

SFERA-III

Solar Facilities for the European Research Area



Introduction to Smart CSP

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Summer School: "Smart CSP: How Smart Tools, Devices, and Software can help improve the Design and Operation of Concentrating Solar Power Technologies" - WP1 Capacity building and training activities - Cologne, Germany, September 14th-15th 2023



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Solar Tower Jülich



source: DLR

Gemasolar



source: Torresol Energy

Parabolic Trough



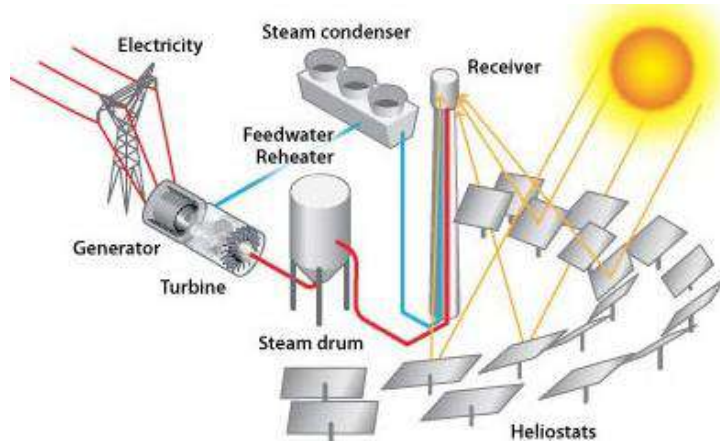
source: DLR

Fresnel Collector

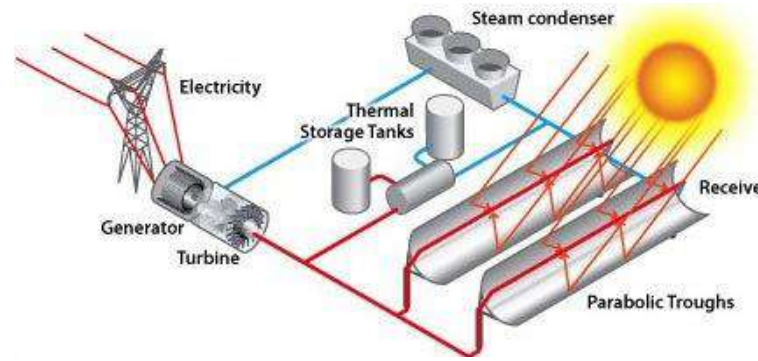


source: DLR

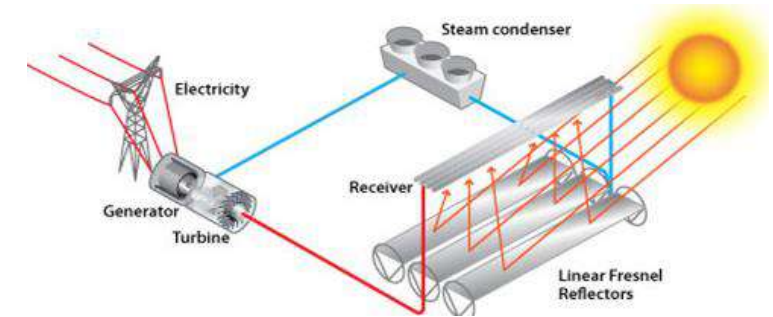
Tower Power Plant



Parabolic Trough



Fresnel Collector

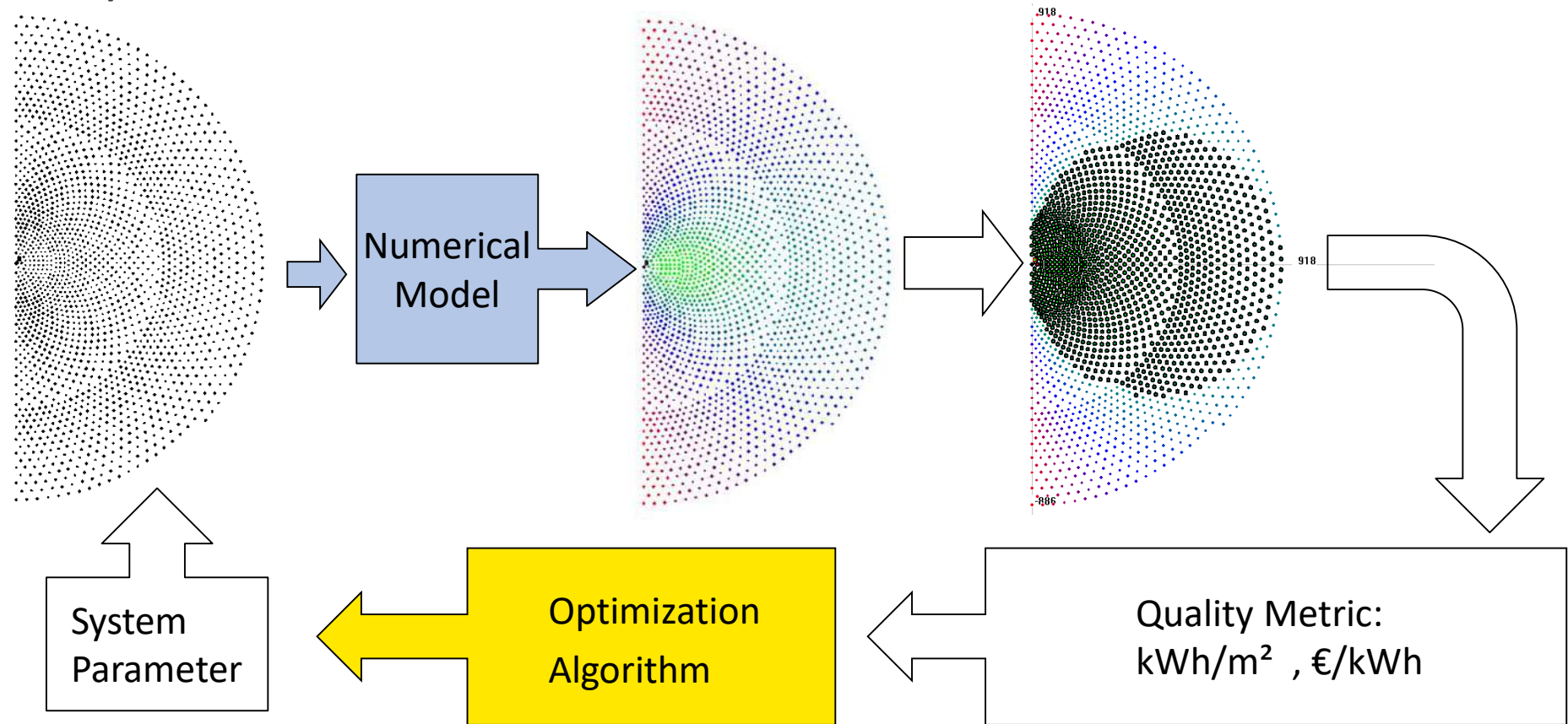


source: US DoE

What is *smart* in the context of CSP?

- Lower investment costs due to a smart design

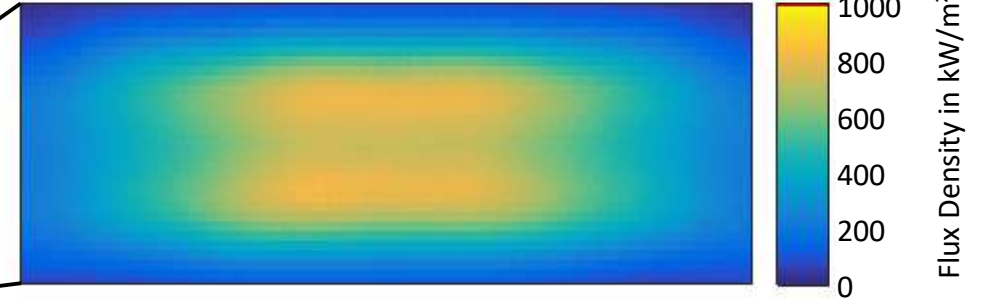
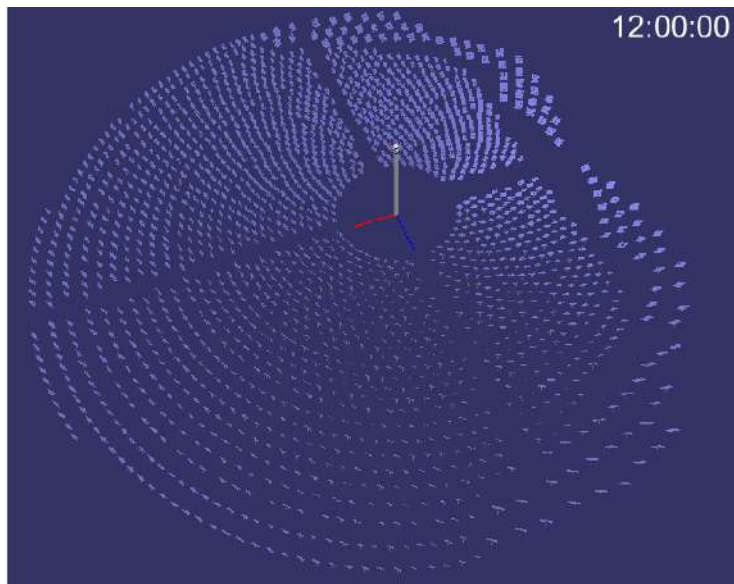
Concentrator Field Layout



What is *smart* in the context of CSP?

