for all IDSs
- Top level “mappings.cfg.json” specifies which IDSs have been mapped for specific DD versions
- Each IDS is in its own folder
  - “globals.json” contains common data
  - “mappings.json” contains actual mappings
- Work being done to split mappings by DD version and shot range to allow for more granularity



Mapping Files: globals.json example

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```
{
    ...
   "COIL_NAMES_GEOM": [
      "d1-upper", "d2-upper", "d3-upper", "d5-upper", "d6-upper", "d7-upper", "dp-upper",
      "p4-upper", "p5-upper", "p6-upper", "px-upper", "d1-lower", "d2-lower", "d3-lower",
      "d5-lower", "d6-lower", "d7-lower", "dp-lower", "p4-lower", "p5-lower", "p6-lower",
     "px-lower", "p1-inner", "p1-outer", "pc"
   ],
   "COIL_NAMES": [
      "D1U", "D2U", "D3U", "D5U", "D6U", "D7U", "DPU",
      "P5U", "P6U", "PXU", "D1L", "D2L", "D3L", "D5L",
      "D7L", "DPL", "P4L", "P5L", "P6L", "PXL"
   ],
   "UNIT_SF": 1000.0,
   ...
}
```

Global keys, values, and names unique to each experiment/IDS
(Used in templating and expression evaluation)

MAST-U real example
COIL_NAMES used to access signal :
/AMC/FLUX_LOOPS/D1U

MAST-U currents are also in kAmps so are scaled by **UNIT_SF** for the IDS

Mapping Files: Map Types

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- **VALUE**
  - Hard-coded value in mapping file
  - Good for static machine description, etc.
- **DIMENSION**
  - Reading the dimension of another mapping
  - Good for mapping lengths of array structures, i.e. flux_loops(N)
- **PLUGIN** (may rename)
  - Call out to a data reader
  - Most common map type
  - Used to fetch actual data from file or data system, i.e. UDA/MDS+
  - Has arguments for scaling, offsetting & slicing returned data

Mapping Files: Map Types

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- **EXPR**
  - Uses powerful expression toolkit to perform more complex mappings
- **CUSTOM**
  - Small set of additional useful transformations that can be used in mappings
  - E.g. COCOS transformation, array concatenation
  - Will be extended as needed but each library that supports the mappings would have to implement funcitonality

```
"b_field_pol_probe[#]/poloidal_angle": {
    "MAP_TYPE": "EXPR",
    "PARAMETERS": {
        "Z": "_pickup[#]/unit_vector/Z",
        "R": "_pickup[#]/unit_vector/R"
    },
    "EXPR": "2*PI-atan2(Z,R)"
},
"_pickup[#]/unit_vector/Z": {
   ...
},
"_pickup[#]/unit_vector/R": {
   ...
},
```

Dynamic Templating

We support dynamic templating in the mapping files using a syntax based on the **Jinja** library for python. In C++ we use the **Inja** library which can perform similar templating.

Simple Example

```
name = "World";
post_inja_string = inja::render("Hello {{ name }}!", name);
-> "Hello World!"
```

We will support a subset of templating functions supported by both **Inja** and **Jinja**

Used extensively in MAST-U Mappings

Able to dynamically substitute strings

JSON Mapping Example

```
"SPECIAL_COIL": "P1",
"COIL_NAMES": ["D1U", "D2U", "D3U"],
...
"signal": "/AMC/PF_COIL/{{ SPECIAL_COIL }}",
-> "/AMC/PF_COIL/P1"
…
"signal_2": "/AMC/PF_COIL/{{ at(COIL_NAMES, 2) }}"
-> "/AMC/PF_COIL/D3U"

"VALUE": "{{ length(COIL_NAMES) }}"
-> "3" -> can be converted to Integer
```

Mapping Indices

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- To avoid mapping duplication indices are extracted from array structures
  - I.e. if “magnetics/flux_loop[3]/flux/data” is not found in mapping file then look for “magnetics/flux_loop[#]/flux/data”
  - Extracted indices are available in mappings as magic “indices” template variable

