ToFu

***To**mography for **Fu**sion*

An advanced open-source Python library for a common approach to tomography

Didier VEZINET

31 st ITPA on Diagnostics, 7-10 Nov. 2016, France

Outline

Section 1

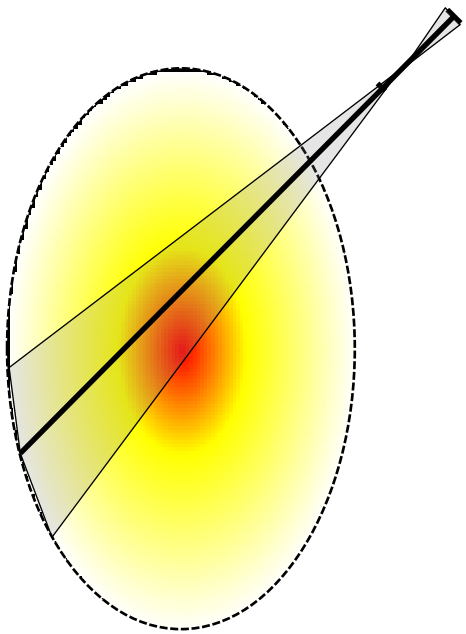
- Reminder on tomography diagnostics
- The need for common and transparent tools

Section 2

- Structure of ToFu
- Spatial integration in ToFu
- Basis functions in ToFu
- ToFu Perspectives
- Example of application

Reminder : tomography diagnostics

$$M_i(t) = \iiint_{V_i} \overrightarrow{\varepsilon(x,t)}.\vec{n}\Omega_i dV \approx E_i \int_{L_i} \varepsilon(l,t)dt$$



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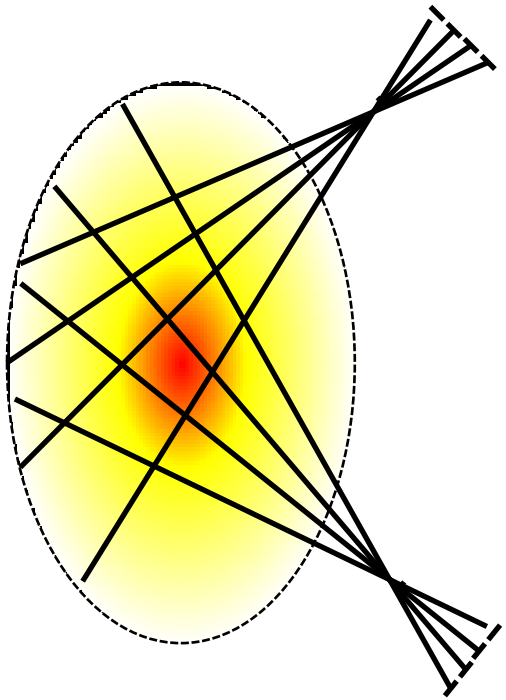


Direct problem (synthetic diagnostic):

Simulated emissivity

=> integrated measurements

Requires : spatial integration

Inverse problem (tomography):

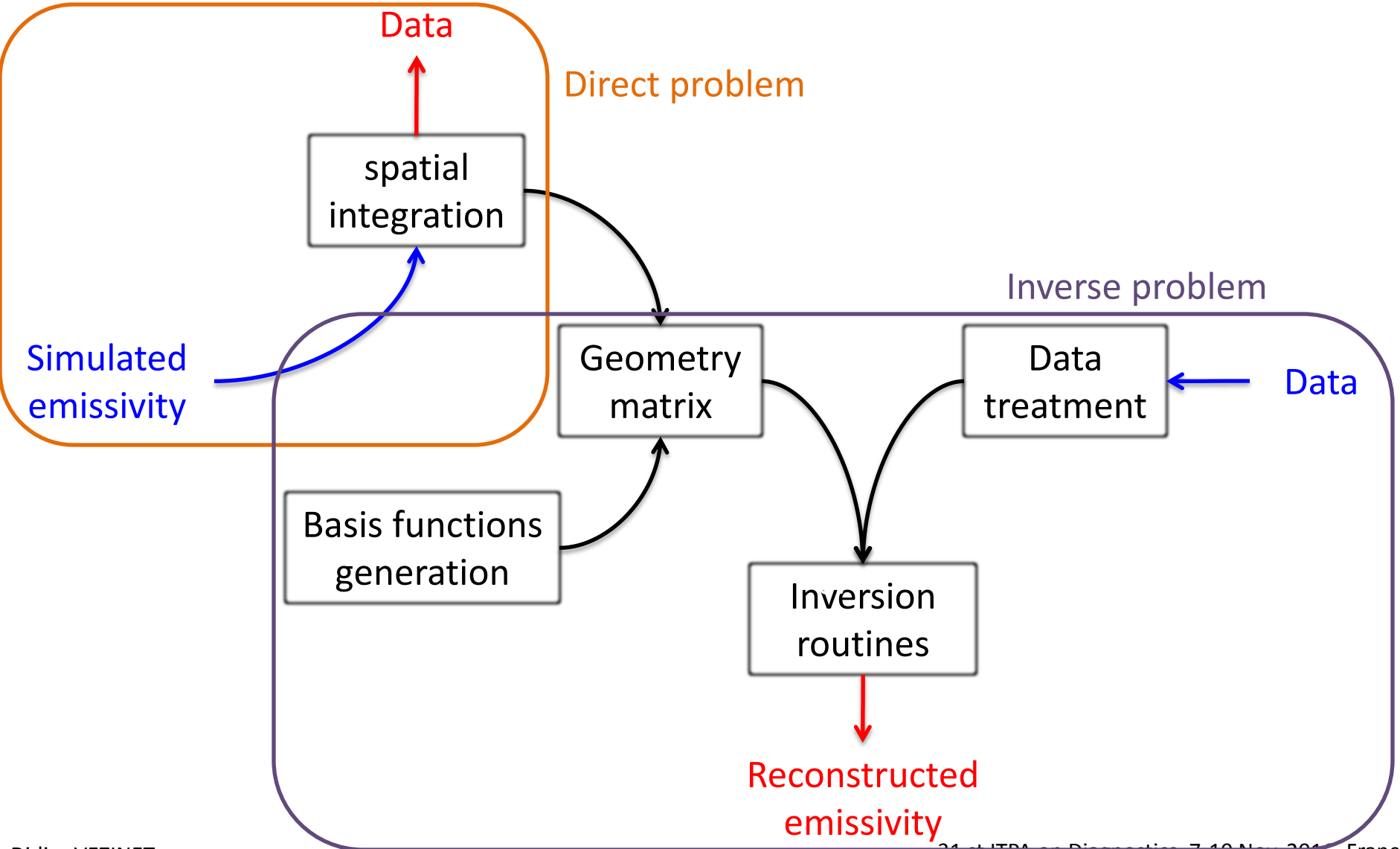
Integrated measurements

=> Reconstructed emissivity

Requires (series expansion):

- Basis functions
- Spatial integration (geometry matrix)
- Data filtering (noise…)
- Inversion routines

Need for common / transparent tools



Need for common / transparent tools

Each lab creates its own tools:

- Optimised for a specific machine
- Rarely documented or commented
- Often created by students, unmaintained after they leave
- A new student comes and re-does most of it….