- Lower investment costs due to a smart design
- Generate the highest possible energy yield with smart operation strategies

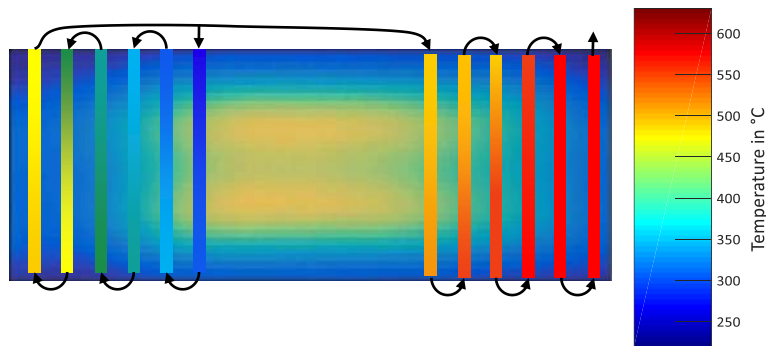
Operation optimization under cloud conditions



- High dynamic system
- Complex demands on control and operational management

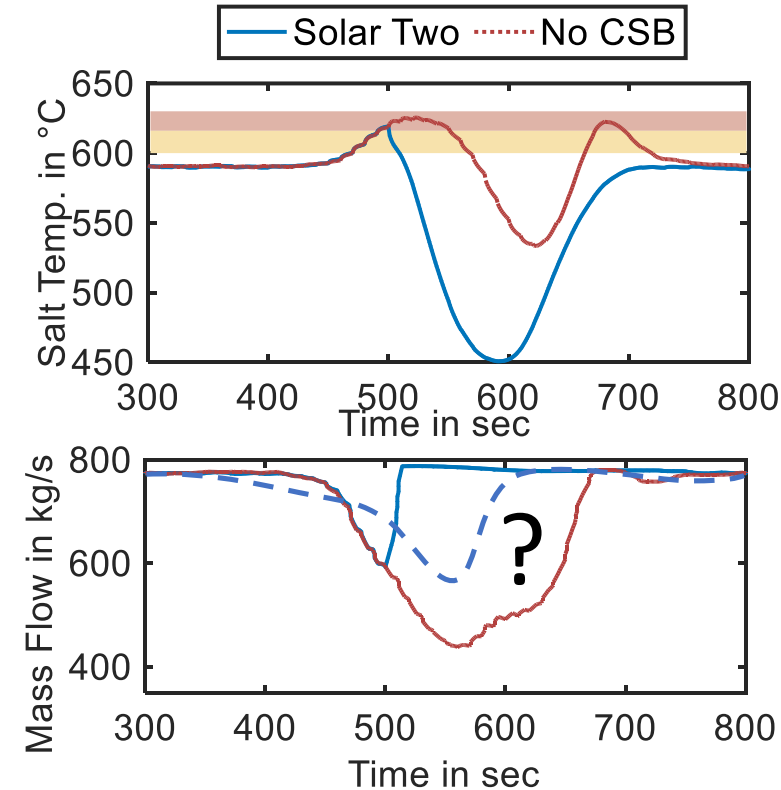
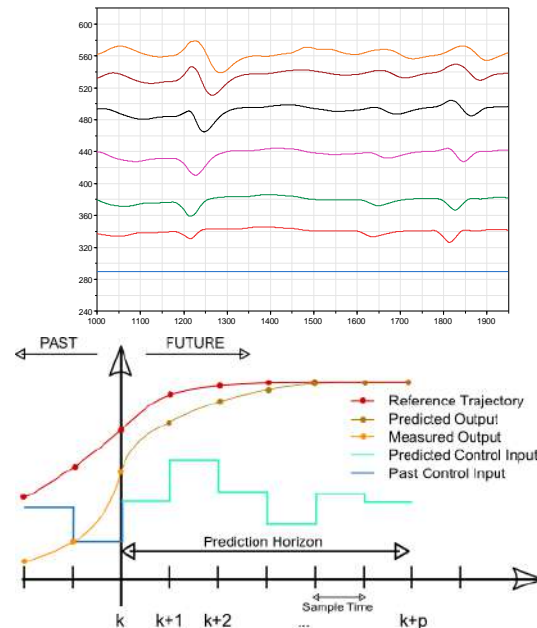
Challenges

- Sequential mass flow
- Dynamic inhomogeneous irradiation
- Dynamic limits
 - Mass flow
 - Temperature



Research Topic

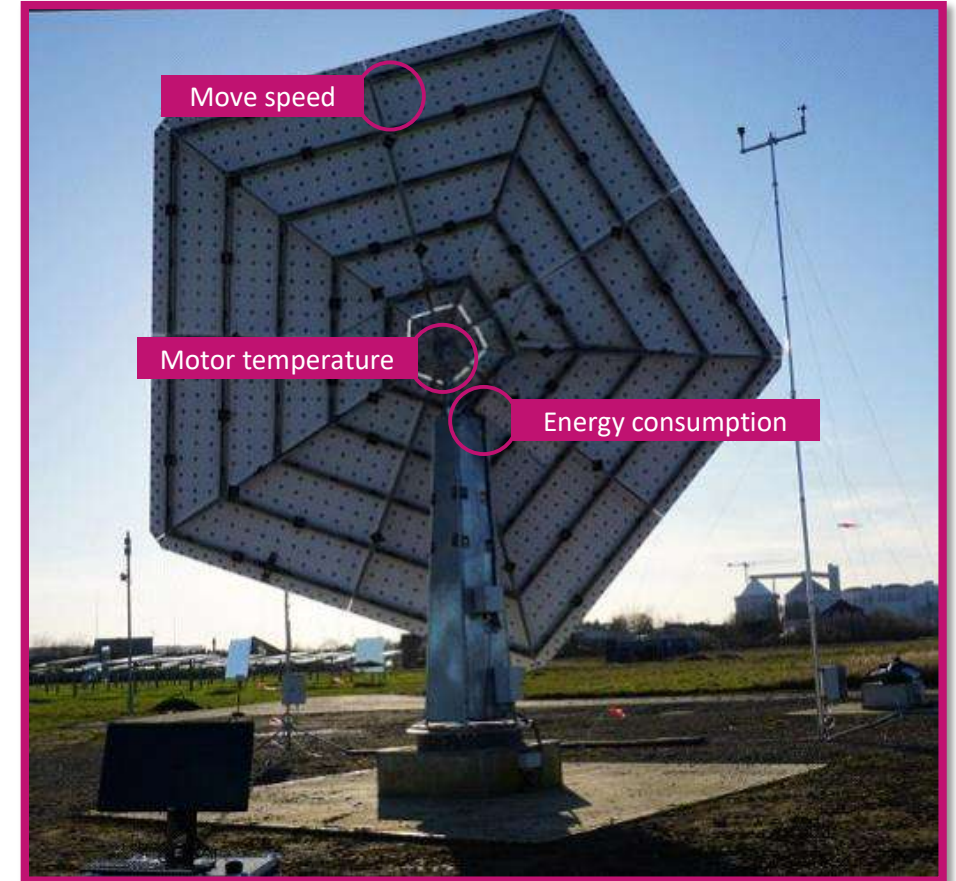
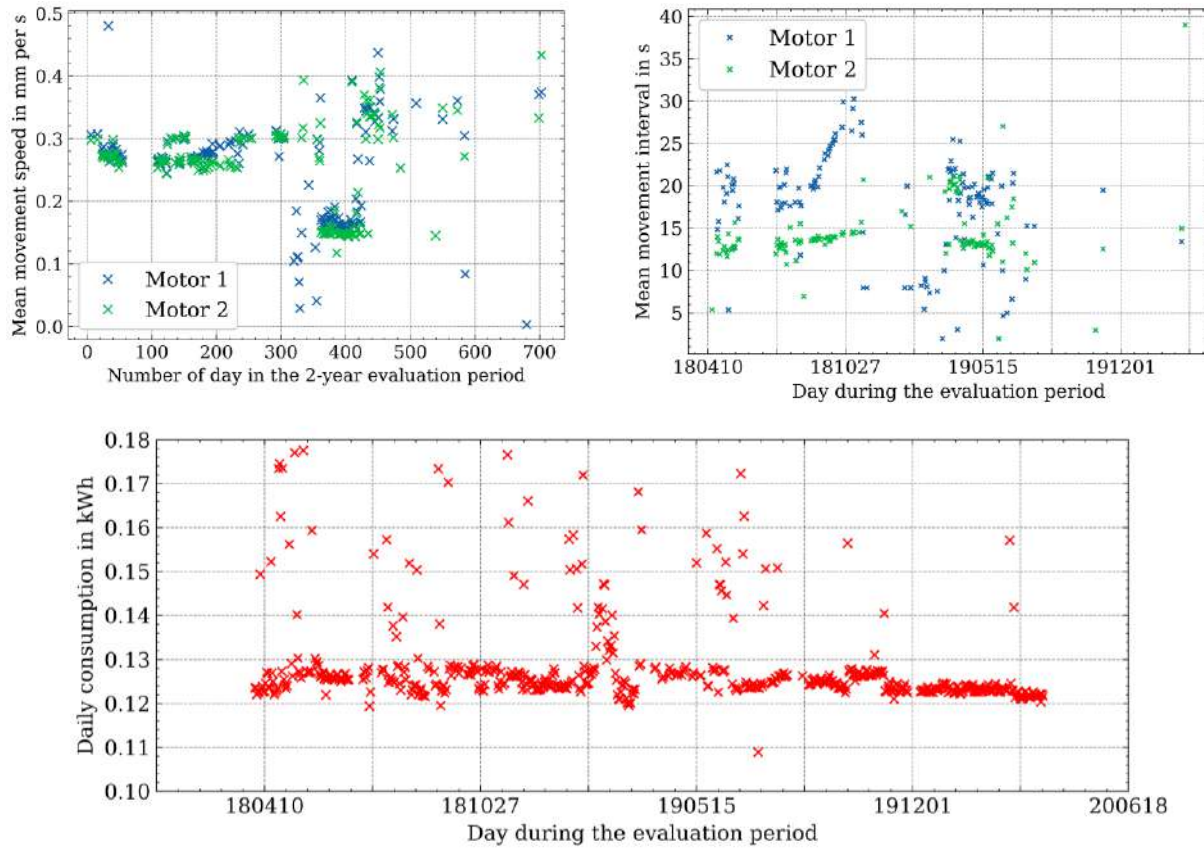
- Model predictive controller
- Optimization mass flow rate



What is *smart* in the context of CSP?

- Lower investment costs due to a smart design
- Generate the highest possible energy yield with smart operation strategies
- Keep O&M cost low within the lifetime of the plant with smart predictions

Condition Monitoring



Steinberg D.; SOLLAB 2023

What is *smart* in the context of CSP?