```
"FL_TYPE": "{{ at(FLUX_LOOPS, indices.0).TYPE }}"
```

```
"flux_loop[#]/identifier": {
    "MAP_TYPE": "VALUE",
    "VALUE": "FLUX_LOOP_{{ indices.0 + 1 }}"
},
"flux_loop[#]/type/name": {
    "MAP_TYPE": "VALUE",
    "VALUE": "{{ FL_TYPE }}"
},
"flux_loop[#]/type/index": {
    "MAP_TYPE": "VALUE",
    "VALUE": "{{ at(FL_TYPE_MAP, at(FLUX_LOOPS, indices.0).TYPE) }}"
},
```

Hidden Mappings and Comments

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Naming convention

Not every entry within the mapping file must be an IDS path

Any entry can be used for intermediate calculations or *'turned off'*

Our naming convention is to prefix keys by an underscore '_' for non-IDS mappings

Comments

JSON by default does not allow comments

Within the mapping file, each map type is allowed a COMMENT field.

This is purely for the person making the mappings, the field is ignored when the mappings are ingested

```
{
    "_b_field_pol_probe[#]/poloidal_angle": {
        "MAP_TYPE": "EXPR",
        "PARAMETERS": {
            "Z": "_pickup[#]/unit_vector/Z",
            "R": "_pickup[#]/unit_vector/R"
        },
        "EXPR": "2*PI-atan2(Z,R)"
    },
    "_sub_mapping": {
        "MAP_TYPE": "PLUGIN",
        "PLUGIN": "UDA",
        "ARGS": {
            signal": "/AMC/PLASMA_CURRENT"
        }
    },
    "_pickup[#]/unit_vector/R": {
        "MAP_TYPE": "VALUE",
        "VALUE": 23.4,
        "COMMENT": "This is a random comment"
    },
}
```

Mapping examples

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See MAST-U mappings (https://github.com/ukaea/IMAS_MASTU_mappings/) for many more examples of how fields can be mapped

IDS: pf_active

```
"coil[#]/element[#]/geometry/rectangle/width": {
    "MAP_TYPE": "PLUGIN",
    "PLUGIN": "GEOMETRY",
    "ARGS": {
        "signal": "/magnetics/pfcoil/{{ PF_GEOM_NAME }}",
        "key": "geom_elements.dR"
    },
    "SLICE": "[{{ indices.1 }}]"
},
```

IDS: tf

```
"b_field_tor_vacuum_r": {
    "MAP_TYPE": "PLUGIN",
    "PLUGIN": "UDA",
    "ARGS": {
        "signal": "/AMC/ROGEXT/TF"
    },
    "SCALE": 0.0048,
    "COMMENT": "From Ampere's law at r=1metre, takes into account
the number of TF coils"
}
```

Mapping Schema and Validation

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Testing and validation step available through pytest (and CI)

1) **JSON Verification**
   Test that all JSON globals.json and mappings.json are valid JSON syntax and can be read / parsed

2) **JSON Schema Validation**
   Validate all mappings.json against the top-level schema defining map types and required fields

3) **Inja Templating Render**
   Using globals.json, verify that all Inja templating strings complete and render to a valid string

4) **EXPR Map Type Validation**
   Test EXPR strings, substitute random floats to the parameters, check the output is sensible and of float type

Mapping Schema and Validation

