CZECH TECHNICAL UNIVERSITY IN PRAGUE

FACULTY OF NUCLEAR SCIENCES AND PHYSICAL ENGINEERING CTU IN PRAGUE

GOLEM data analysis and electric probes introduction

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Outline

I. Data processing principles

II. Data access from shot-homepage

III. Best data processing practices

IV. Electric probes introduction

Why do we need data processing?

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- Data processing is the most important part of every experiment.
- Discharge produces various raw data.
- The data needs to be processed.
- Several processing tools can be used:
  - Programming languages - Python, MATLAB, GNUPLOT, Octave, etc.
  - Spreadsheets - Excel (not recommended).
- Main output - figures, tables, etc.

What is data processing?

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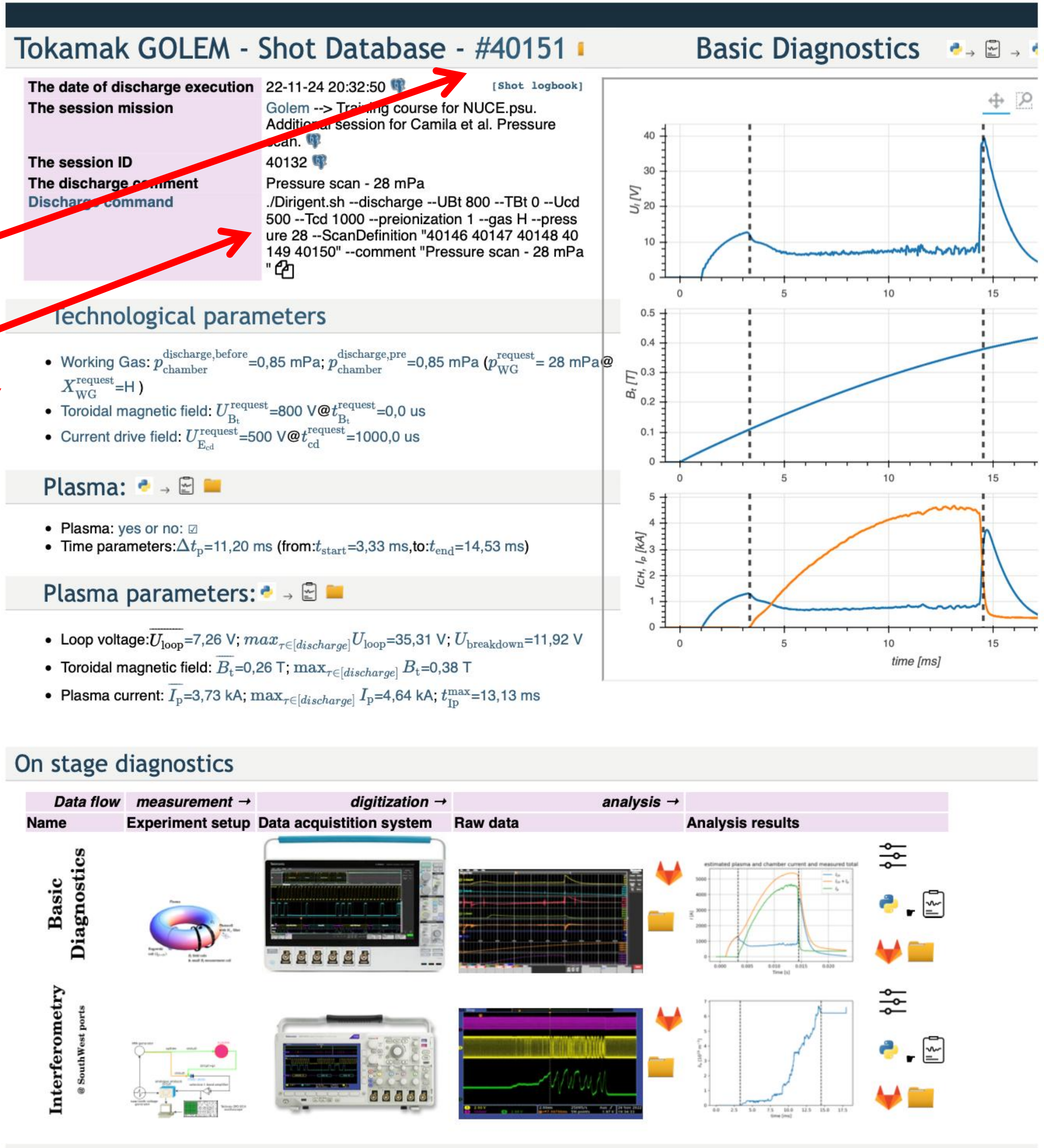
- Data collection - gather data from a source.
- Sorting data - sort the raw data (remove incorrect data, remove offset, ...)
- Data input - prepare the data for processing
- Data processing - processing the data input (integrate, differentiate, sum, ...)
- Data output - creating visualization, figures, ...
- Data storage - save the data (for the next use)

Data loading from GOLEM shot-homepage

GOLEM data and where to find them?