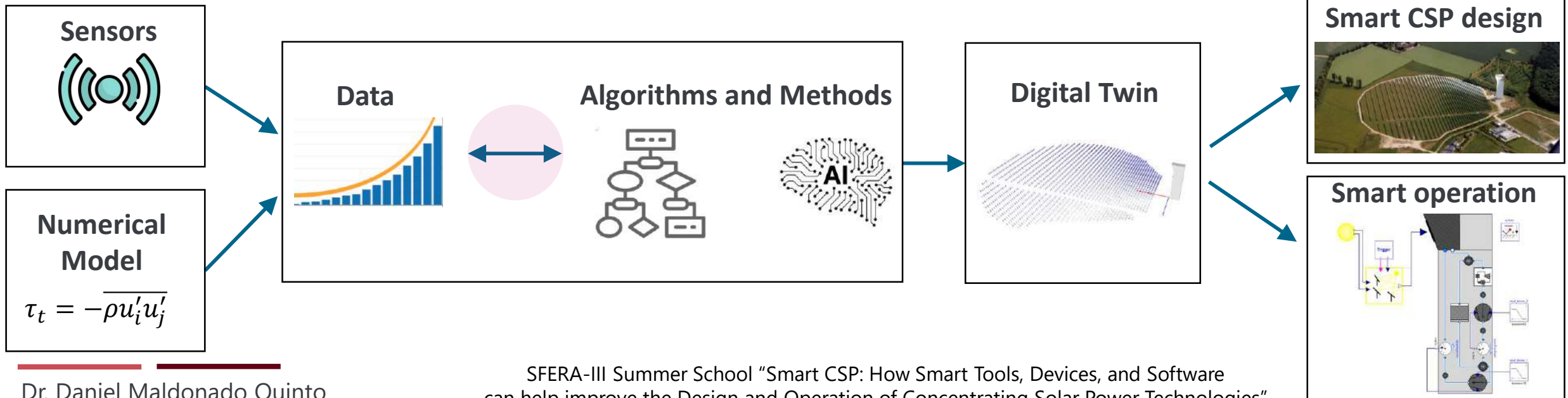
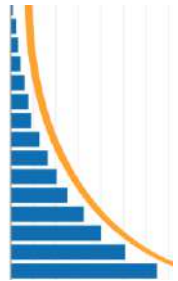
- Lower investment costs due to a **smart design**
- Generate the highest possible energy yield with **smart operation strategies**
- Keep O&M cost low within the lifetime of the plant with **smart predictions**

operation - data

before

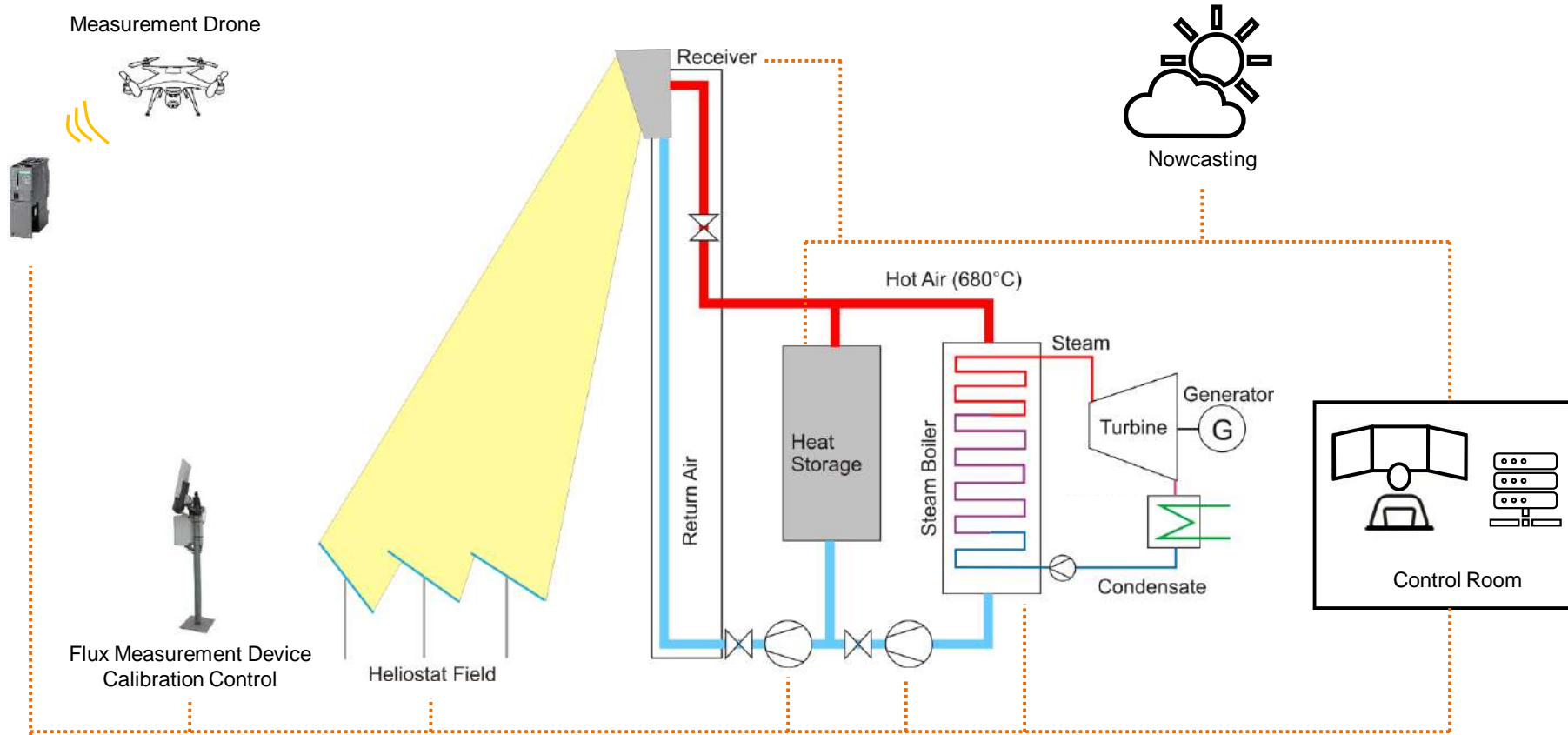
during

future



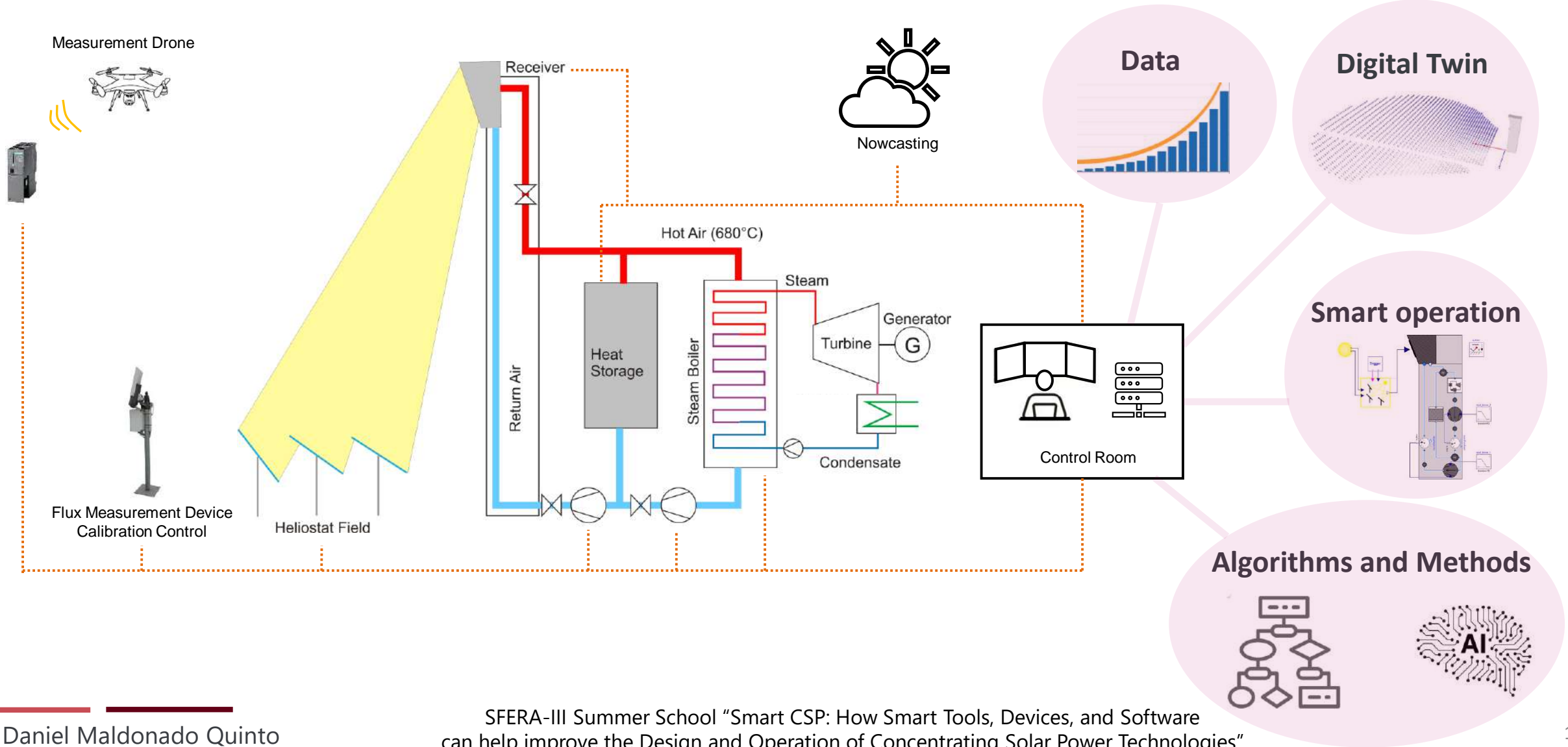
Smart CSP

Interconnection of all Components and Systems



Smart CSP

Interconnection of all Components and Systems

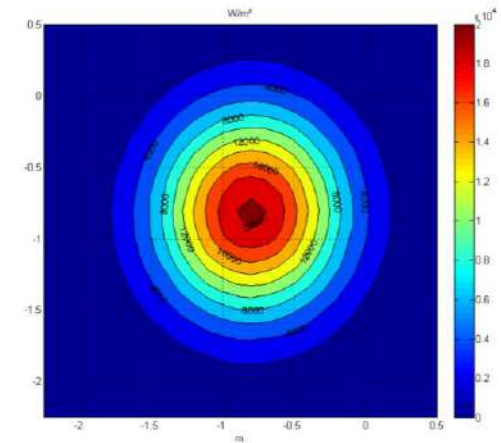


Predicting flux density distributions on the receiver

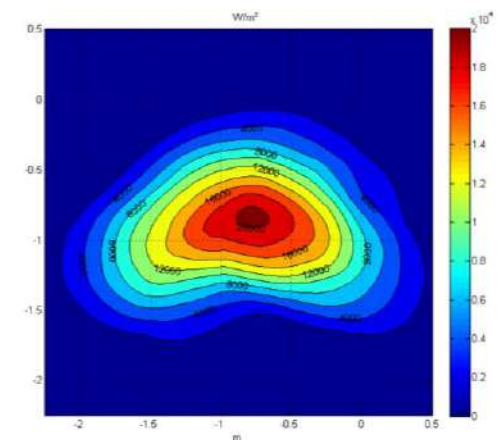
- Requirement to find smart operation strategies
- Most critical part of the plant (dynamics, efficiency, lifetime)
- Difficult to measure (high temperatures, high flux)
- **State of the art:** Raytracer with heliostat model
 - Inaccurate if we do not have deflectometry data
 - Degradation over time is not considered