=> Many unmaintained black-box codes
=> High redundancy and work time used
=> Low reproducibility & transparency, little long-term improvements

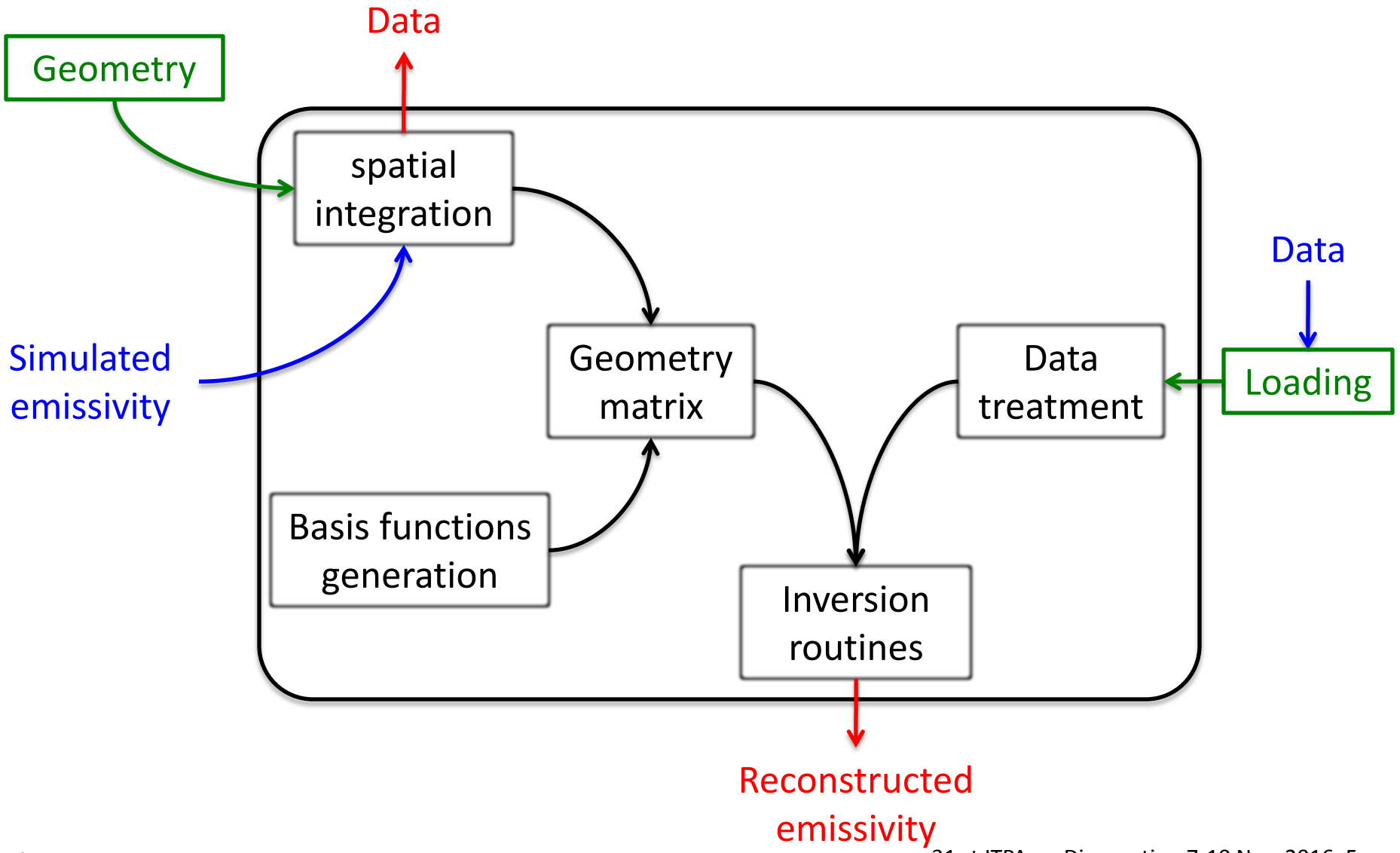
Tomography very sensitive to errors, noise and bias
=> Reputation for low reproducibility (reliability ?)

Value of a common tool:

- **Accessible to** everyone (e.g.: open-source)
- **Documented online**
- **Generic** (not machine-dependent)
- **Transparent**, for reproducibility and updates (e.g.: open-source)
- **Flexible** (user-defined choices)

Python

Structure of ToFu



Spatial integration in ToFu

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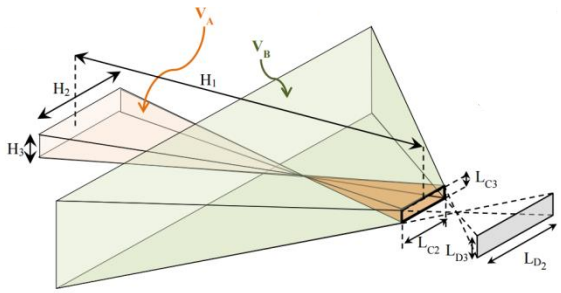

LOS — Iterative refinement of LOS — **VOS**

Simplicity — Accuracy

[1] C. Ingesson et al, Journ. Opt. Soc. Am. 16, 1999

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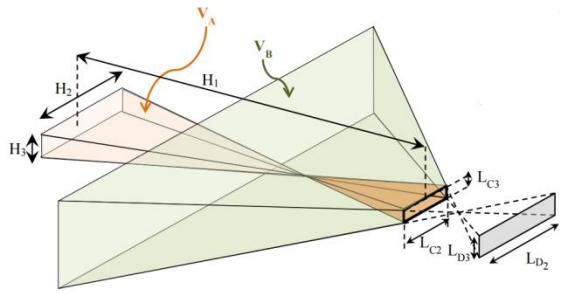
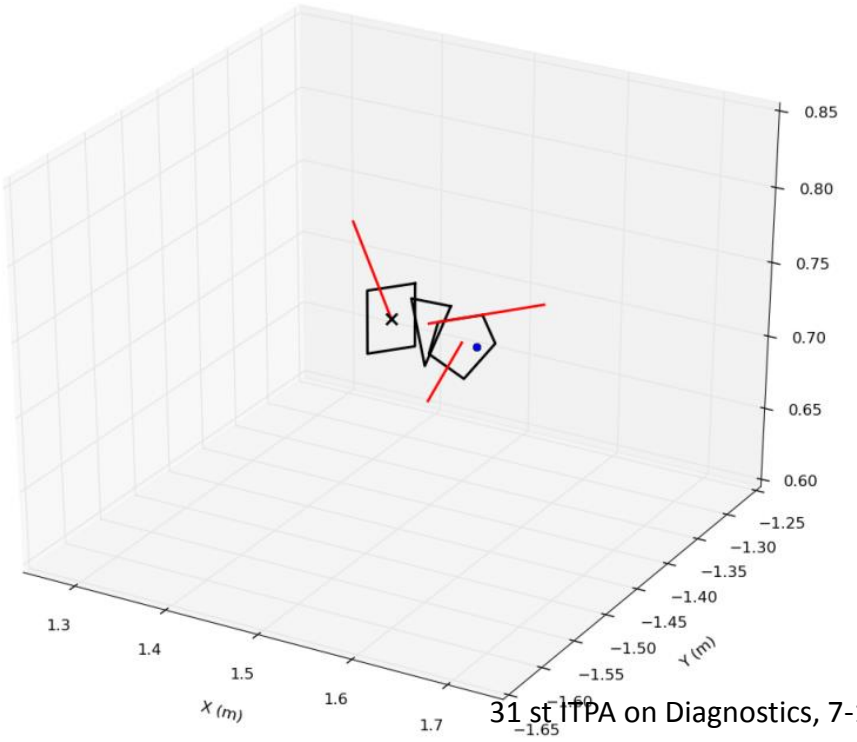


