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EUROfusion – AI&ML Project

WPTE – Tokamak Exploitation

# AI-Assisted Causality Detection and Modelling of Plasma Instabilities for Tokamak Disruption Prediction and Control

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# Introduction and Motivation

**Disruptions** are one of the most critical issue in tokamaks, and it is fundamental to **avoid** disruption by plasma **instability prevention or recovery**

⇩

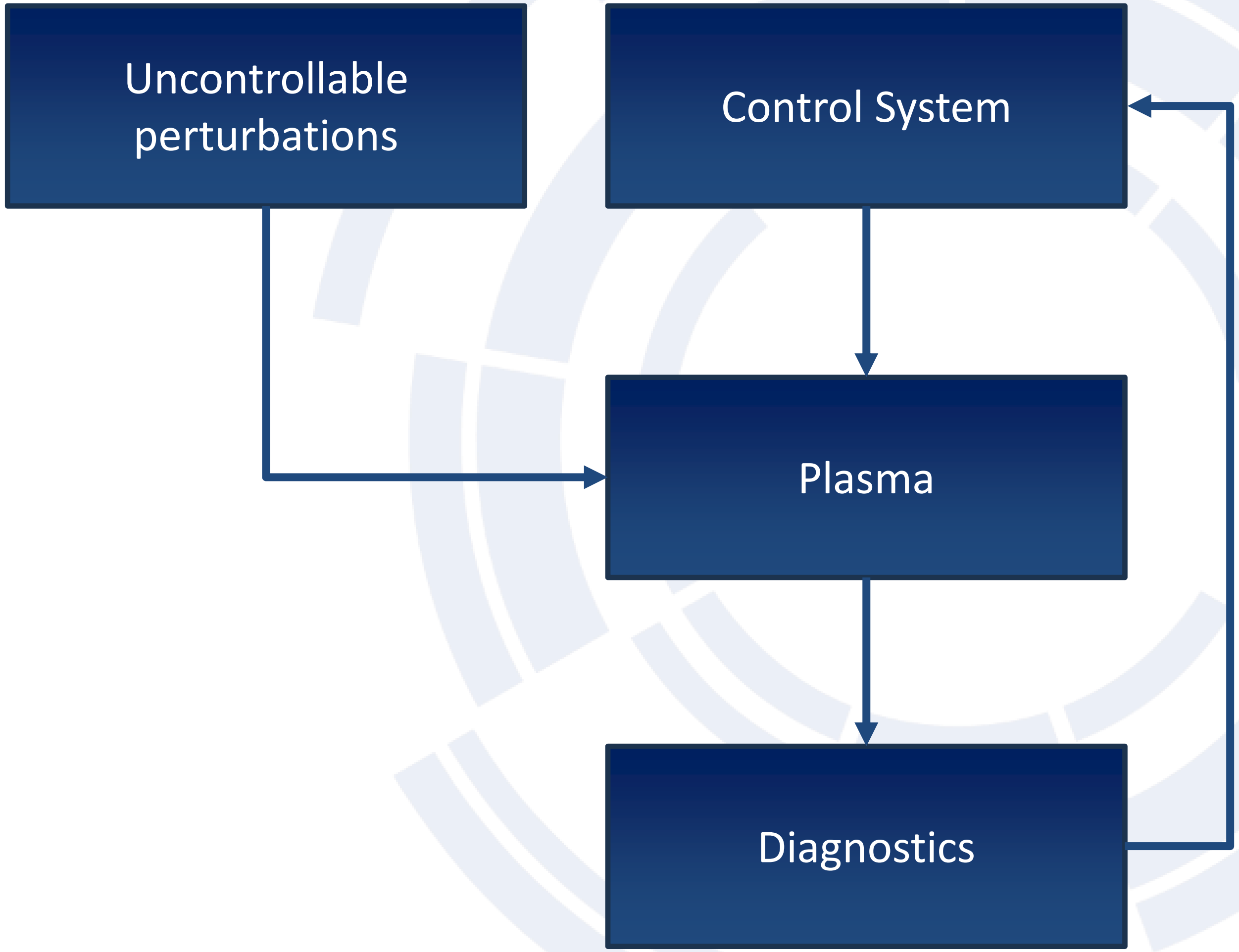
The stability of plasma must be ensured by **efficient control techniques** [1]

⇩

Artificial intelligence can be used to develop **simple and accurate time-series models** for control and physical understanding

⇧

Plasma are **complex physical system**





[1] Gianmaria De Tommasi, "Plasma Magnetic Control in Tokamak Devices", 38 (2019) https://link.springer.com/article/10.1007/s10894-018-0162-5