Let's look for a smart approach

Simulated ideal heliostat

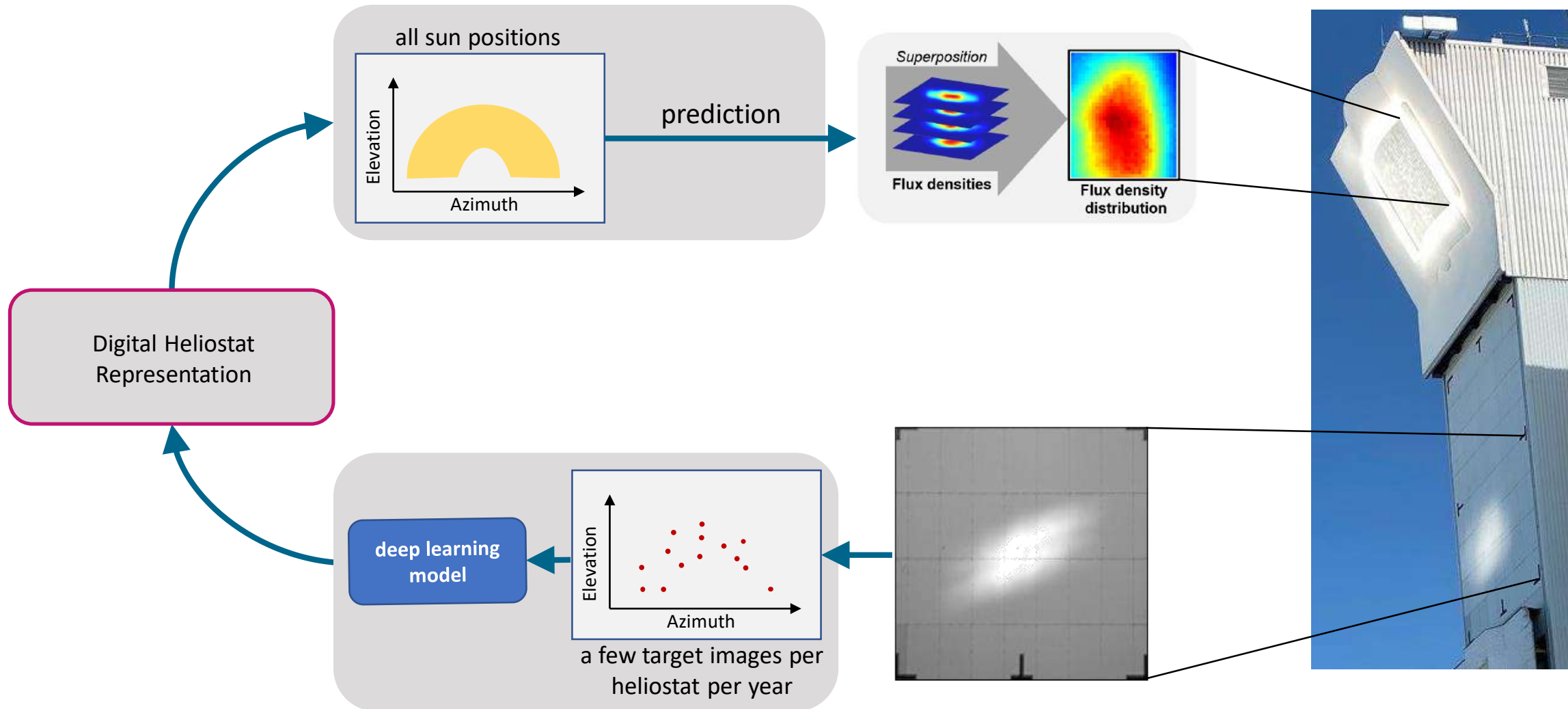


Simulated measured heliostat



Smart Approach

Predicting Flux Density Distributions



Smart Approach

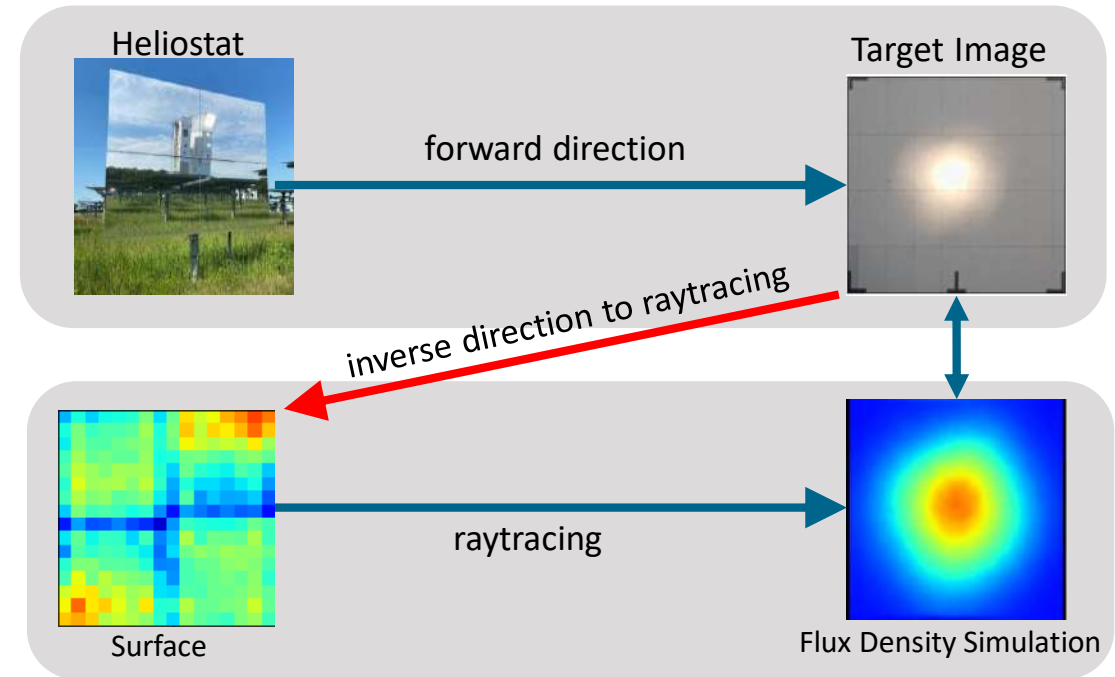
Digital Heliostat Representation

Raytracing

- Accurate description of physics
- Accuracy depends on how precisely the parameters and material properties are known

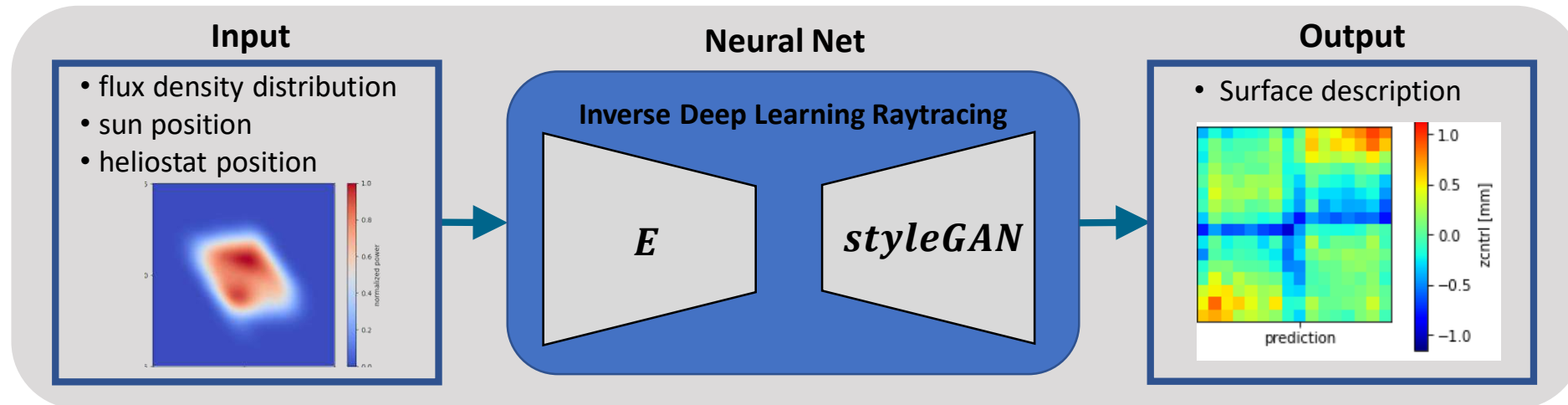
Deep Learning Inversion of a Raytracer

- Black box character
- Accuracy depends on the amount of data, data distribution and data quality
- Training data can be simulated with a raytracer