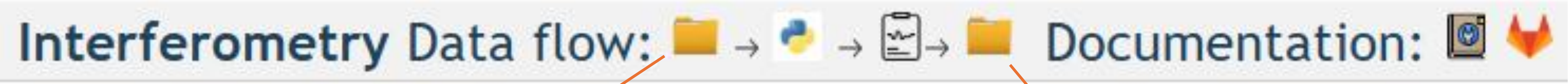
Shot homepage

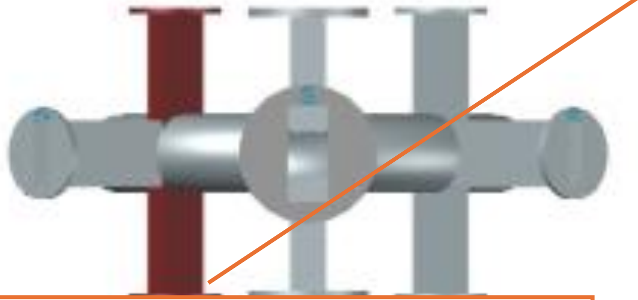
- Discharge number
- Discharge command
- Technological parameters
- Plasma parameters
- Diagnostics



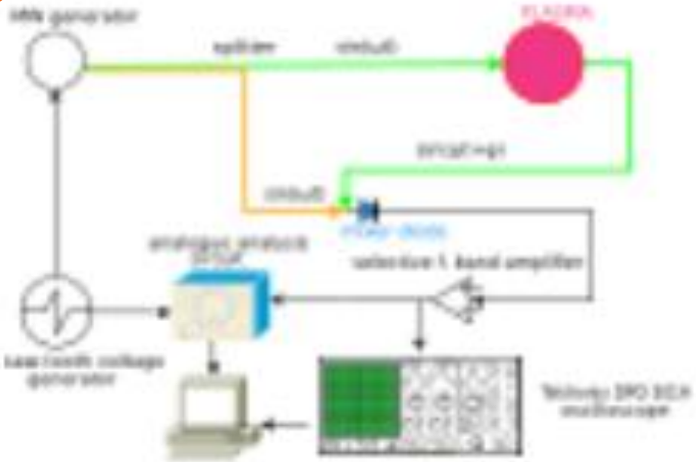
GOLEM data location

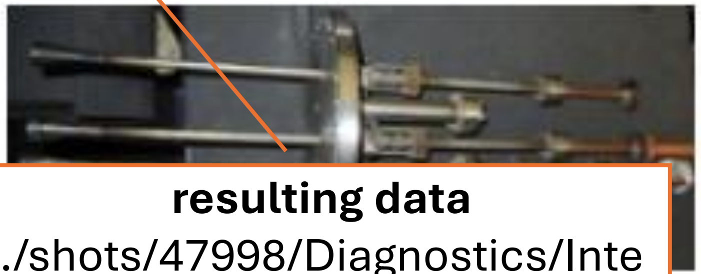
- **last shot:** http://golem.fjfi.cvut.cz/shots/0/
- **specific shot:** http://golem.fjfi.cvut.cz/shots/47998/





raw data
./shots/47998/Devices/Oscilloscopes/TektrDPO3014-a/





resulting data
./shots/47998/Diagnostics/Interferometry**/Results/…csv**

GOLEM data location

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- last shot: http://golem.fjfi.cvut.cz/shots/0/
- specific shot: http://golem.fjfi.cvut.cz/shots/47998/

Tokamak GOLEM - Shot Database - #47998

[Shot logbook]

Time stamp	25-03-10 11:42:20
The session mission	TrainingCourses/PlasmaSchools/FUMTRAIC.fr/25/ExperimentationFull steam
The session ID	47996
The discharge comment	Master test from Prague
Discharge command	/Dirigent.sh --discharge --operation.discharge "style='remote',voice='on',analysis='on'" --infrastructure.bt_ecd "U_Bt=1000,t_Bt=0,U_cd=400,t_cd=1000,O_Bt='CW',O_cd='CW'" --infrast ...