LOS — Simplicity

VOS — Accuracy



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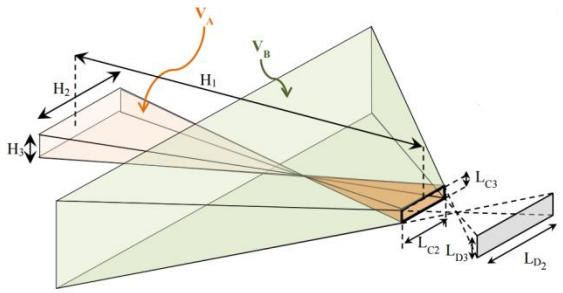

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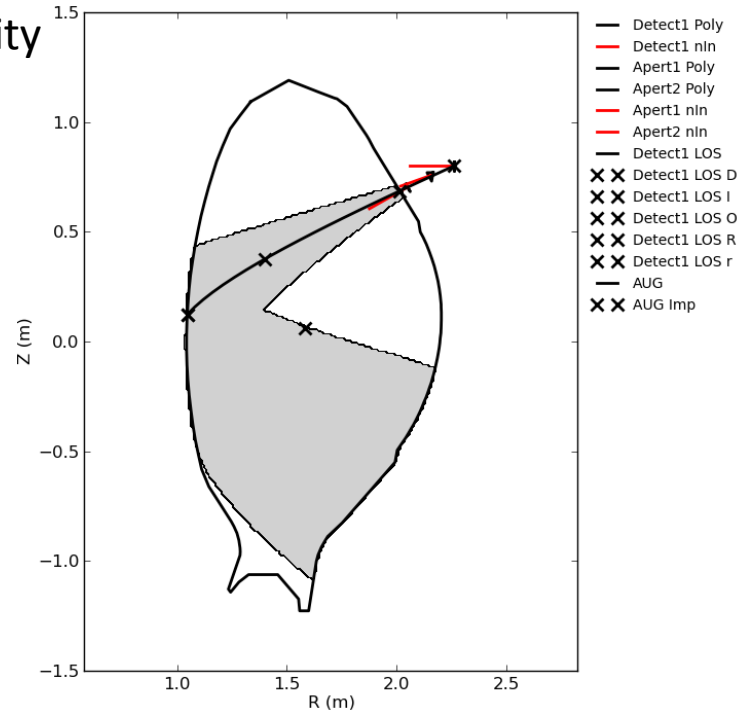
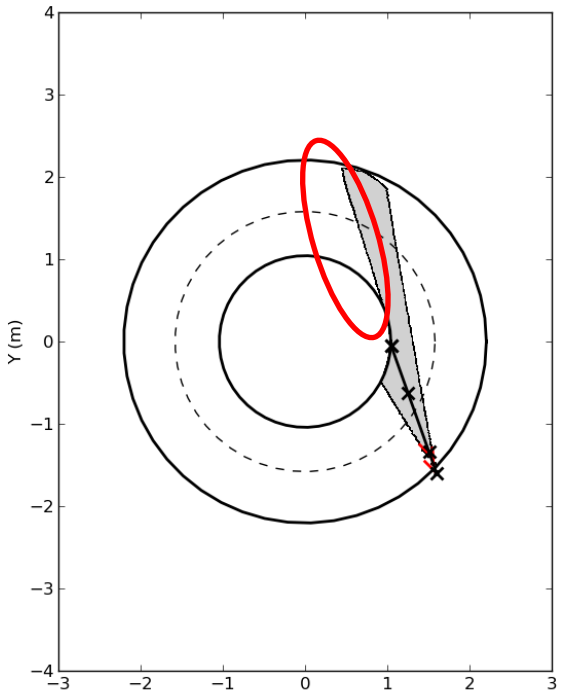


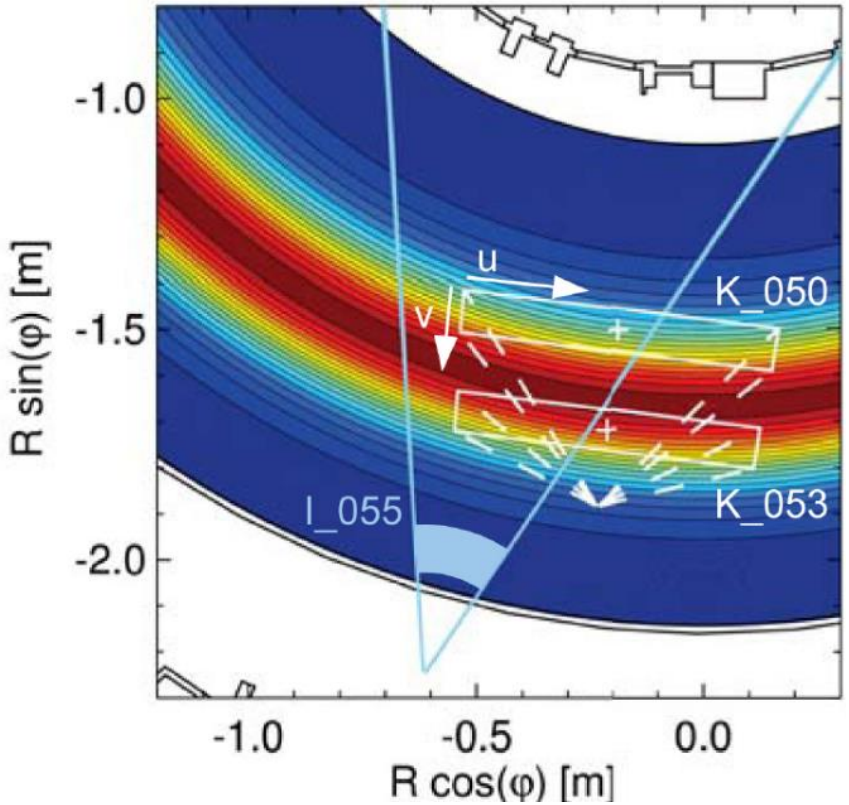


Spatial integration in ToFu

Why VOS ?