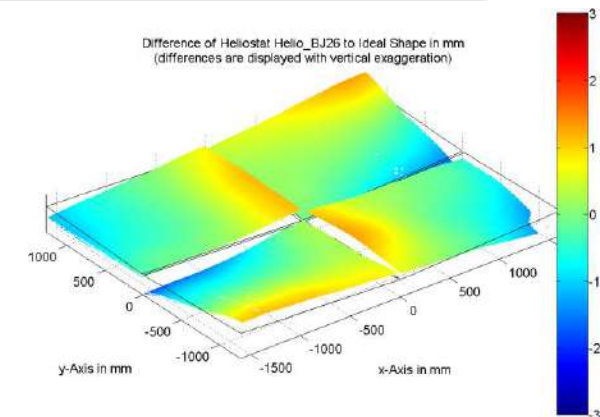


source: Lewen J., et al., SolarPACES 2023, Sydney

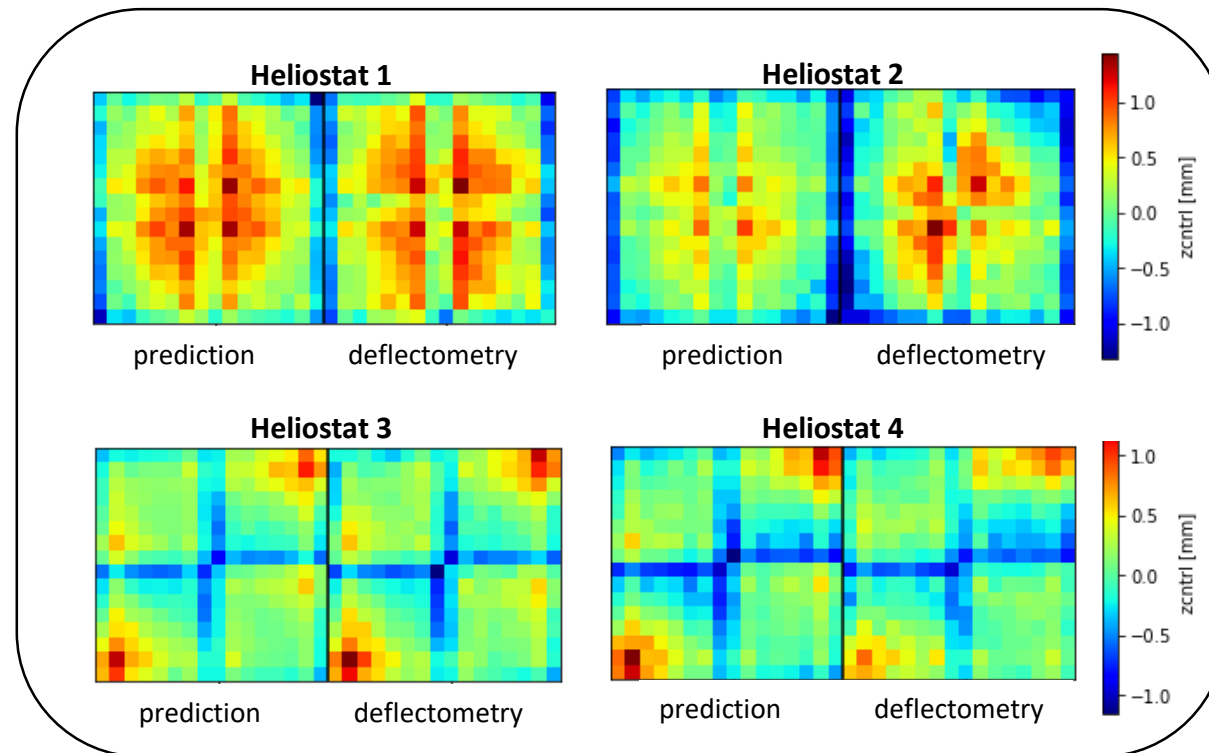
Deep Learning Model



source: Lewen J., et al., SolarPACES 2023, Sydney

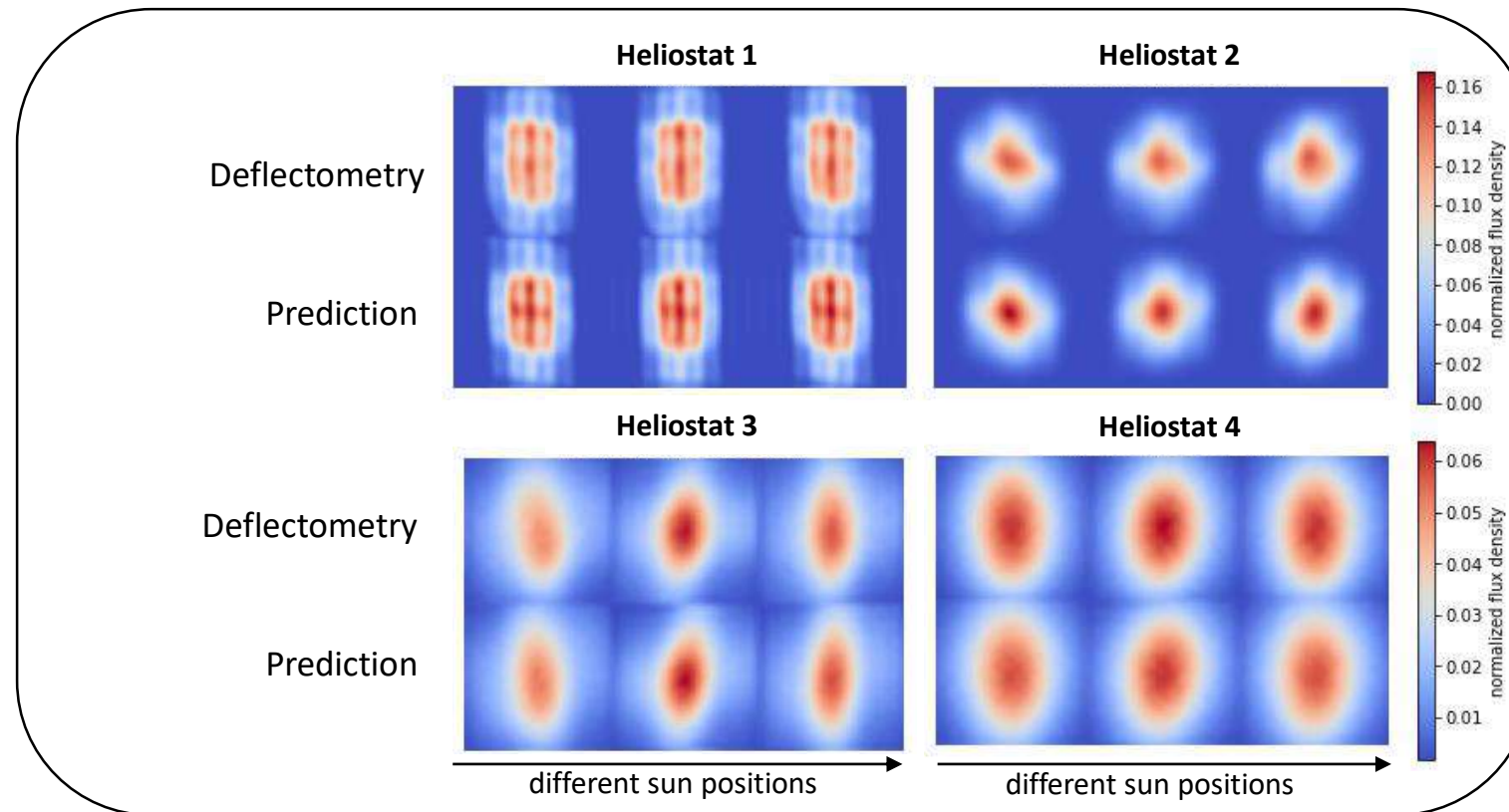


Deep Learning Prediction of Heliostat Surfaces



source: Lewen J., et al., SolarPACES 2023, Sydney

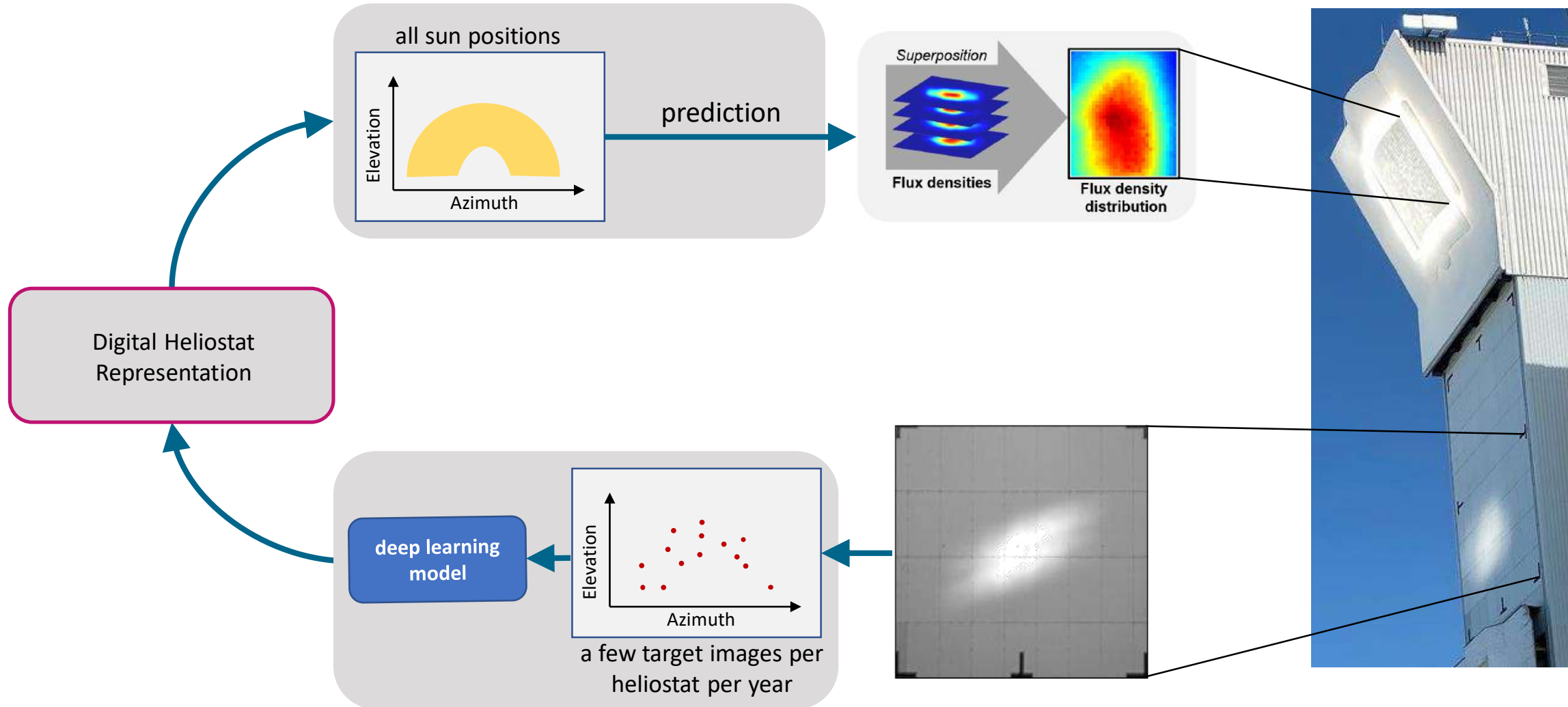
Prediction of Flux Density Distributions