all diagnostics data
./shotdir/47998/Diagnostics/

Data loading via pandas

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Array

- data_ULoop_URL = http://golem.fjfi.cvut.cz/shots/47998/Diagnostics/PlasmaDetection/U_Loop.csv
- import pandas as pd

  data = **pd.read_csv(url, delimiter=‘,’ ,**

  index_col=0,

  names=[“time”, "data”])

We will then convert pandas.DataFrame into
xarray.DataArray

Single value

- R_chamber_URL = http://golem.fjfi.cvut.cz/shots/47998/Production/Parameters/SystemParameters/R_chamber
- import pandas as pd

  number = **float(pd.read_csv(url,**

  header=None).values[0, 0])

Python xarray package

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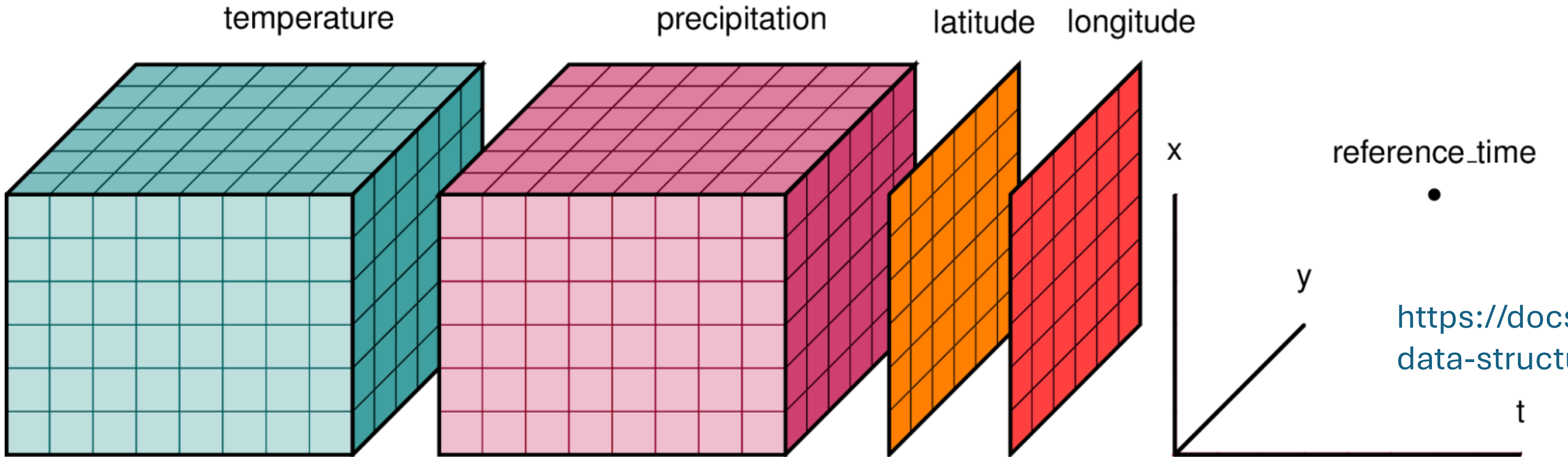
- Multidimensional arrays - **DataArray** or **Dataset**.
- More intuitive, more concise, and less error-prone.
- Introduces labels in form of dimensions, coordinates, and attributes.
- Example: **dimensions** (x, y, t), **coordinates** (latitude (x), longitude (y)), **data__var** (temperature(x, y, t), precipitation(x,y,t))



https://docs.xarray.dev/en/v0.3.1/data-structures.html

Best programming practices

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- Document your code - make comments.
- Use one statement per line (do not use print(“A”); print(“B”); ...).
- Code indentation (proper tabs, spaces, etc).
- Do not repeat yourself
- Use a Proper Naming Convention.
- Avoid magic numbers.