- **Shift towards LFS**

  Toroidal curvature and beam width



[2] M. Weiland et al, Nuc. Fus. 57

Spatial integration in ToFu

Why VOS ?

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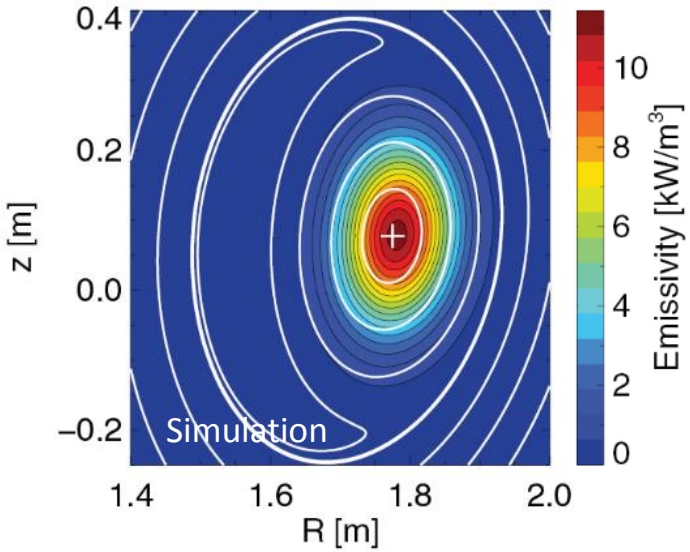
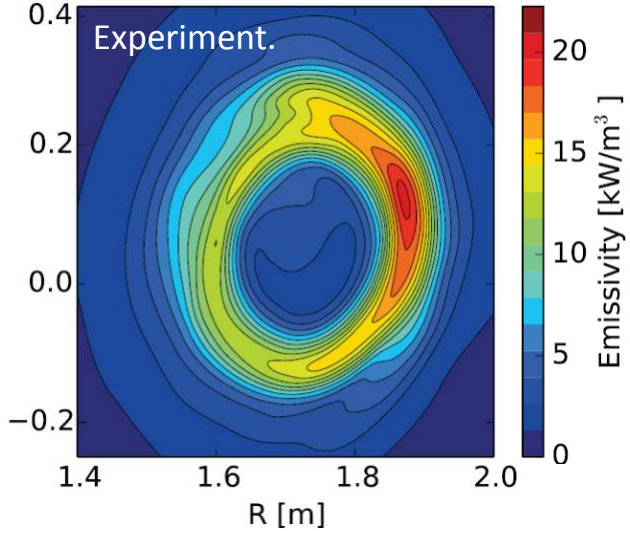
- **No 2nd derivative perpendicular to LOS**
  - Core SXR with W (very peaked or hollow)
  - Divertor region for bolometry





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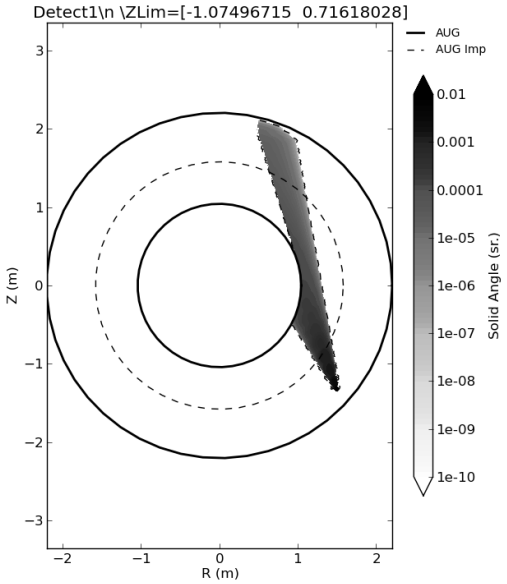
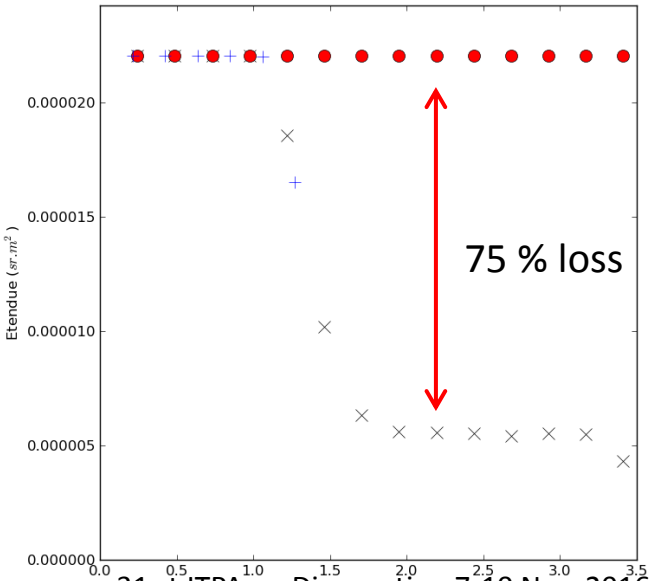
    - Toroidal views





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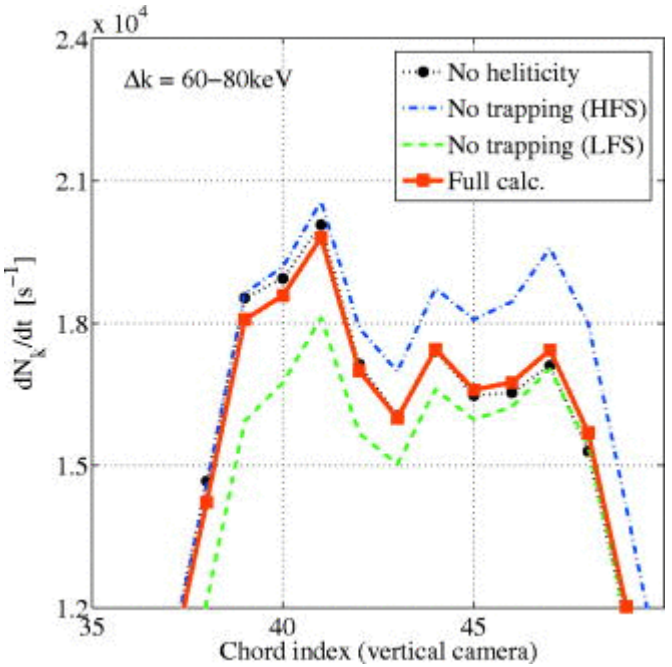
- **Anisotropic radiation**
  - High energy electrons (HXR, runaways…)