source: Lewen J., et al., SolarPACES 2023, Sydney

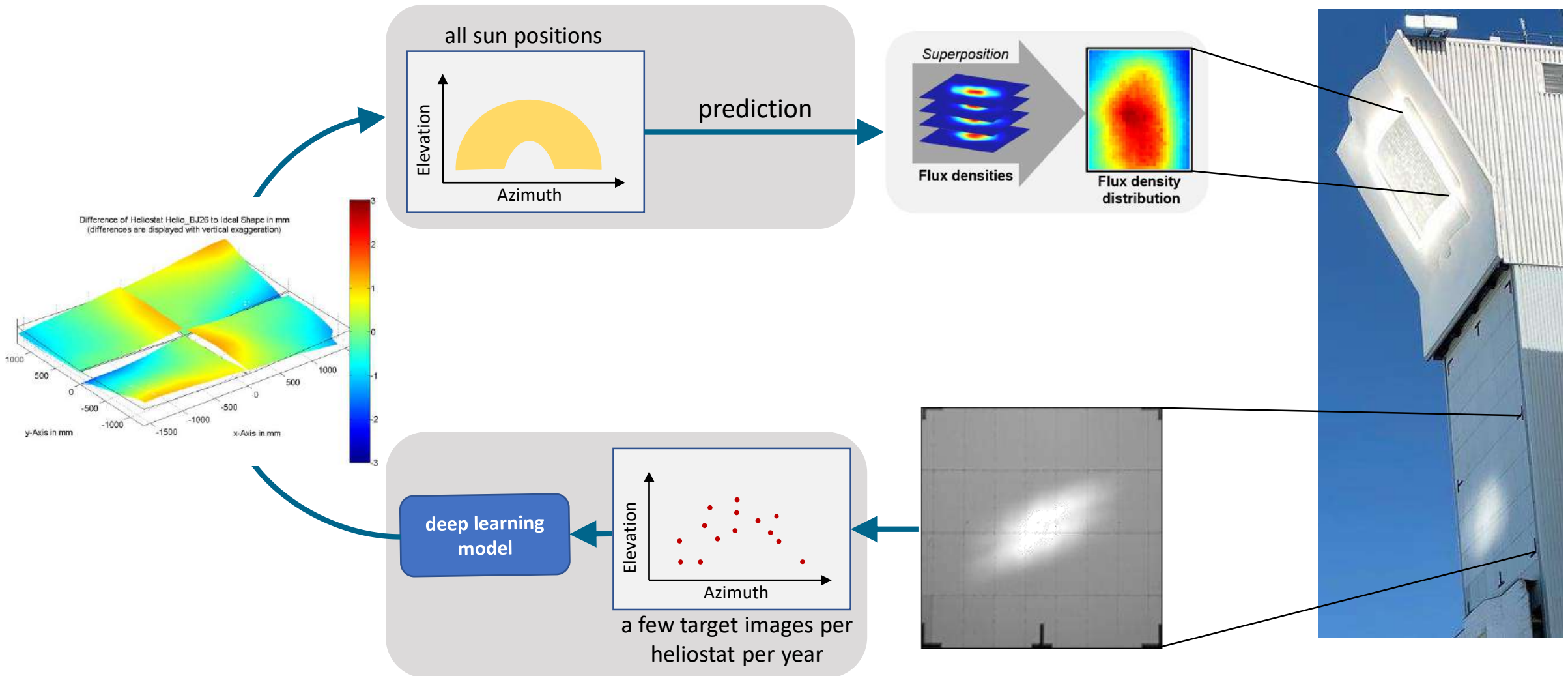
Smart Approach

Predicting Flux Density Distributions



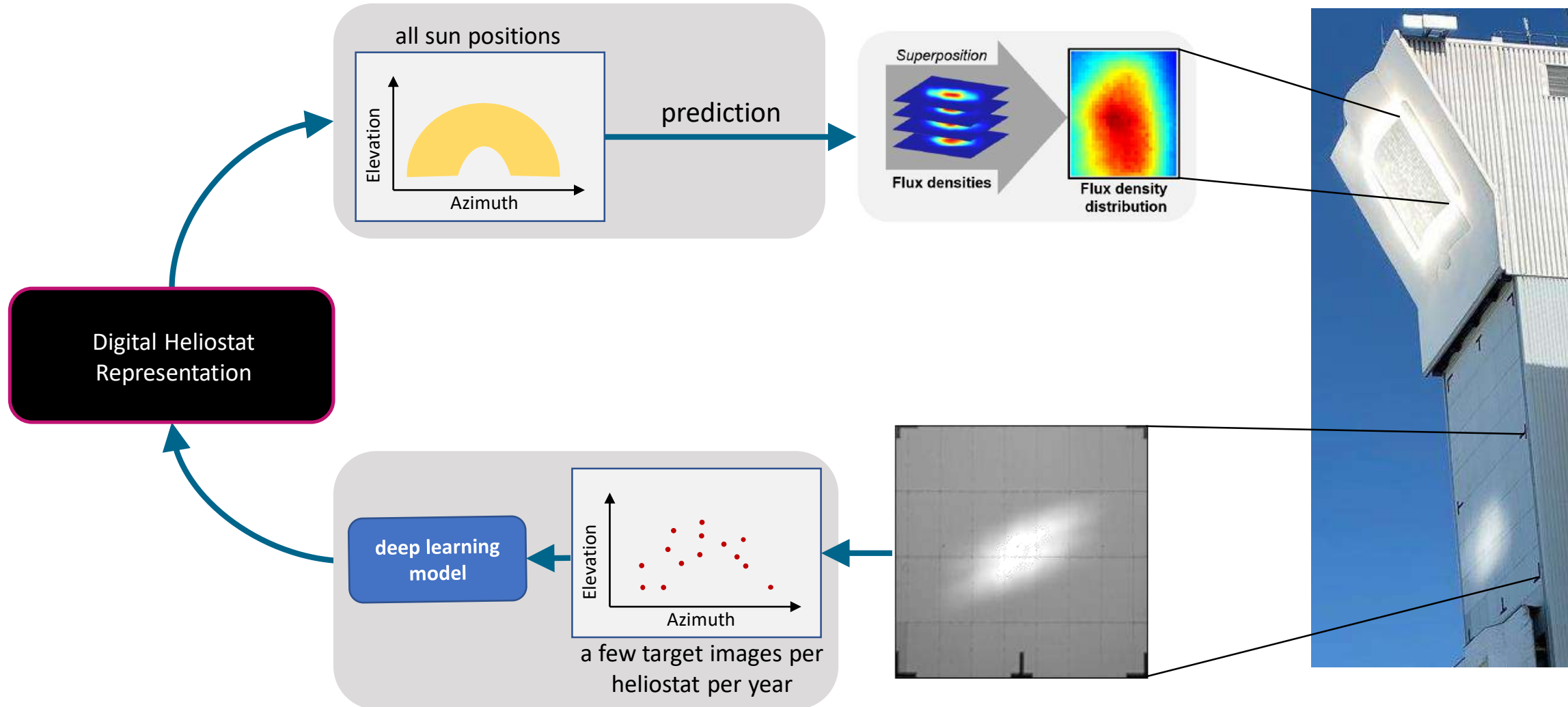
Smart Approach

Predicting Flux Density Distributions



Smart Approach

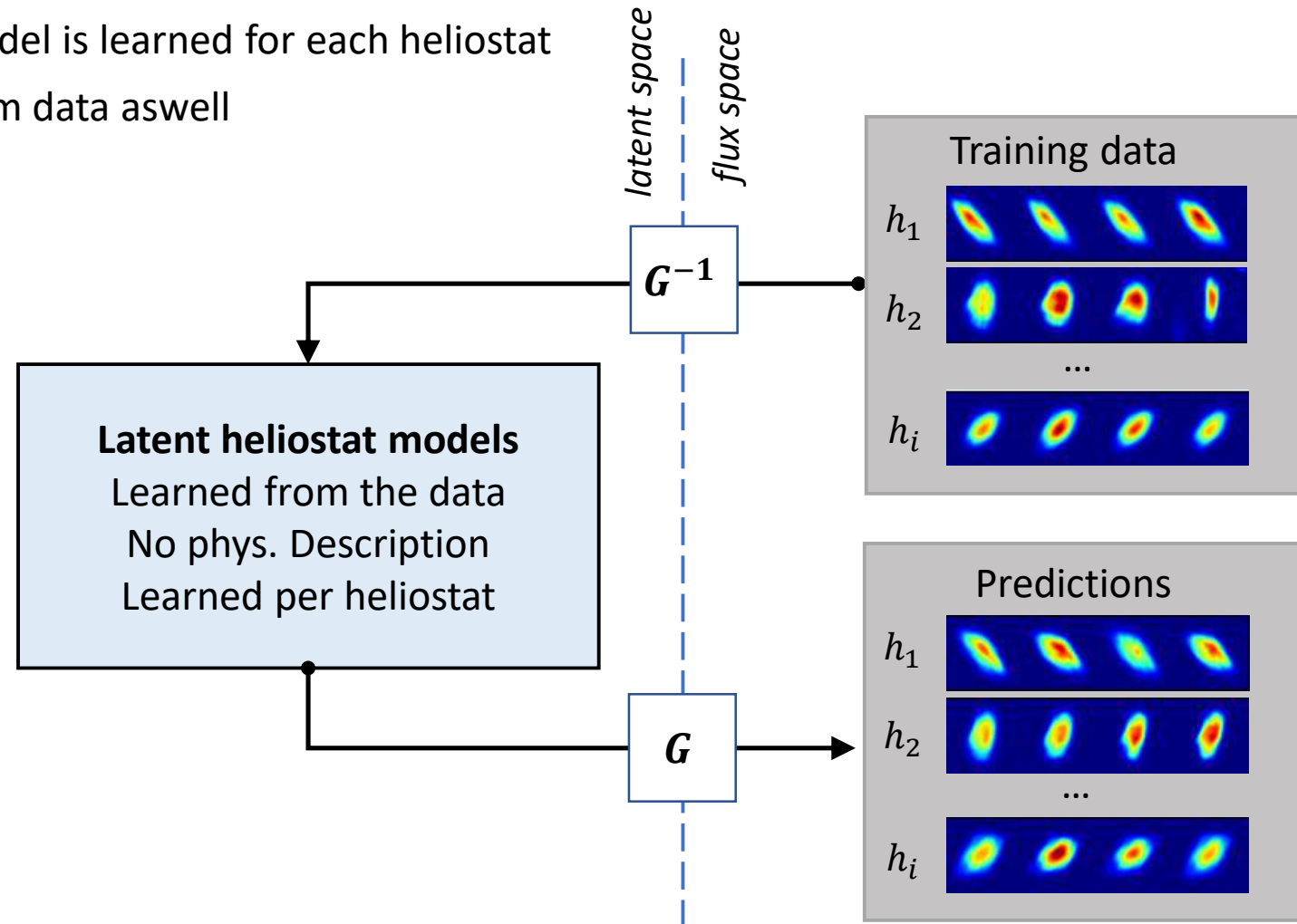
Predicting Flux Density Distributions



Smart Approach

Predicting Flux Density Distributions

- Abstract (not physically) latent model is learned for each heliostat
- Mapping function \mathbf{G} is learned from data as well