Data-processing conclusion

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- Conversion of the data to useful information.
- Almost all experiments raw data has to be analyzed.
- Data can be processed using several programming languages:
  - **Python,** MATLAB, Octave, GNUPLOT, or Excel.
- Python is currently one of the best programming languages for data analysis.
- Follow best practices.
- The most important - enjoy the process of data analysis :)

Electric probes introduction

Langmuir probes and Ball-pen probes

Motivation for el. probes

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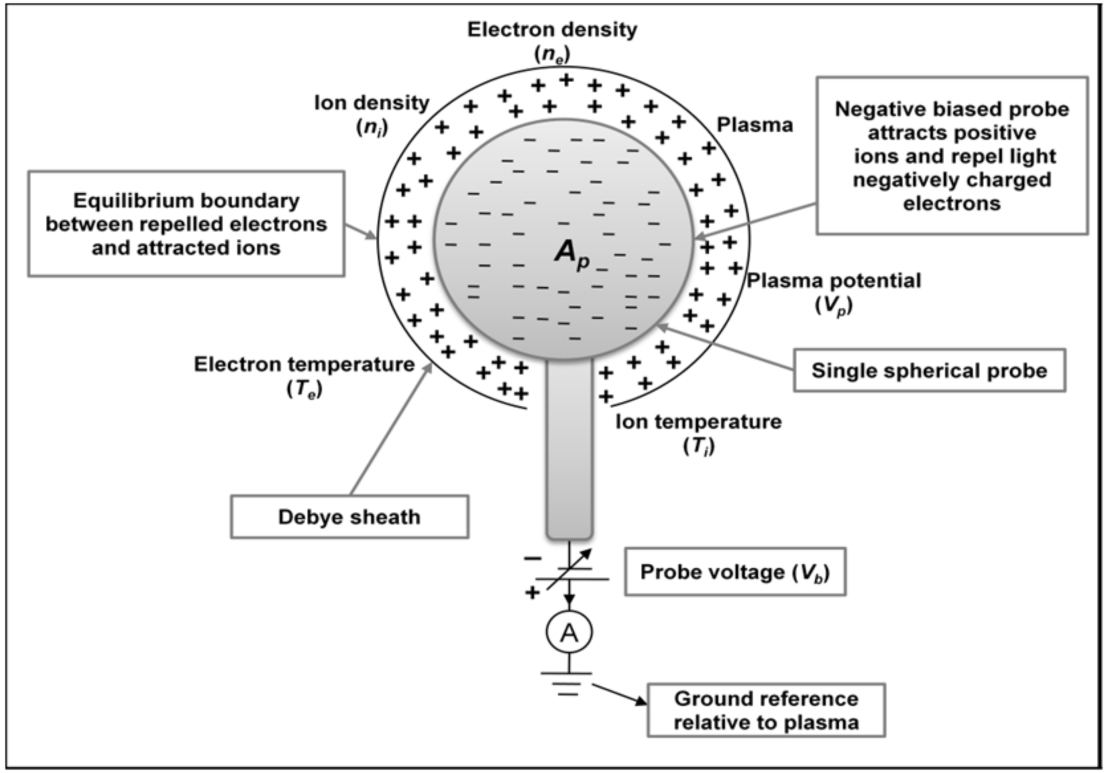
- **Advantages:**
    - very simple measurements (voltage and current)
    - very cheap compared to other diagnostics
    - measurement of various plasma properties (density, electron and ion temperature, floating potential, plasma potential, electric fields)
    - very fast (high temporal resolution)
- **Disadvantages:**
    - only plasma edge studies
    - probes influence plasma

Langmuir probe

- Langmuir probe = simple wire inserted into plasma
- probe collects charged plasma particles (ions and electrons)
- voltage and current on the probe measured
- electrons faster than ions ➔ more electrons than ions collected
- if probe not grounded ➔ probe charged to negative voltage so that no current flows ➔ floating potential U_{fl} measured
- if voltage applied on the probe ➔ **IV-characteristics** measurement



