# Surrogate modelling of ray-tracing and radiation transport code for faster real-time plasma profile inference in a magnetic confinement device

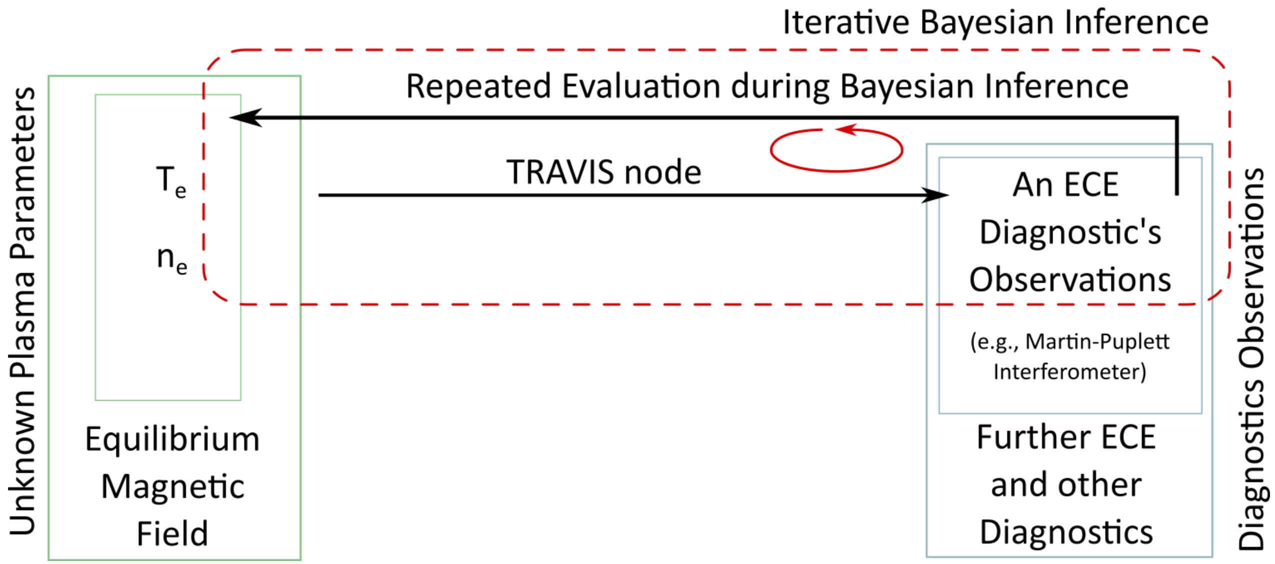
FSD Science Coordination Meeting / KoM AI&ML projects

**Jan-Matthias Braun**, Henrik Bindslev, Esmaeil Nadimi
Applied AI & Data Science Group, University of Southern Denmark

project devised in collaboration with

Daniel Böckenhoff, Neha Chaudhary, Pavel Aleynikov & Nikolai Marushchenko
Max Planck Institute for Plasma Physics Greifswald

# Background




- Infer plasma parameters, e.g. electron temperature, density
- Complex relation between spectral intensity of the ECE radiation and, e.g., the desired parameters, the magnetic fields, the mixing of radiation polarisations upon reflections off the vacuum vessel walls
- TRAcing VISualized (TRAVIS) code: radiation transport code solving accounting for wave absorption and emission
- Applied Bayesian inference is computationally expensive
- Example: inferring the $T_e$ profile for a single steady state discharge of 10 seconds duration with 1 kHz sampling can take days