[3] Y. Peysson et al, Phys. Plasm. 15

Basis functions in ToFu

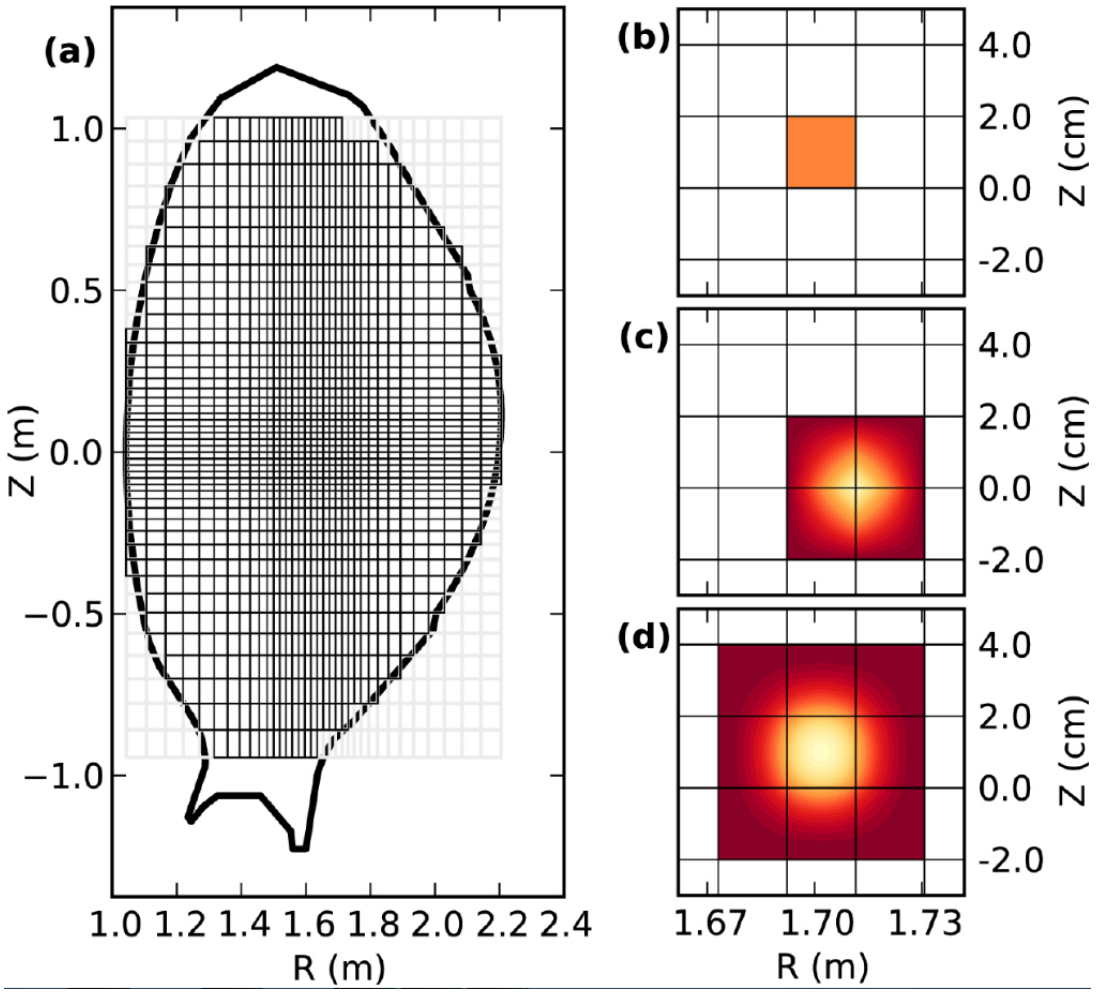
Local Basis Functions (LBF)

- Variable mesh size
- Bidimensional b-splines, deg 0-3

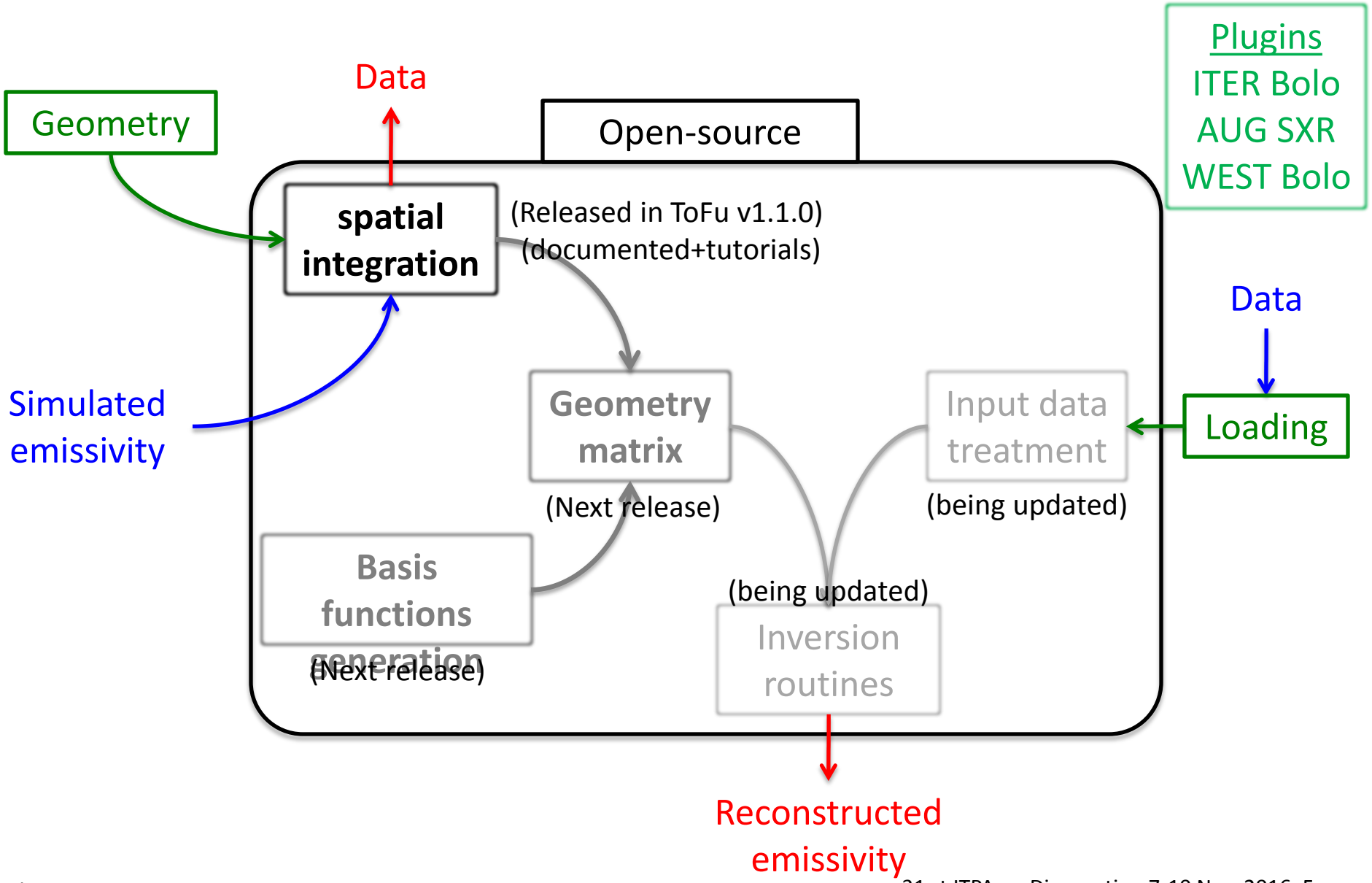
Global Basis Functions (GBF)