International Journal of Physics. 2017, 5(3), 73-81. DOI: 10.12691/ijp-5-3-2

GOLEM Rake probe

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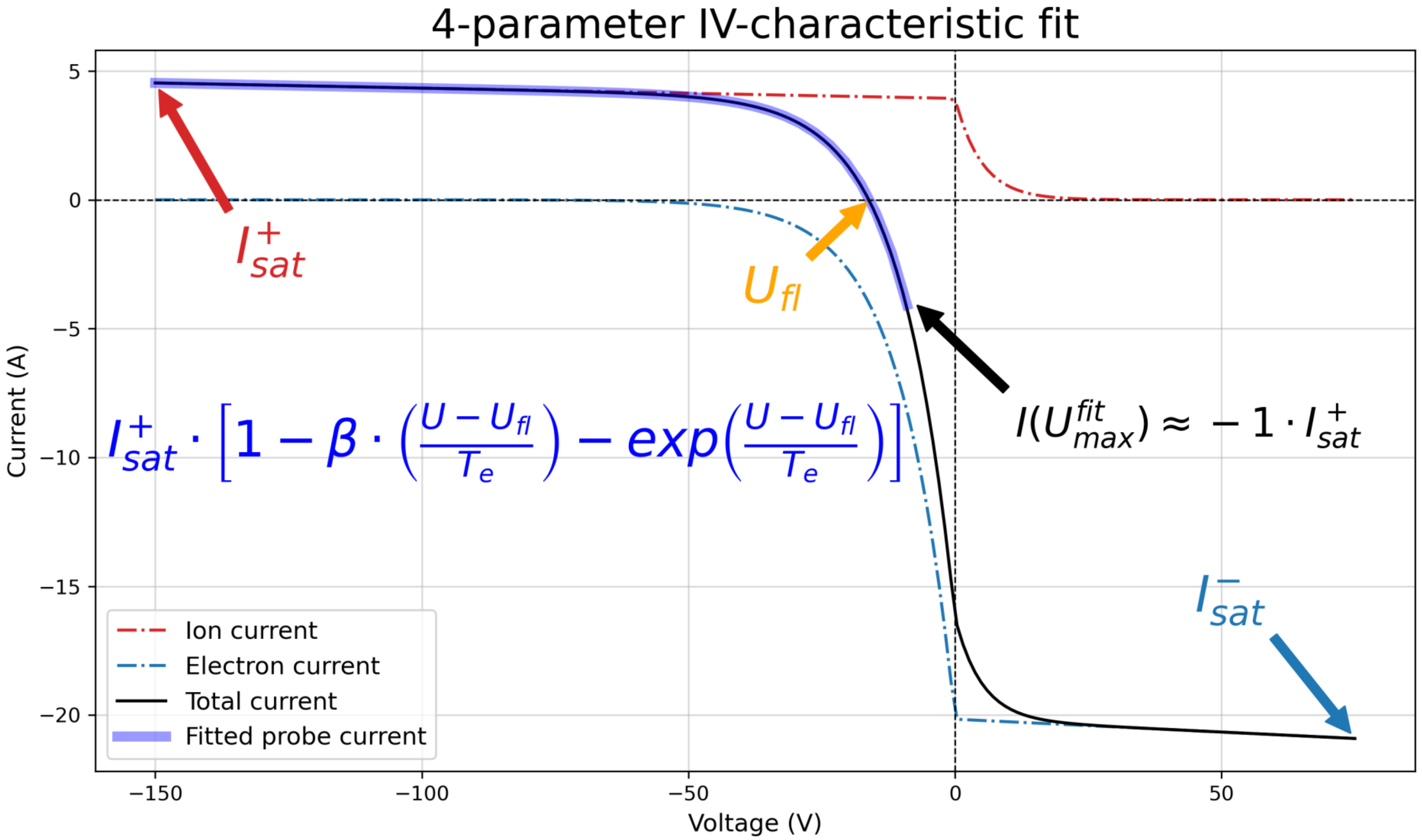
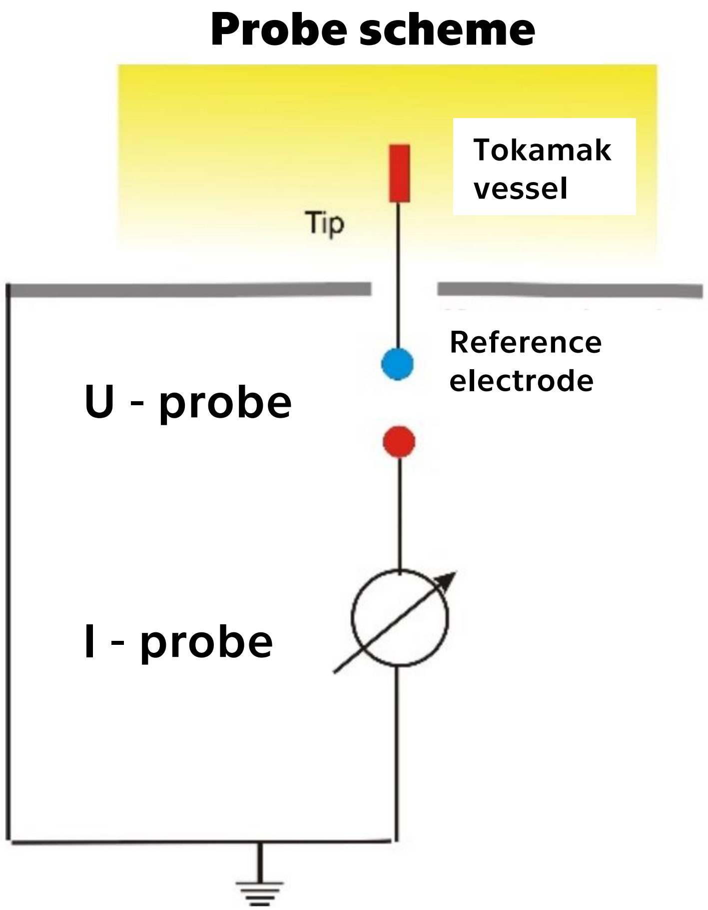
- 2D array of Langmuir probes
- Radial profile measurement during one shot
- ➔ electric fields, cross-correlations, etc. measurements