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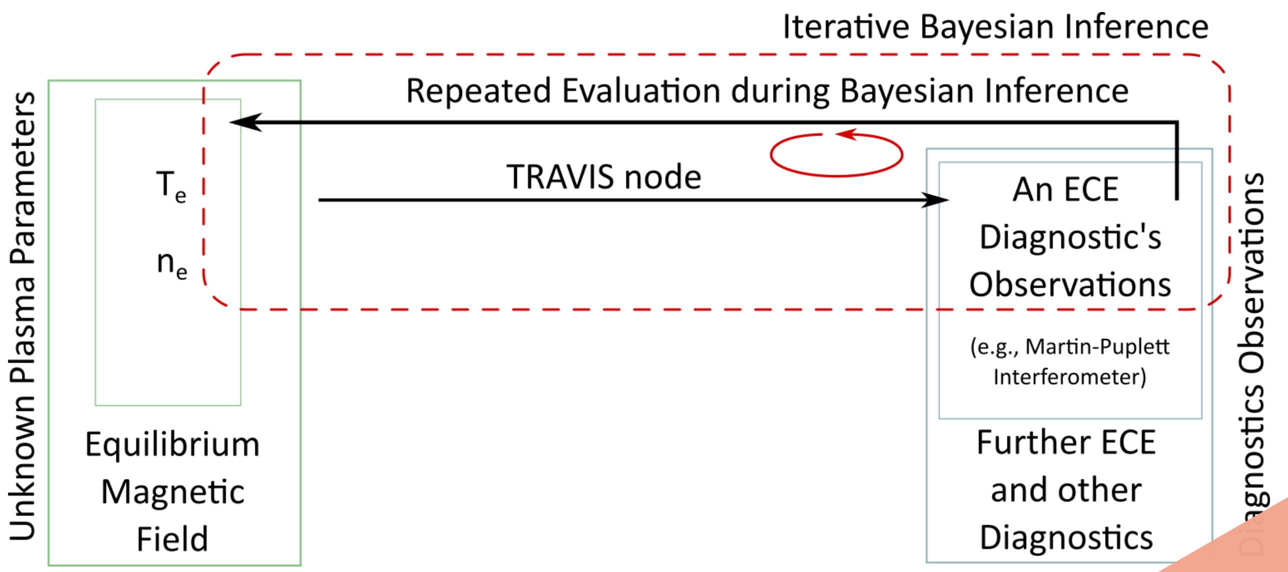


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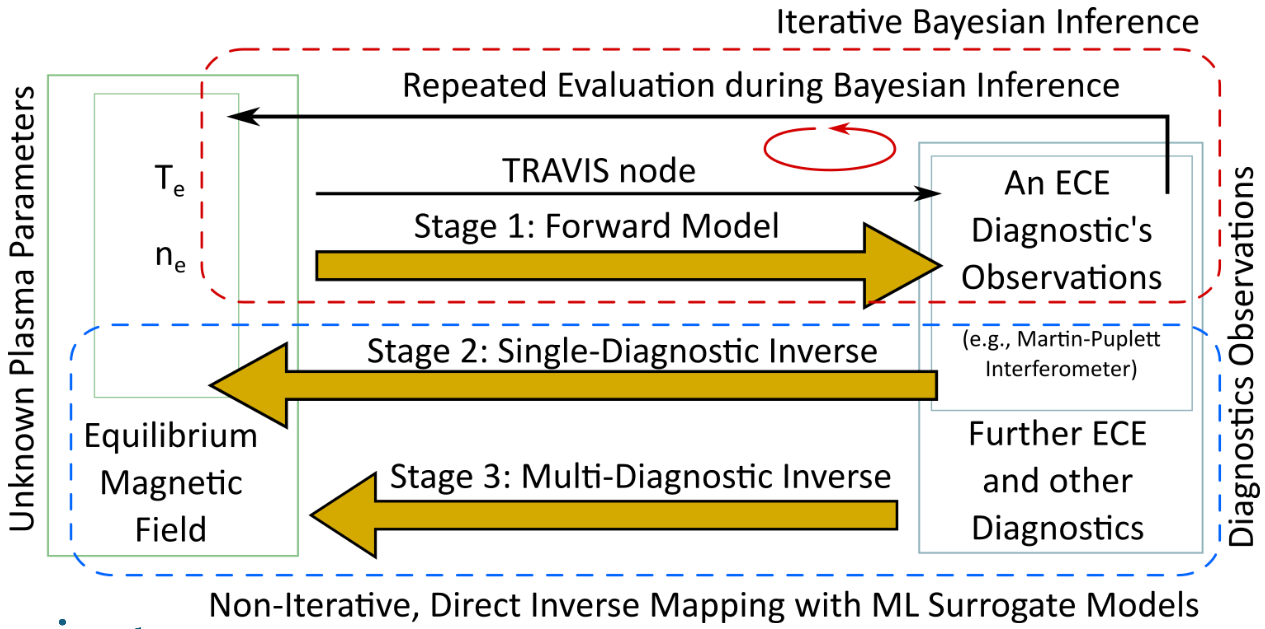
**What can we try to achieve with AI/ML based approaches?**

# Project




## Approach

- Replace iterative Bayesian inference with surrogate AI models to provide fast inverse mappings
- Application to plasma parameter inference from diagnostics
- Target real-time application in the control room (min or even ms scale)
- Expect general applicability of resulting models & knowledge