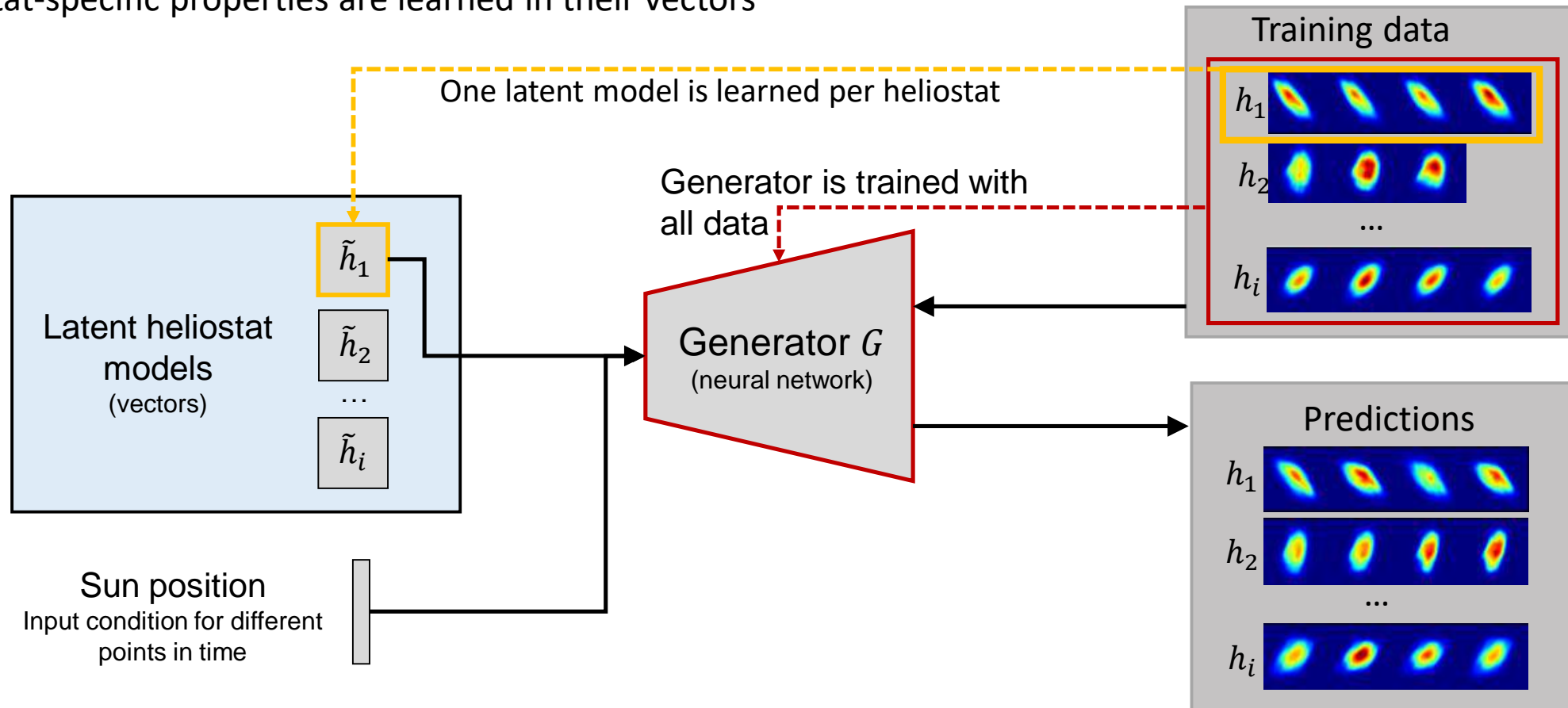


source: Kuhl M., 2023

Smart Approach

Predicting Flux Density Distributions

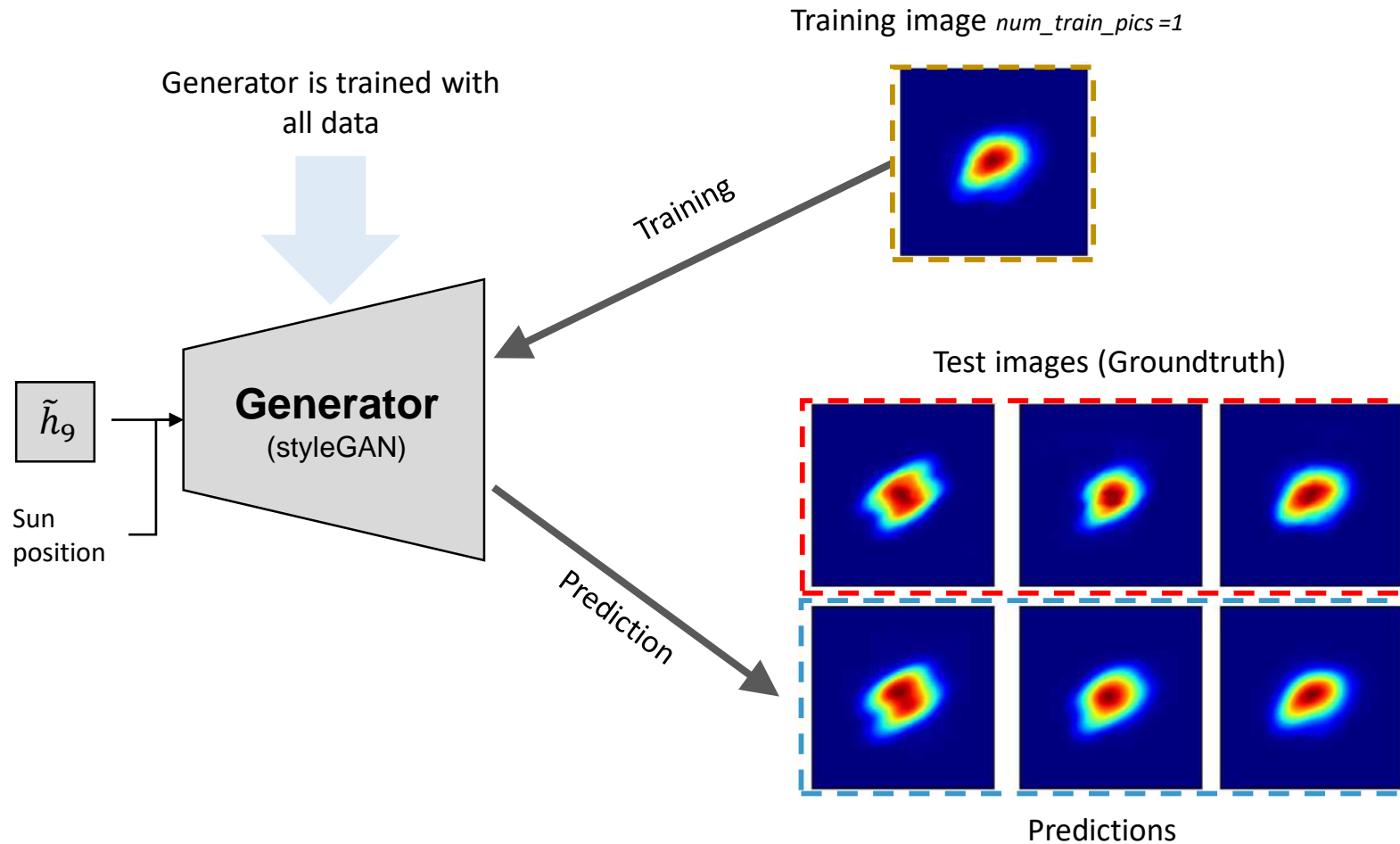
- Generator learns flux density prediction generalizing to all heliostats
- Heliostat-specific properties are learned in their vectors



source: Kuhl M., 2023

Smart Approach

Predicting Flux Density Distributions



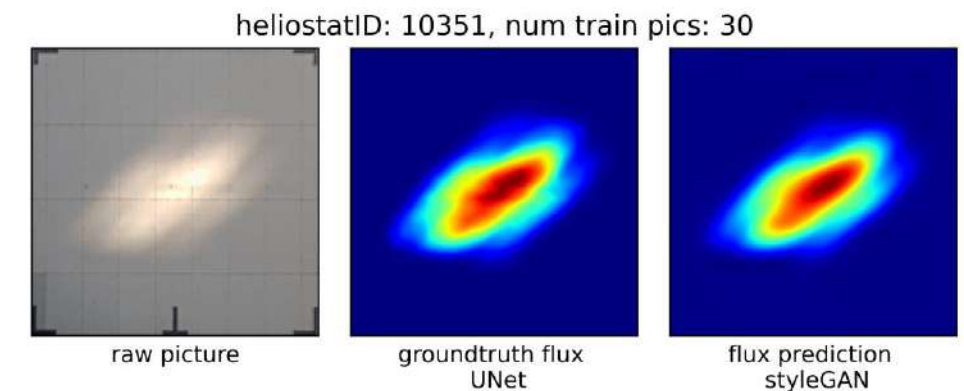
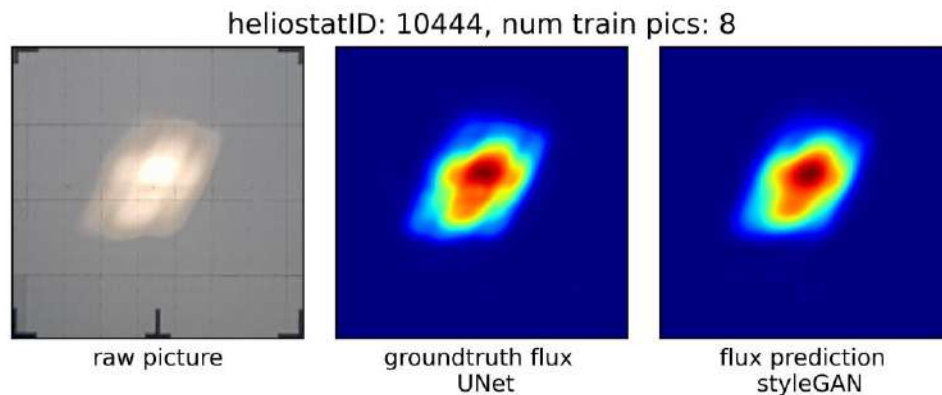
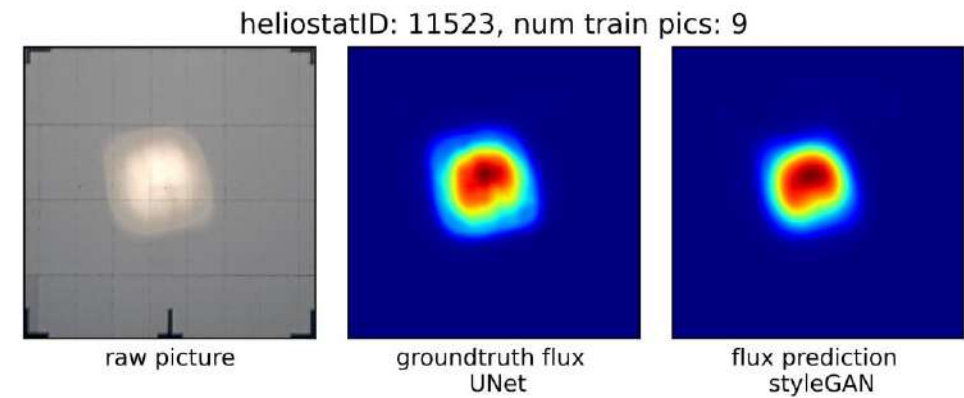
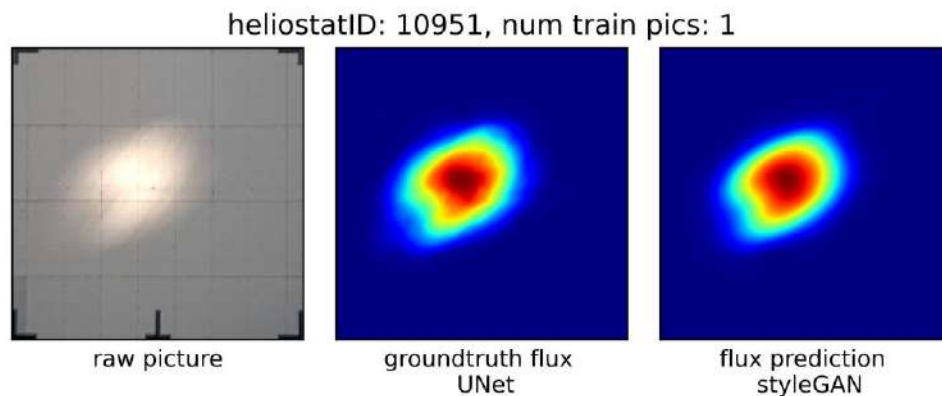
Prediction also for focal spot shapes that do not appear in the training of the heliostat