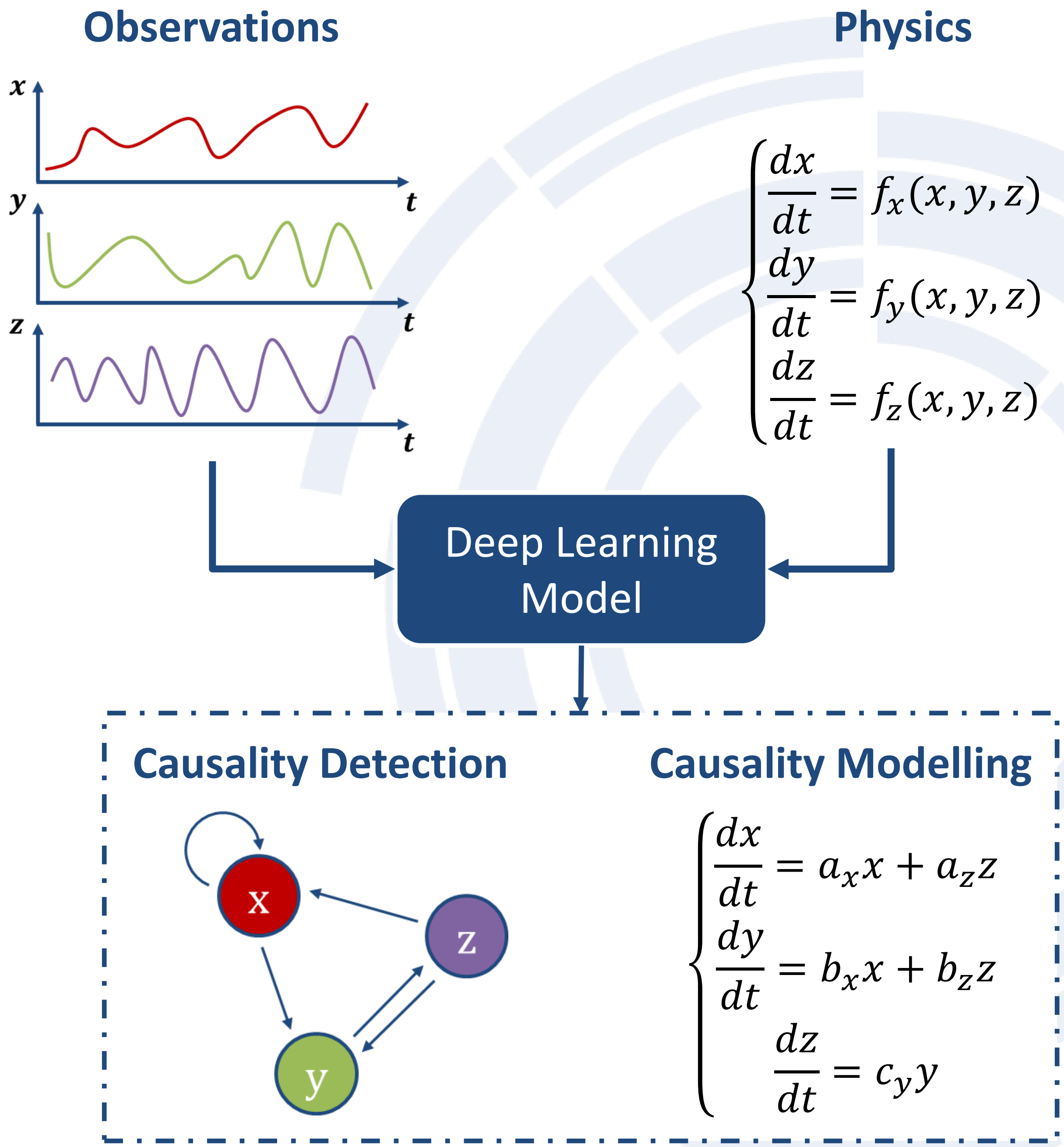
# Objectives

An **easy-to-use software package** for **analysing and modelling causality** relations between times series.

The software will be **fully general** to be applied to different time-series. It will implement also the possibility to **take into account physical or empirical a priori knowledge** to guide the algorithm to find better solutions.

The use of this software may lead to **simple, accurate, and reliable model** developments for nuclear fusion **time-dependent** variables.

Use the Deep Learning Model to **analyse and modelling Radiative** (Core Radiation, MARFE, etc.) and **Thermal Instabilities** ($T_e$ Hollowness and Edge Cooling) in Tokamaks.