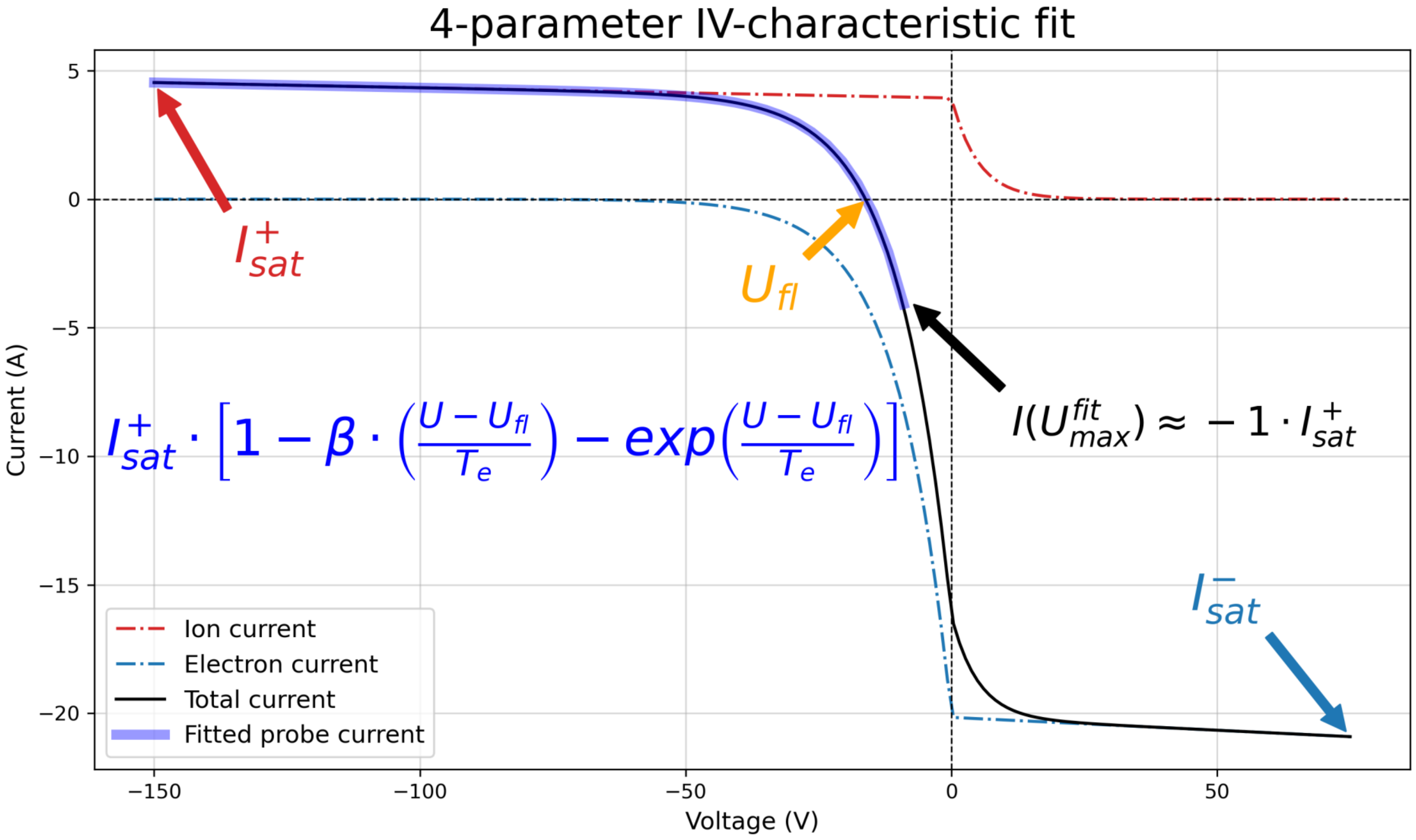
General IV-characteristic scheme of Langmuir-type probes





