Development of a parallelized open-source python library for synthetic diagnostics and inversions for fusion devices

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Context: Energy generation

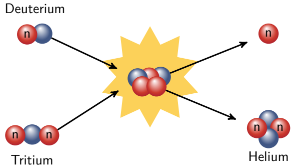
Current solutions present some drawbacks:

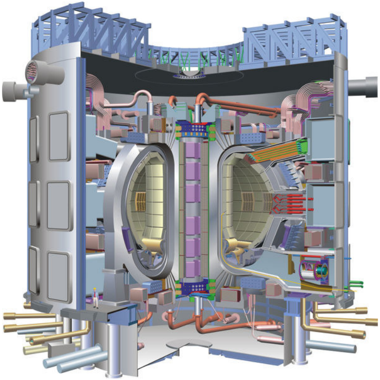
- Limited resources
- Production of carbon dioxide
- Radioactive waste
- Not too efficient
- Harmful to surrounding environment

$\Rightarrow$ Fusion reactor: cleaner, more reliable, more powerful energy source ?

Context: Controlled fusion and magnetic confinement

D-T Fusion reaction





Temperature > 100 Million°K.

$\Rightarrow$ Gas composed of positive ions and negative electrons: plasma

$\Rightarrow$ Plasma responds strongly to electromagnetic fields

$\Rightarrow$ Energy breakeven point still not obtained: $Q = \frac{E_{\text{output}}}{E_{\text{input}}} = 0.67$

$\Rightarrow$ Current reactors: diffrent shapes, sizes, heating methods, confinement techniques, etc.

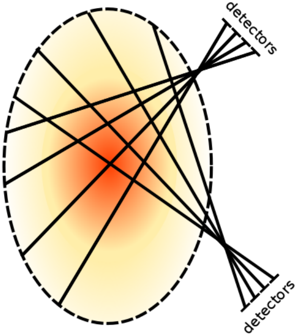
Toakmak diagnostics

- **Diagnostics:** Set of instruments to measure for the uderstanding, control and optimization of the plasma performance.

- Magnetic diagnostics: currents, plasma stored energy, plasma shape and position;
- Neutron diagnostics (ie. cameras, spectrometers, etc.): fusion power;
- Optical systems (interferometers): temperature and density profiles;
- Bolometric systems (tomography): spatial distribution of radiated power;
- Spectroscopic: X-ray wavelength range, impurity species and density, input particle flux, ion temperature, helium density, fuelling ratio, plasma rotation, and current density.
- Microwave diagnostics probe the main plasma and the plasma in the divertor region in order to measure plasma position.

Tomography diagnostics

$$M_i(t) = \iiint\limits_{V_i} \overrightarrow{\varepsilon(x,t)} \cdot \vec{n}\,\Omega_i \; dV$$



- **Direct problem** (synthetic diagnostic):

Simulated emissivity $\longrightarrow$ integrated measurements

Spatial integration

- **Inverse problem** (tomography):

Integrated measurements $\longrightarrow$ Reconstructed emissivity

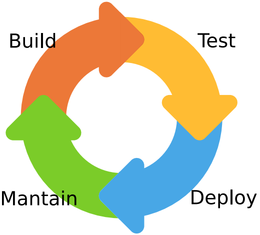
Mesh and basis functions construction, spatial integration, data filtering, inversion routines, etc.

Tomography very sensitive to errors, noise and bias
$\longrightarrow$ Reputation for low reproducibility / reliability

A code for Tomography for Fusion

Develop a common tool:

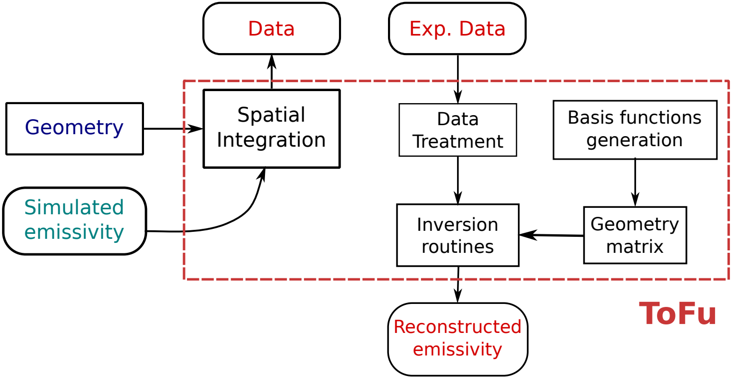
- Accessible to everyone (open-source)
- Generic (geometry independent)
- Portable (developped in Python)
- Optimized (reliability and performance)
- Documented online
- Standardization of diagnostics
- Long-term costs saving to the community



For tomography diagnostics: The **To**mography for **Fu**sion code (**ToFu**[a][b])

[a] repository: https://github.com/ToFuProject/tofu
[b] documentation: https://tofuproject.github.io/tofu/index.html

Tofu's structure



Geometry reconstruction: ray-tracing techniques

To reconstruct emissivity we need to take account:

- Geometry defined with minimal data
  polygon (R, Z) extruded along φ
- Symmetry of vessel along φ
- Upto hundreds of structural elements in vessel
- Scale of the vessel: 10^4 bigger than smaller structural detail