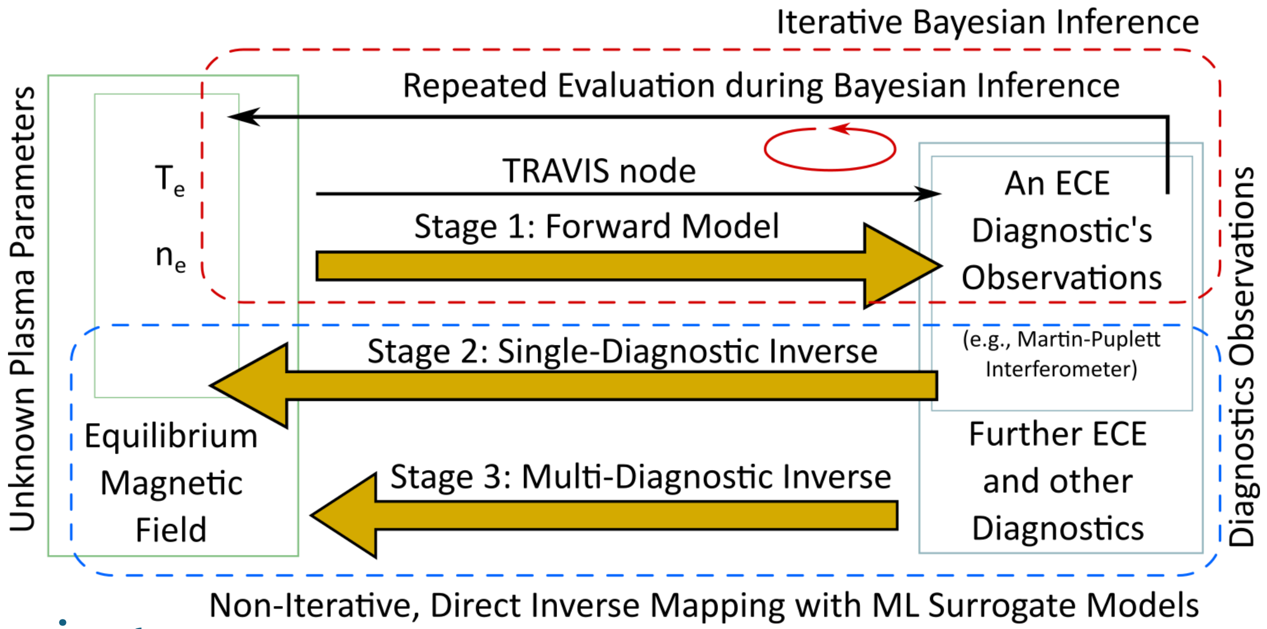
## Partners

- MPI for Plasma Physics in Greifswald (IPP)
- University of Southern Denmark (SDU) as associated 3rd party via the Technical University of Denmark (DTU)

# Project

**Methods**

- ANNs as generic function approximators
- Direct inverse mapping has huge potential
- Complexity analysis:
    - Trade off speed vs accuracy
    - Requirements per application
- Focus on estimation of error and uncertainty due to requirements for plasma operation
- Investigate Physics Informed Neural Networks (PiNNs), Kolmogorov-Arnold Networks, and especially for stages 2 & 3 Bayesian Networks (also as PiNN variants) and ANNs/PiNNs with Bayesian last layer; architectures…
- Optimisation: sampling strategy for training, using, e.g., ridge regression, Sobolev-type regularisation

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SDU)

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# Team – Backgrounds & Roles

**SDU**

- Henrik Bindslev – Fusion, Collective Thomson Scattering, modelling mm-waves in plasmas
- Esmaeil Nadimi – AI/ML in energy and health care applications
- Jan-Matthias Braun – AI/ML in biosignal analysis and adaptive control
- Collaboration with DTU on Collective Thomson Scattering

**IPP**

- Daniel Böckenhoff – AI/ML applications for fusion
- Neha Chaudhary – Experiment design & execution
- Pavel Aleynikov & Nikolai Marushchenko – TRAVIS

# Outline

**Development of surrogate models in three stages**

- Stage 1: Surrogate forward model (Dec. 2024)
- Stage 2: Full inverse model for the TRAVIS node (July 2025)
- Stage 3: Full inverse model for combined diagnostics (Dec. 2025)

**Further Outcomes**

- Integration into the MINERVA framework (June 2025)
- Documentation towards the use of AI models (Dec. 2025)