Fit of Langmuir probe IV-characteristics

- **P. Macha et al 2023 Nucl. Fusion 63 104003**
- 4-parameter fit of the ion-branch
  - I_{sat}^{+} ion saturated current
  - U_{fl} floating potential
  - T_e electron temperature
  - β sheath expansion coefficient
- sheath expansion effect
  - Debye sphere broadening due to high $|U|$
- this fit mostly includes negative *U*
  - $U_{max} \equiv U(I \approx -1 \cdot I_{sat}^{+})$
  - **for LP** (high +voltage can damage the probe)



Floating potential

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- probe not grounded ➔ charged by plasma ➔ measure U_{fl} voltage with zero current
- Generally:
  - α calibration constant
  - Φ plasma potential

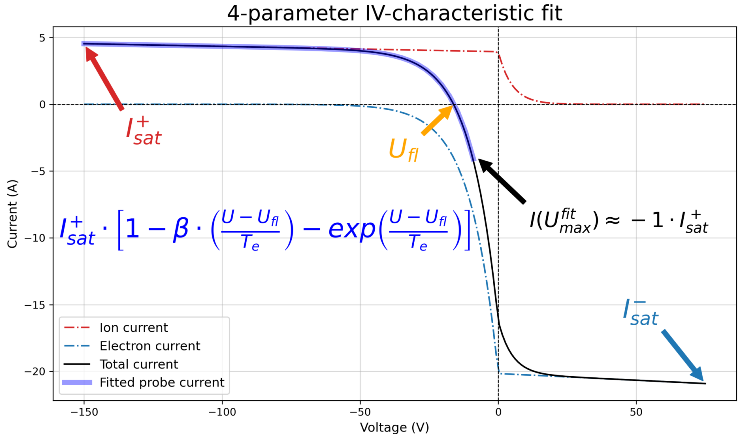
$$U_{fl} = \Phi - \alpha T_e$$

- Calibration constant α

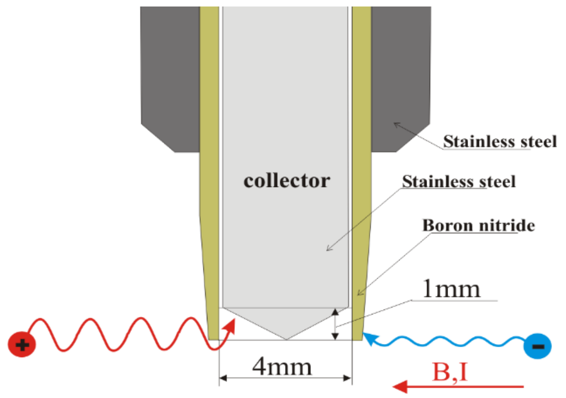
$$\alpha = ln\left({}^{I_{sat}^{-}} / {}_{I_{sat}^{+}} \right)$$

- Ball-pen probe
  - electron flow geometrically shielded $\Rightarrow \Gamma_e \approx \Gamma_i$

$$\Rightarrow U_{fl}^{(BPP)} \cong \Phi$$



Ball-pen probe



https://en.wikipedia.org/wiki/Ball-pen_probe

Measurement examples

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T_e measurement

1. from basic diagnostics (central T_e)
2. from IV-characteristics fitting
3. using the calibration constant $\alpha^{(LP,\,BPP)}$

$$\boldsymbol{U_{fl} = \Phi - \alpha T_e} \longrightarrow U_{fl}^{(LP)} = U_{fl}^{(BPP)} - \alpha^{(LP,\,BPP)}\, T_e$$

$$\alpha := \ln\left(I_{sat}^{-} / I_{sat}^{+} \right)$$

$$\alpha^{(LP,\,BPP)} = \alpha^{LP} - \alpha^{BPP}$$

$$\boldsymbol{T_e} = \frac{U_{fl}^{(BPP)} - U_{fl}^{(LP)}}{\alpha^{(LP,\,BPP)}}$$

n_i measurement

- using results from the IV-characteristics: I_{sat}^{+} , T_e

$$\boldsymbol{n_i} = f(T_e, I_{sat}^{+}) = \frac{I_{sat}^{+}}{e \cdot c_s^i \cdot S_{probe}}$$

$$\left(c_s^i\right)^2 = \frac{\gamma\, k_B\, T_i}{m_i} \approx \frac{2 \cdot e \cdot T_e\,[ev]}{m_i}$$