- Equilibrium-based : in progress

(Fourier-Bessel,
Fourier-Zernicke,
Fourier-Splines
…)

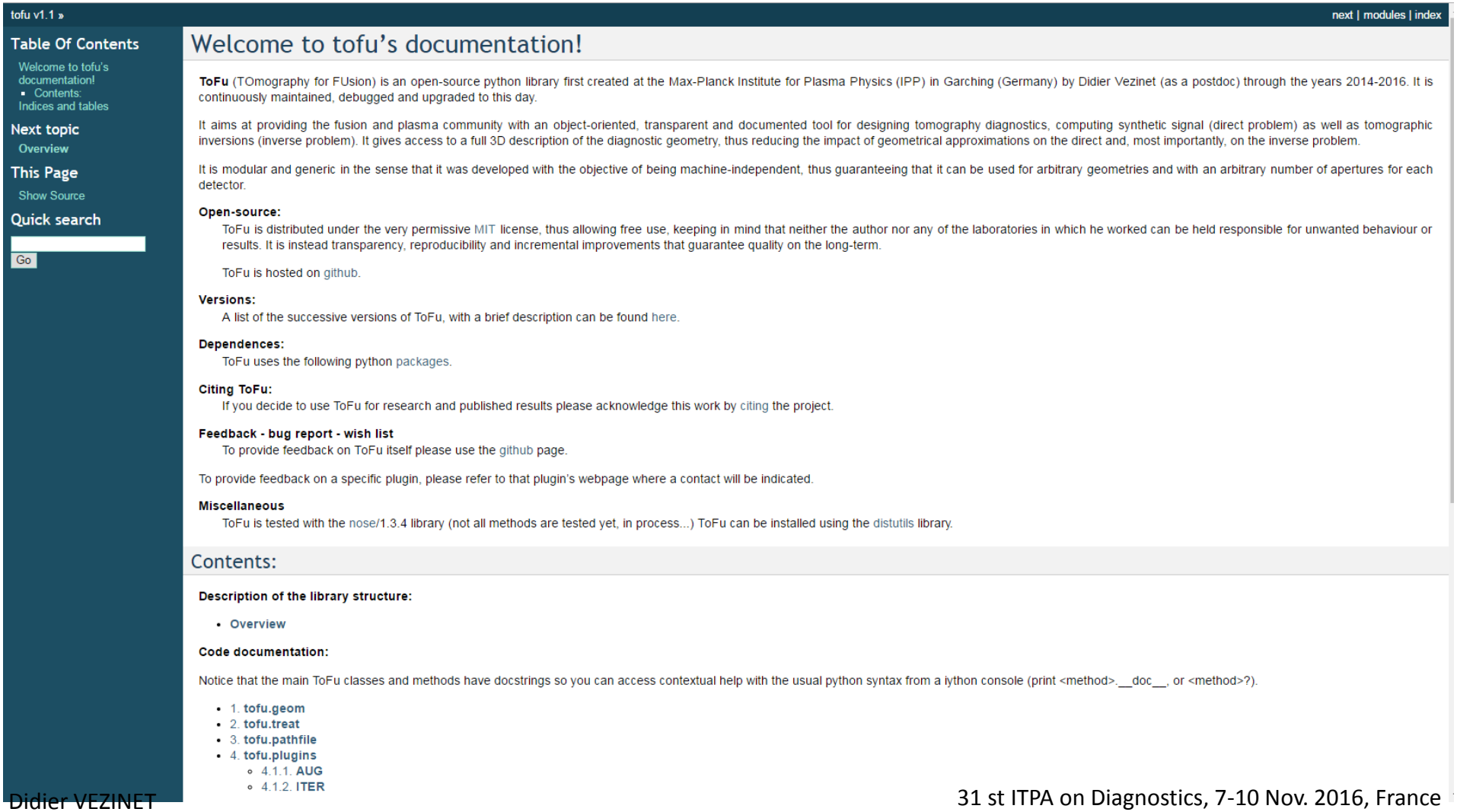


ToFu current status



ToFu current status

- Open-source under permissive MIT license
- Code available on GitHub (packaging to be done) at https://github.com/Didou09/tofu
- Online documentation at https://didou09.github.io/tofu/index.html



tofu v1.1 »

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Overview

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Welcome to tofu's documentation!

ToFu (TOmography for FUsion) is an open-source python library first created at the Max-Planck Institute for Plasma Physics (IPP) in Garching (Germany) by Didier Vezinet (as a postdoc) through the years 2014-2016. It is continuously maintained, debugged and upgraded to this day.

It aims at providing the fusion and plasma community with an object-oriented, transparent and documented tool for designing tomography diagnostics, computing synthetic signal (direct problem) as well as tomographic inversions (inverse problem). It gives access to a full 3D description of the diagnostic geometry, thus reducing the impact of geometrical approximations on the direct and, most importantly, on the inverse problem.

It is modular and generic in the sense that it was developed with the objective of being machine-independent, thus guaranteeing that it can be used for arbitrary geometries and with an arbitrary number of apertures for each detector.

Open-source:

ToFu is distributed under the very permissive MIT license, thus allowing free use, keeping in mind that neither the author nor any of the laboratories in which he worked can be held responsible for unwanted behaviour or results. It is instead transparency, reproducibility and incremental improvements that guarantee quality on the long-term.

ToFu is hosted on github.

Versions:

A list of the successive versions of ToFu, with a brief description can be found here.

Dependences:

ToFu uses the following python packages.

Citing ToFu:

If you decide to use ToFu for research and published results please acknowledge this work by citing the project.

Feedback - bug report - wish list

To provide feedback on ToFu itself please use the github page.

To provide feedback on a specific plugin, please refer to that plugin's webpage where a contact will be indicated.

Miscellaneous

ToFu is tested with the nose/1.3.4 library (not all methods are tested yet, in process...) ToFu can be installed using the distutils library.