```
tests/test_schema.py::test_valid_globals[map_globals7] PASSED
tests/test_schema.py::test_valid_globals[map_globals8] PASSED
tests/test_schema.py::test_valid_globals[map_globals9] PASSED
tests/test_schema.py::test_valid_structure[map_schema0] FAILED
tests/test_schema.py::test_valid_structure[map_schema1] PASSED
tests/test_schema.py::test_valid_structure[map_schema2] PASSED
tests/test_schema.py::test_valid_structure[map_schema3] PASSED
tests/test_schema.py::test_valid_structure[map_schema4] PASSED
tests/test_schema.py::test_valid_structure[map_schema5] PASSED
tests/test_schema.py::test_valid_structure[map_schema6] PASSED
tests/test_schema.py::test_valid_structure[map_schema7] PASSED
tests/test_schema.py::test_valid_structure[map_schema8] PASSED
tests/test_schema.py::test_valid_structure[map_schema9] PASSED
tests/test_templating_inja.py::test_cython_include PASSED
tests/test_templating_inja.py::test_template_syntax_fail[/magnetics/pfcoil/{{indices.1/test-expected0] PASSED
tests/test_templating_inja.py::test_template_syntax_fail[/magnetics/pfcoil/{{unknown}}/test-expected1] PASSED
tests/test_templating_inja.py::test_templating_in_json[get_keys_and_globals0] FAILED
tests/test_templating_inja.py::test_templating_in_json[get_keys_and_globals1] PASSED
tests/test_templating_inja.py::test_templating_in_json[get_keys_and_globals2] PASSED
tests/test_templating_inja.py::test_templating_in_json[get_keys_and_globals3] PASSED
tests/test_templating_inja.py::test_templating_in_json[get_keys_and_globals4] PASSED
tests/test_templating_inja.py::test_templating_in_json[get_keys_and_globals5] PASSED
tests/test_templating_inja.py::test_templating_in_json[get_keys_and_globals6] PASSED
tests/test_templating_inja.py::test_templating_in_json[get_keys_and_globals7] PASSED
tests/test_templating_inja.py::test_templating_in_json[get_keys_and_globals8] PASSED
tests/test_templating_inja.py::test_templating_in_json[get_keys_and_globals9] PASSED