# Methodology

Development of an AI framework for:

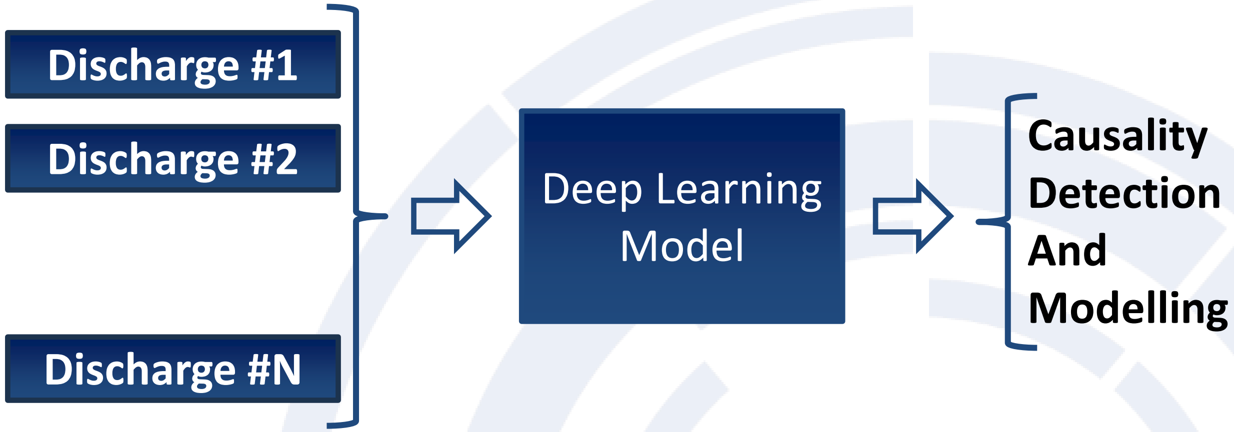
**Causality Detection and Modelling:**

- From **Multi-Experiments** (multi plasma discharges): it ensure reliability and accuracy of the results.
- Plasma **state-variables** from **proxy** measurements (**causes modelling from effects**).

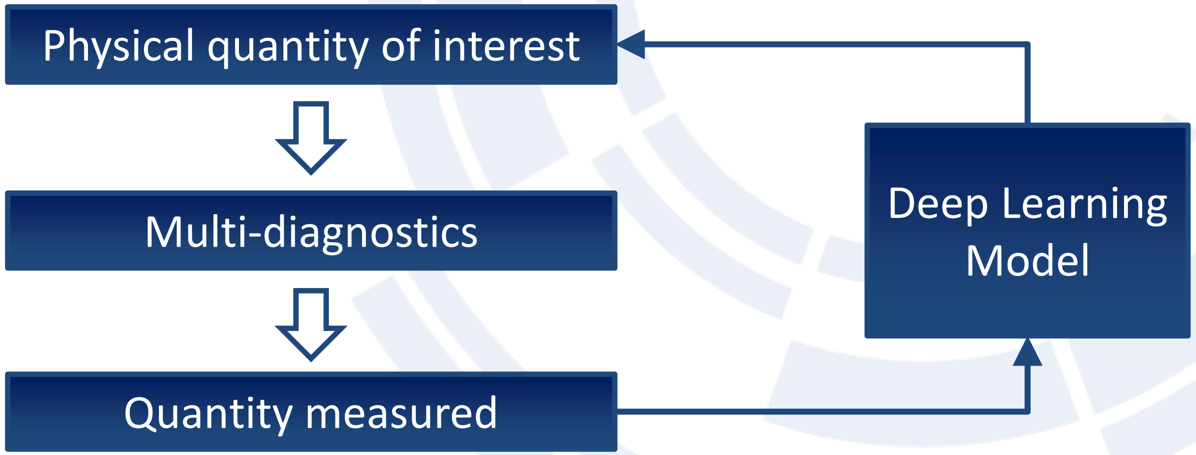
The framework will combine different cutting-edge technologies:

- **Deep learning models** (e.g. deep autoencoders, CNN, etc.) [2]
- **Physics-Constrained Loss Functions** (implementing also uncomplete physics) [3]
- **Genetic Programming** (useful to extract analytical models easy to interpret and use) [4]

**Multi-Experiments**




**Analysis of unobservable variables by proxies and indirect measurements**





[2] J.Vega, A.Murari et al Nat. Phys. 18, 741–750 (2022) https://doi.org/10.1038/s41567-022-01602-2
[3] R. Rossi et al 2023 Nucl. Fusion 63 126059 https://iopscience.iop.org/article/10.1088/1741-4326/ad067c
[4] A Murari et al Evolutionary Computation 31 (4) 2023 https://doi.org/10.1162/evco_a_00330

# Project Timeline

**May 2024 - Project start**

Main architecture of deep learning models developed and methodology tested with synthetic cases (**Deliverable #1**)

Genetic programming via Symbolic Regression optimised for Time-Series models (**Deliverable #2**)

**End of 2024**

Tuning of the models for a specific nuclear fusion case (plasma instability, control of radiation and density)

Selection of experimental pulses for test (**Deliverable #3 and #4, part 1**)

Application of the models to experimental plasma discharges, analysis of the results (**Deliverable #3 and #4, part 2**)

Finalisation of codes and documentation for EUROfusion scientific community

**End of 2025**

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