Contents:

Description of the library structure:

- Overview

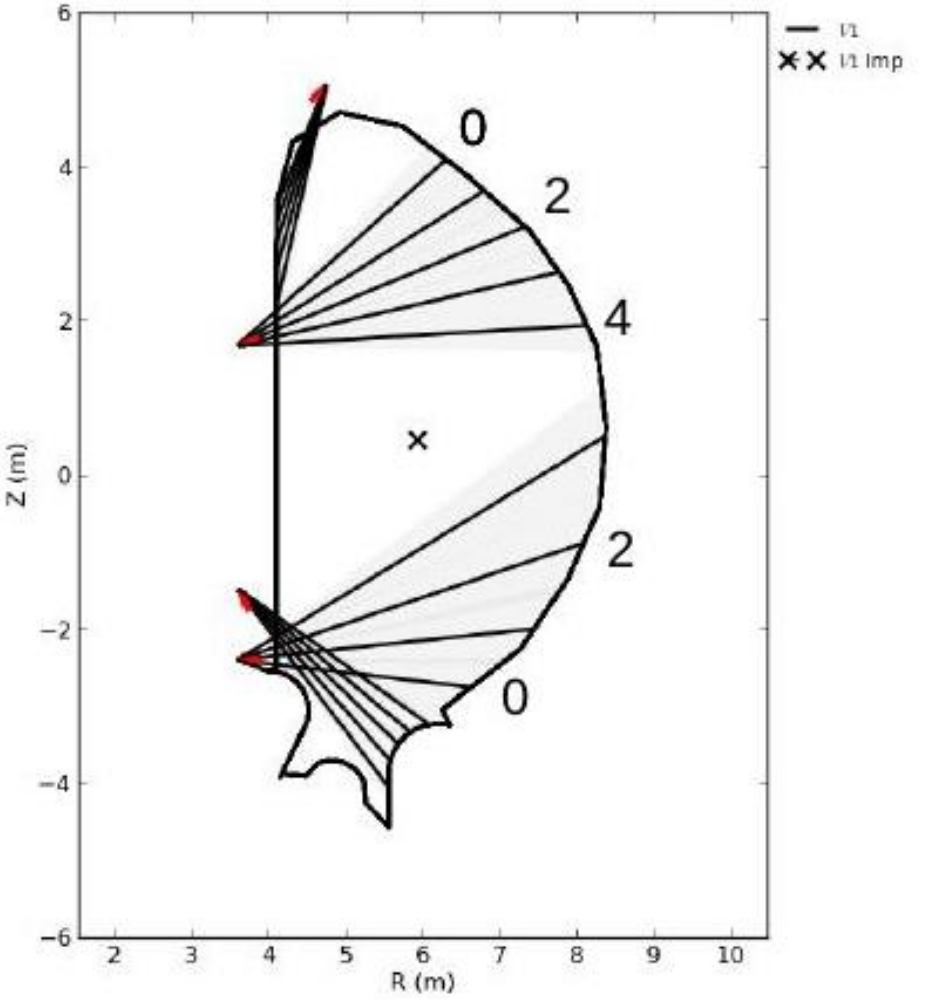
Code documentation:

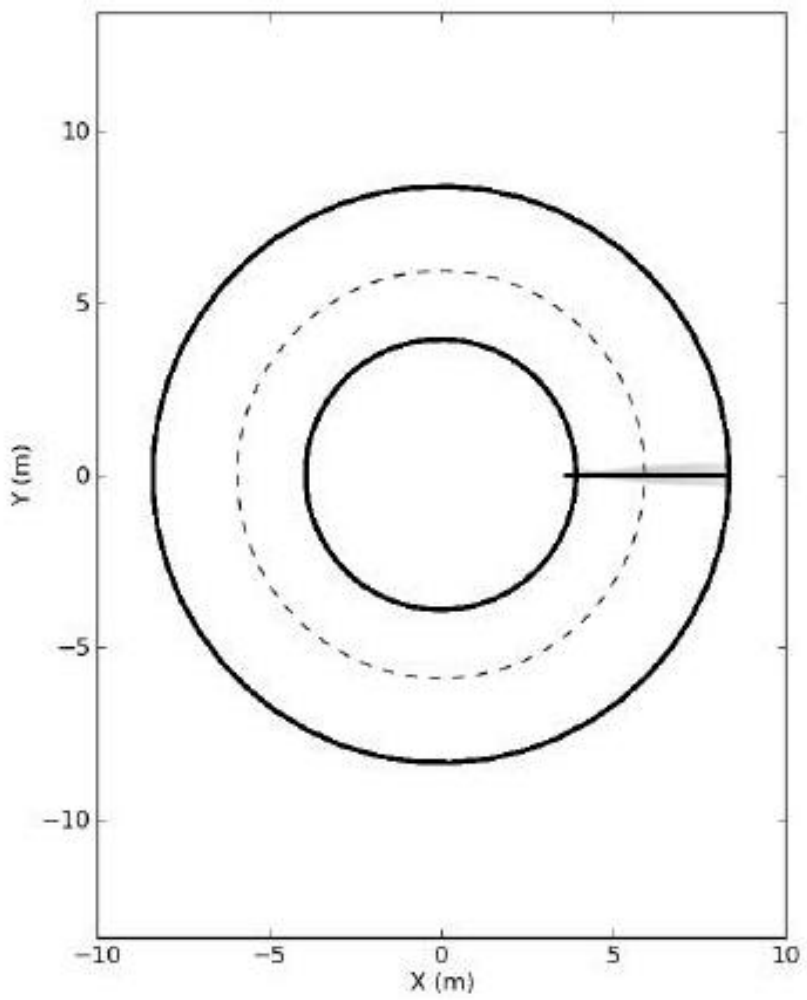
Notice that the main ToFu classes and methods have docstrings so you can access contextual help with the usual python syntax from a ipython console (print <method>.__doc__, or <method>?).

- 1. **tofu.geom**
- 2. **tofu.treat**
- 3. **tofu.pathfile**
- 4. **tofu.plugins**
  - 4.1.1. **AUG**
  - 4.1.2. **ITER**

ToFu examples: ITER bolometry analysis

(Courtesy of G. Veres et al, FPA384, Progress Meeting 07)