(assumes $T_i = T_e$)

GOLEM Combined probe-head

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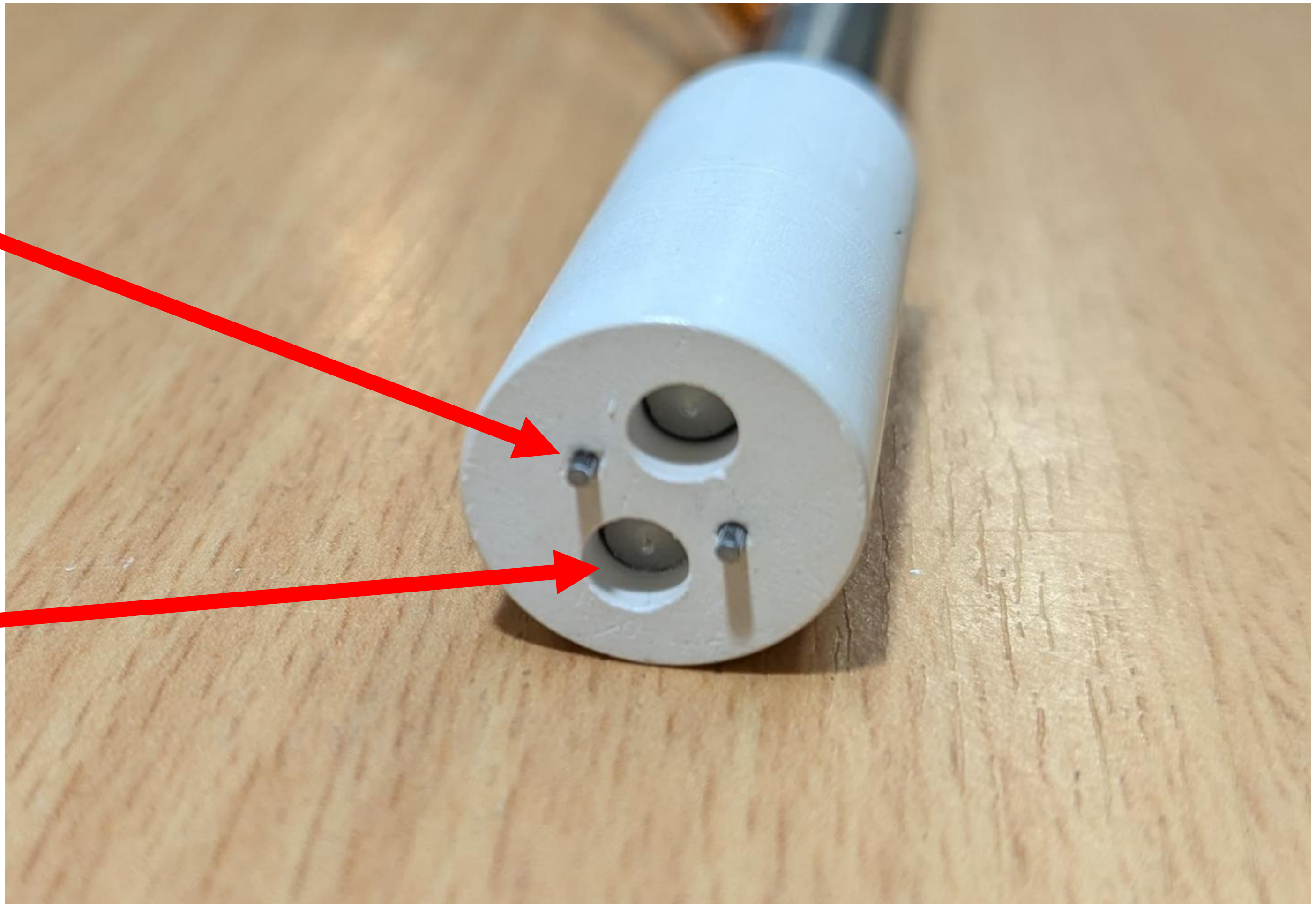
Langmuir probe



Ball-pen probe

Conclusion

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- **Electric probes** are a useful tool for measuring in the **plasma edge region**.
- Various modifications of electric probes exist for specific measurements.
- The possibility of measuring a wide range of plasma properties (**density, temperature, plasma potential**).
- Thanks to the flexibility of the GOLEM tokamak, it is possible to combine different probe configurations for various types of experiments.

Thank you for your attention

And good luck with your data analysis!