tests/test_validator.py::test_json_open PASSED
tests/test_validator.py::test_json_open_fail PASSED
tests/test_validator.py::test_json_schema_pass PASSED
tests/test_validator.py::test_json_schema_fail PASSED
tests/test_validator.py::test_json_schema_comp PASSED
```

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3. Mapping Technologies

Mapping technologies

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pytokamap

- Work in progress library developed by Samuel Jackson
- Using the JSON mappings to transform MAST data
- https://pypi.org/project/pytokamap/ (warning: alpha code)
- Plans to develop this further to make more generic – maybe integrate with OMAS

UDA IMAS plugin

- On-line mappings
- Utilising existing IMAS remote data functionality (new in AL5)
  - "imas://server:port/uda?path=/path/to/ids/data"
- "imas://server:port/uda?mapping=machine?machine_args"

IMAS UDA stack

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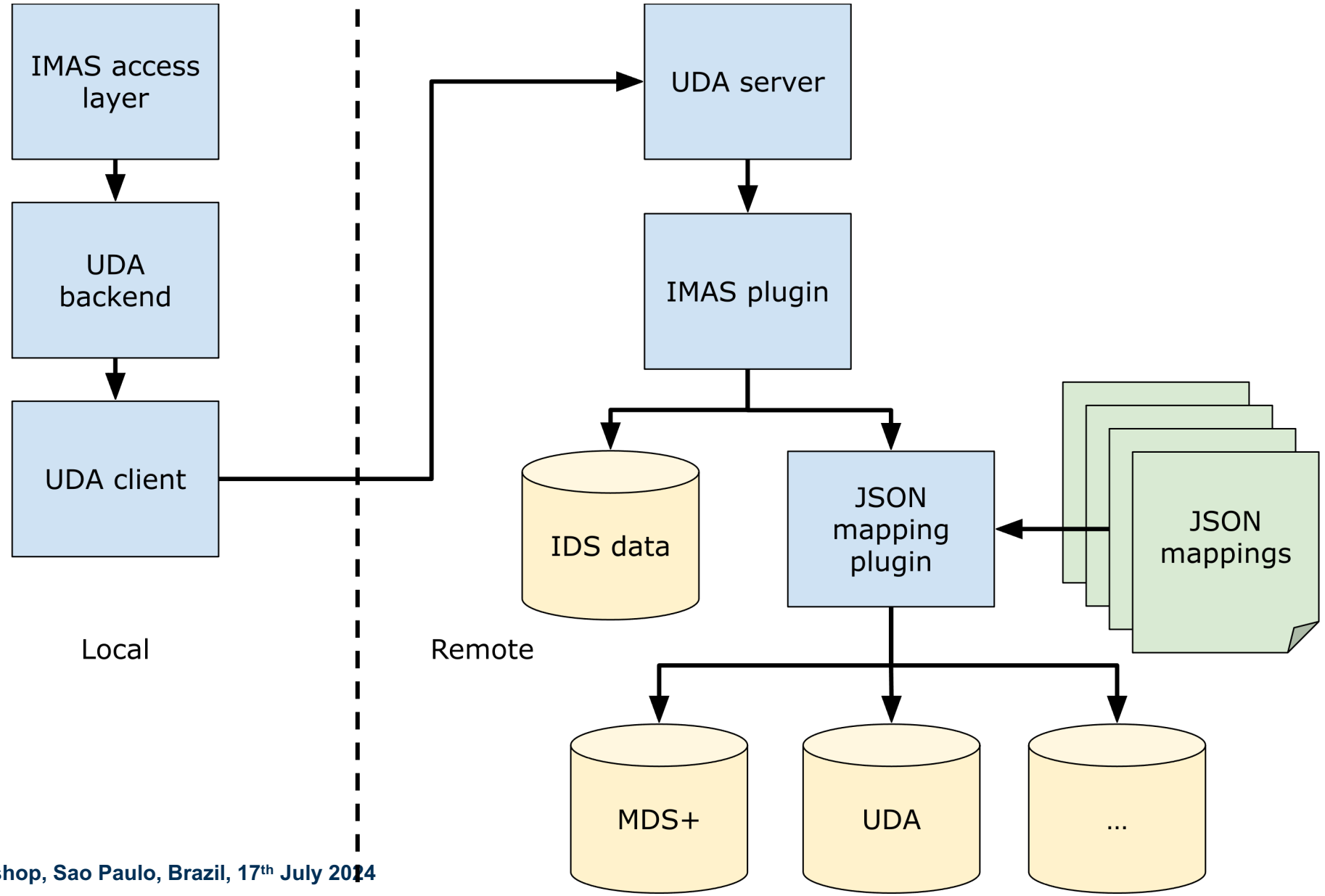
- Makes use of existing remote data fetching capabilities of IMAS (AL5)
- The IMAS plugin can handle requests with “path=…” in the URI as normal but requests with URI containing “mapping=…” get forwarded to a mapping plugin
- A new mapping plugin has been created to handle the JSON mapping files
- Requests for data are handled using existing (or new) data access plugins, e.g.
  - For MAST/MAST-U a UDA plugin can read the data from the MAST UDA server
  - For C-Mod a (new) MDSplus plugin can read the data from the C-Mod MDSplus server
  - For NetCDF/HDF5 files the file reader plugins can be used
  - Bridge plugins for other data systems/files can be created as required

IMAS UDA stack



pytokamap

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- Tool created by Sam Jackson to use the TokaMap mappings
- https://github.com/ukaea/pytokamap
- Python tool which reads MAST data from MAST UDA data system, maps and then saves to zarr or NetCDF format