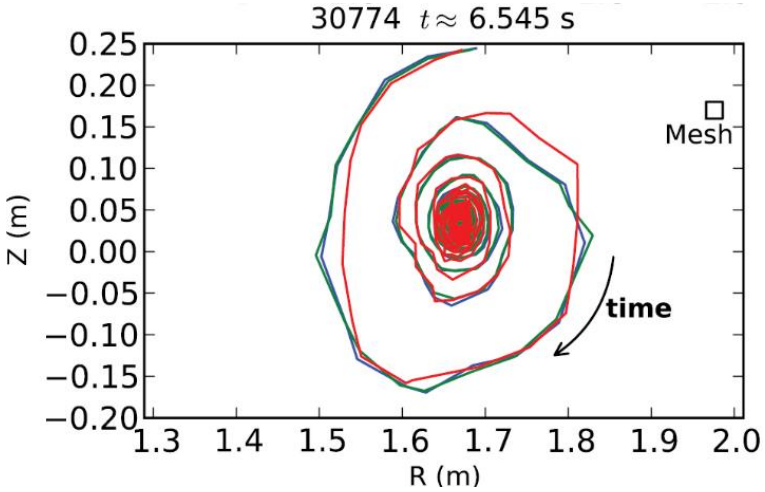


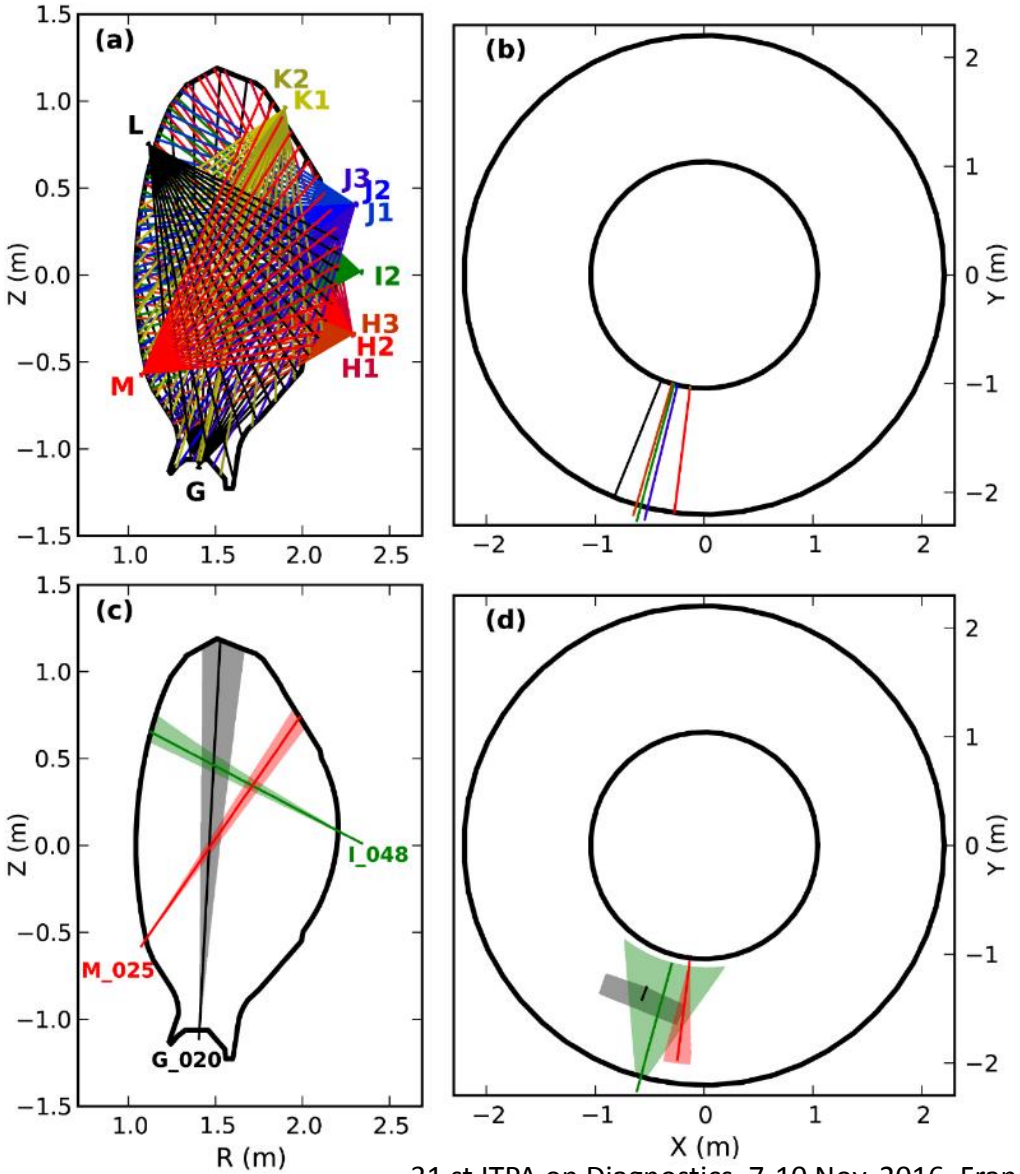


[4] D. Vezinet et al, Nuc. Fus. 56, 2016

ToFu examples: AUG SXR for MHD

- SXR diagnostic on AUG
- Inversions (localization of maximum)





[4] D. Vezinet et al, Nuc. Fus. 56, 2016

ToFu perspectives

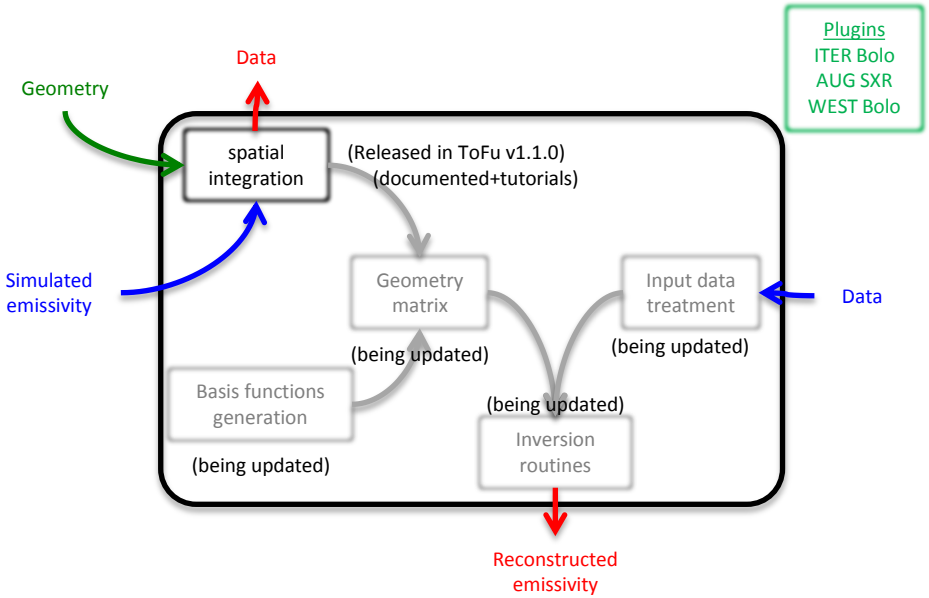
Priority

Natural: finish and maintain
- Release updated modules with doc
- Non-linear regularization (MFI, Bayes…)
- Create additional plugins (on-demand)
- Export to python 3

Update: faster geom. more flexible bsplines
- Optimize & parallelize geom (CPU, GPU)
- Add ray tracing option (for reflections)
- Replace BF by advanced NMPP bspline library

Extend: Spectroscopy diagnostics
⇒ 1D & 2D spectroscopy
⇒ Spectral & spatial inversion

Full problem: uncertain geometry
⇒ Iterate on the geometry too
⇒ Fast and accurate 3D computation
⇒ « Cross-calibration »



Postdoc (computer scientist)

1 ppy/year for 2 years ?

Anisotropic emissivity:
⇒ Investigate possible inversions

PhD
3 years

Open-source !

ITER and the whole community benefit from it !

- **Direct problem:**
  - Diagnostic design and performance analysis (bolo, SXR, HXR…)
  - Code validation

- **Inverse problem:**
  - Transparent & reproducible tomography
  - Impurity (W) transport and MHD studies
  - Potential runaway and superthermal studies

- **Incremental improvements by the community**

- **Tool available for every machine**

- **Sets community-defined minimum standards !**
  (proprietary solutions must do as least as good)

Thank you for your attention !