- *knowledge transfer between heliostats in the generator*



Smart Approach

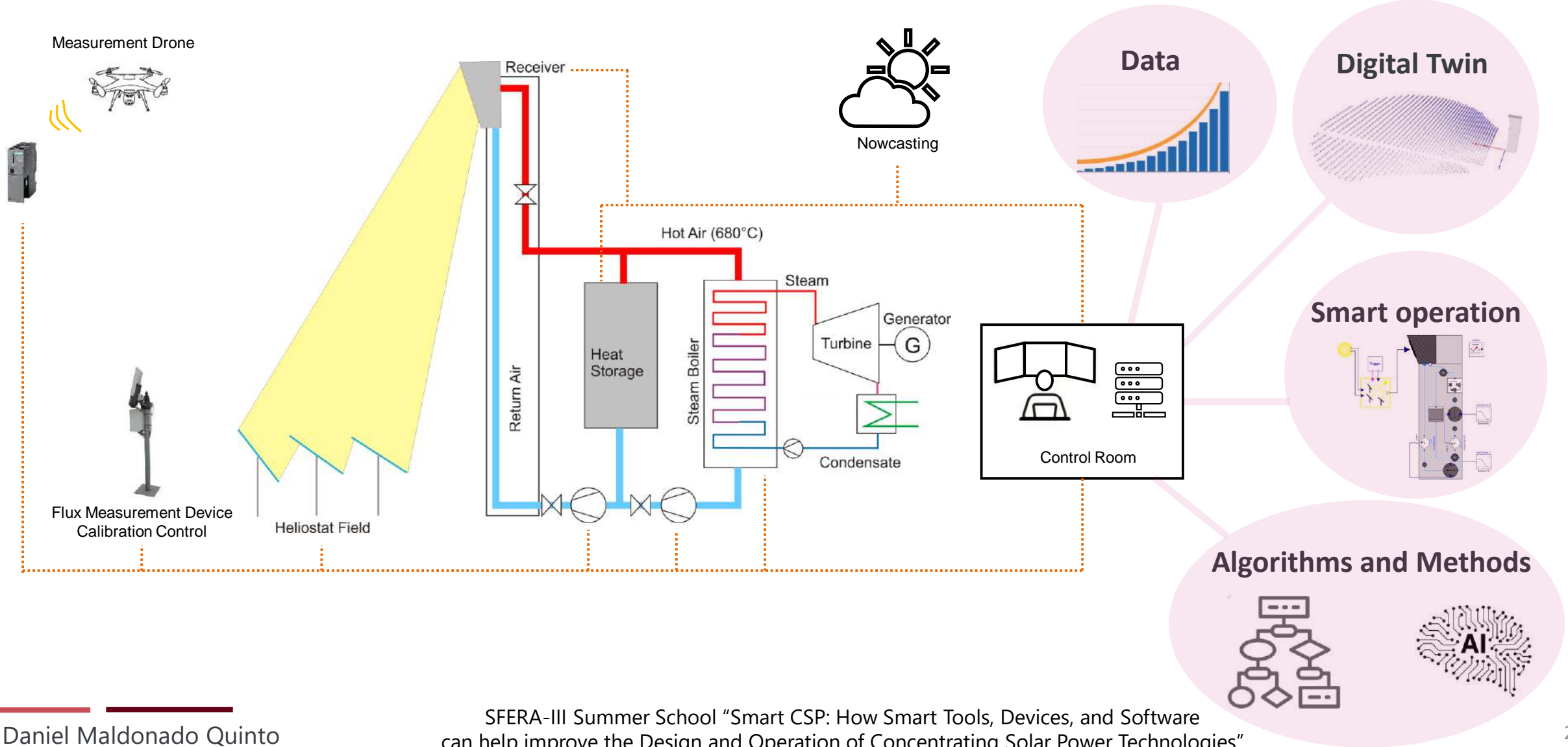
Predicting Flux Density Distributions



source: Kuhl M., 2023

Smart CSP

Interconnection of all Components and Systems



Control & Operation

- General and receiver-related safety functions
- Ability to control several different heliostat types simultaneously
- Multi-receiver operation
- Monitoring for fast and safe control of the field

Data

- Insight into heliostat states, parameters and errors
- Simple system configuration via files and database
- Display of relevant weather data like DNI and windspeed

User management

- Different user types with individual access rights



Condition Monitoring

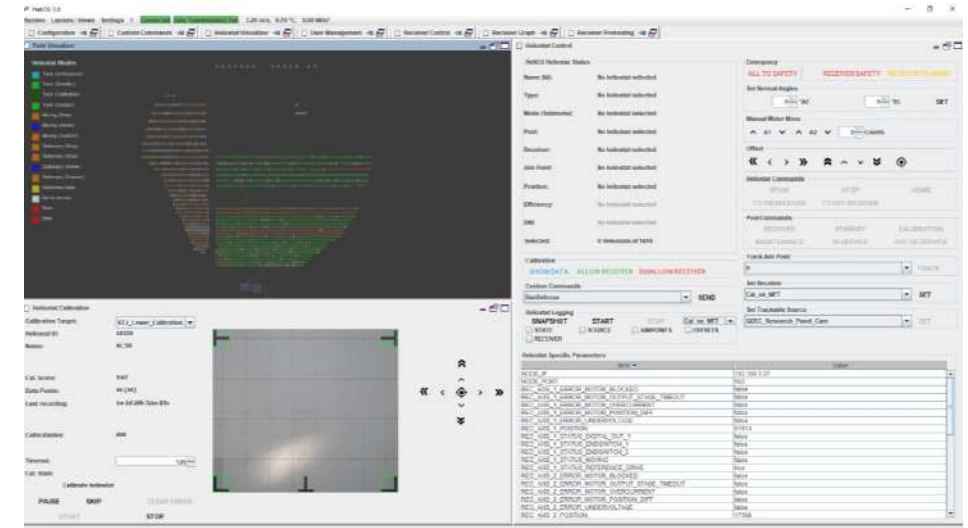
- Real-time monitoring and analysis of the plant condition
- Prioritization of maintenance work based on condition monitoring data

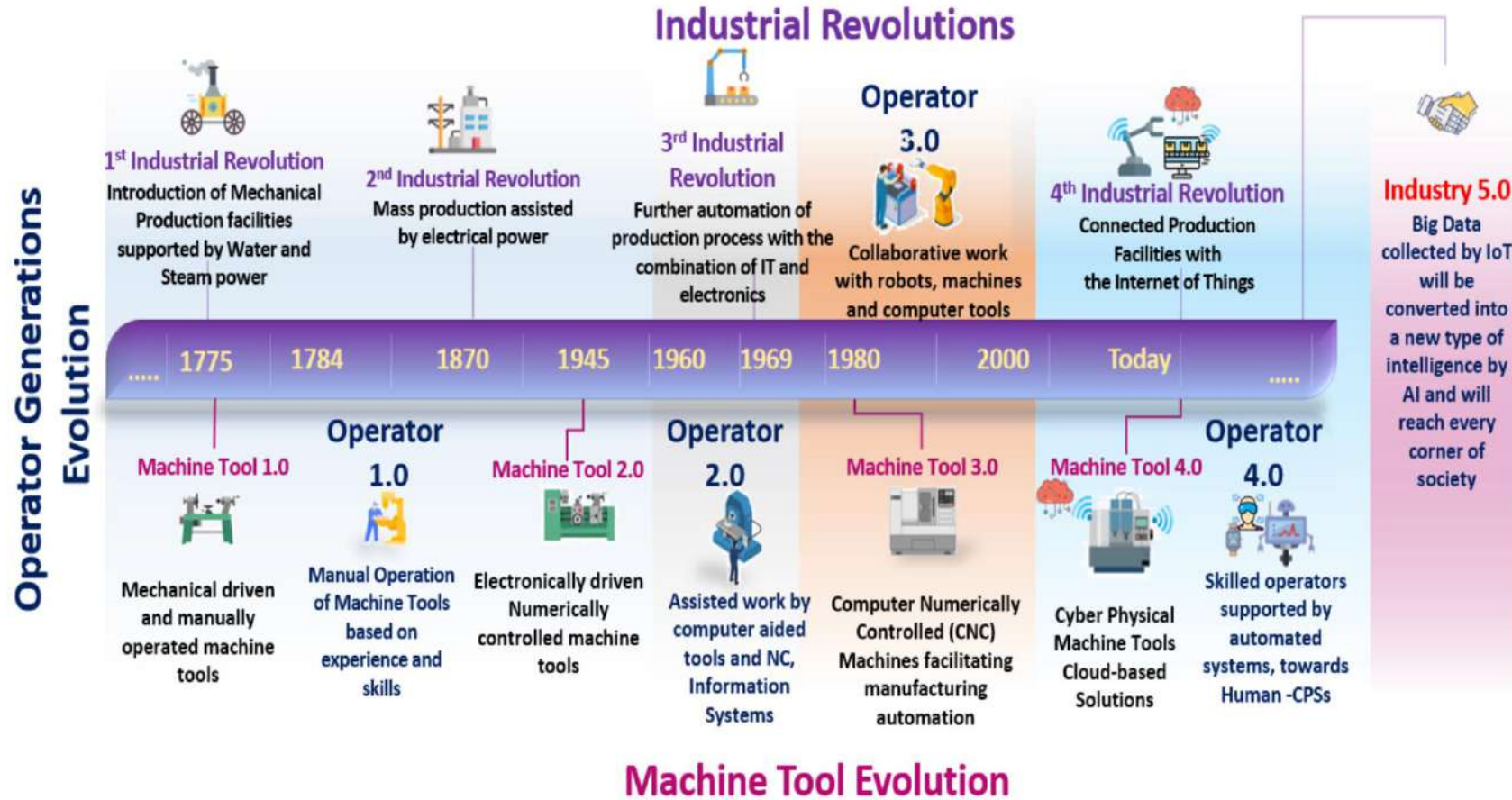
(AI-supported) Algorithms

- Heliostat path planning
- Heliostat selection for efficient operation and calibration
- On-demand receiver control and flux density distribution
- Multi-spot and anomaly detection in calibration process

Real-time

- NowCasting - Use of real-time weather data for precise energy forecasting and operational optimization
- Real-time transmission and data evaluation of e.g. drone measurements via 5G





Mourtzis, D. (2021). "Towards the 5th industrial revolution: A literature review and a framework for process optimization based on big data analytics and semantics." Journal of Machine Engineering 21(3)

Smart Tools, Devices and Software

- Are used even earlier than before, in form of digital twins
- Will be more data driven, from both simulations and measurement data of the real plant
- Will be self-adaptive to account for changes such as degradation
- Will be fully integrated/interconnected with the plant **and** the operator

CSP becomes a CPS (Cyber-Physical-System)

Thank you