```
import pytokamap
mapper = pytokamap.load_mapping("uda.jinja", "globals.json")
mapper.to_zarr(30420, "30420.zarr")
mapper.to_netcdf(30420, "30420.nc")
```

- WIP package with plans on extending – see later
- Available on pypi but in very alpha state

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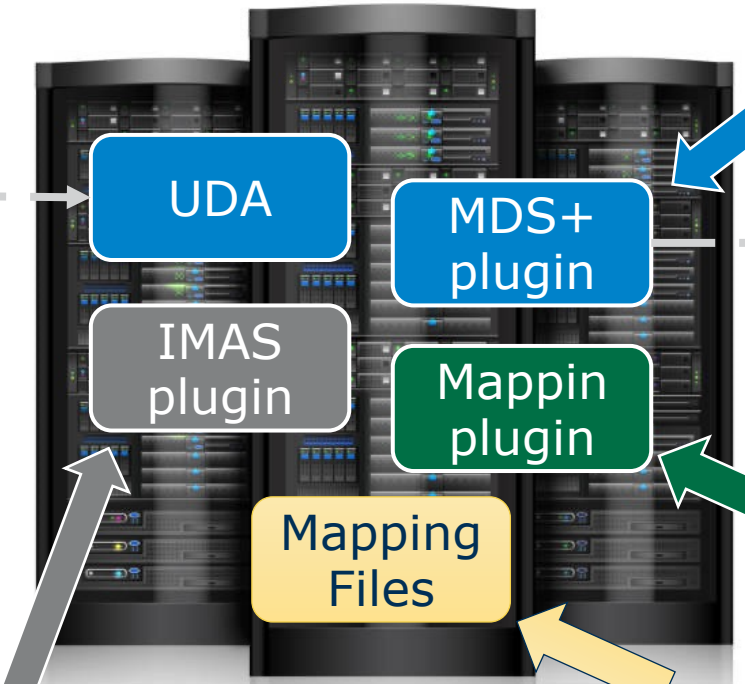
4. Mapping Alcator C-Mod

Installation at MIT

Thanks to Stephen Lane-Walsh for his help with setting up mappings at MIT



IMAS

https://github.com/ukaea/uda

C-Mod MDS+ Server

https://github.com/ukaea/JSON-mapping-plugin

https://github.com/MIT-PSFC/IMAS-CMod-mappings

https://git.iter.org/projects/IMAS/repos/uda-plugins/browse

Installation at MIT

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```
# Install UDA
cmake -B build-release -DCMAKE_INSTALL_PREFIX=../install-release -DBUILD_SHARED_LIBS=ON -DCMAKE_BUILD_TYPE=Release
cmake --build build-release/ -j
cmake --install build-release/

# Install IMAS plugins
export PKG_CONFIG_PATH=$HOME/UDA/install-release/lib/pkgconfig
cmake -B build-release -DCMAKE_INSTALL_PREFIX=../install-release -DBUILD_PLUGINS=imas -DCMAKE_BUILD_TYPE=Release
cmake --build build-release/ -j
cmake --install build-release/
./build-release/scripts/activate-plugins.sh

# Install IMAS mapping plugin
cmake -B build-release -DCMAKE_INSTALL_PREFIX=../install-release -DCMAKE_BUILD_TYPE=Release
cmake --build build-release/ -j
cmake --install build-release/
./build-release/scripts/activate-plugins.sh
```

MIT mappings

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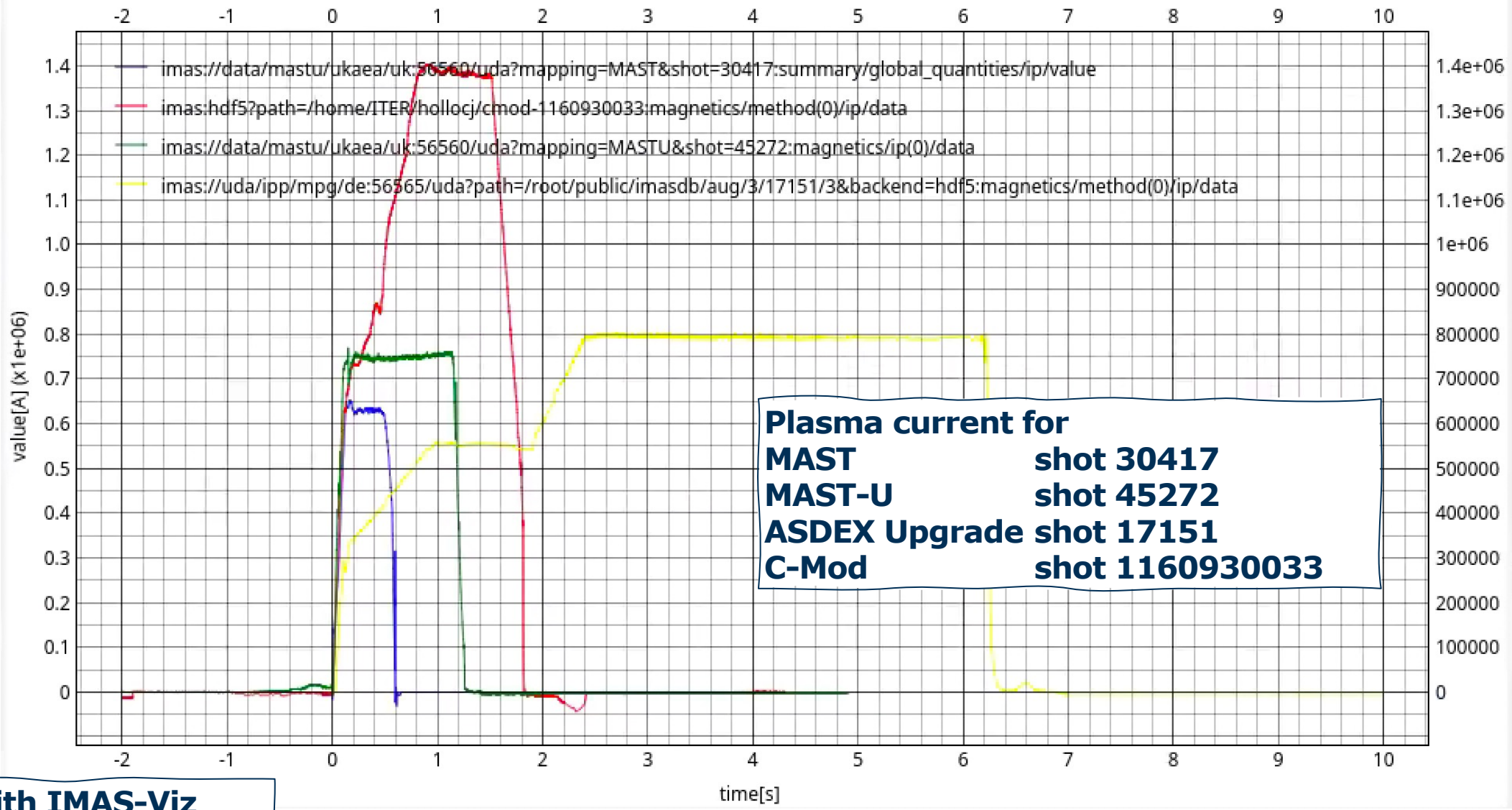
- Initial development of mappings for Alcator C-Mod
  - Available at https://github.com/MIT-PSFC/IMAS-CMod-mappings

- Developed a MDSPLUS plugin to read from C-Mod MDSplus data system

- Only a limited set of signals have been mapped so far – hope to provide ongoing support for more mappings!

```
"globals_quantities/ip/value": {
    "MAP_TYPE": "PLUGIN",
    "PLUGIN": "MDSPLUS",
    "ARGS": {
        "expression": "\\ip"
    }
},
```

Results



Plotting data with IMAS-Viz – MAST, MAST-U, C-Mod & AUG

***WIP mappings – COCOS for C-Mod data not validated**

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5. Future Work

Future Work

- Plans on making the mappings themselves FAIR
  - Make sure the mappings are self describing
  - Ensure the mappings can be used in multiple tools
  - Provide tools for maintaining & finding mappings
  - Building on Simple Standard for Sharing Ontological Mappings (SSSOM)† work
- OSCARS proposal – hope to hear about this soon
- Extend pytokamap – potential ideas:
  - Integrate with OMAS to make use of its ability to read and write multiple formats
  - Ensure compatibility between mappings used in IMAS plugin and pytokamap
- Extend mapping syntax and functionality as needed

†https://mapping-commons.github.io/sssom/

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Questions?

Thank you for your time