Collecting datasets of PV power stations for performance analysis

Claudia Buerhop

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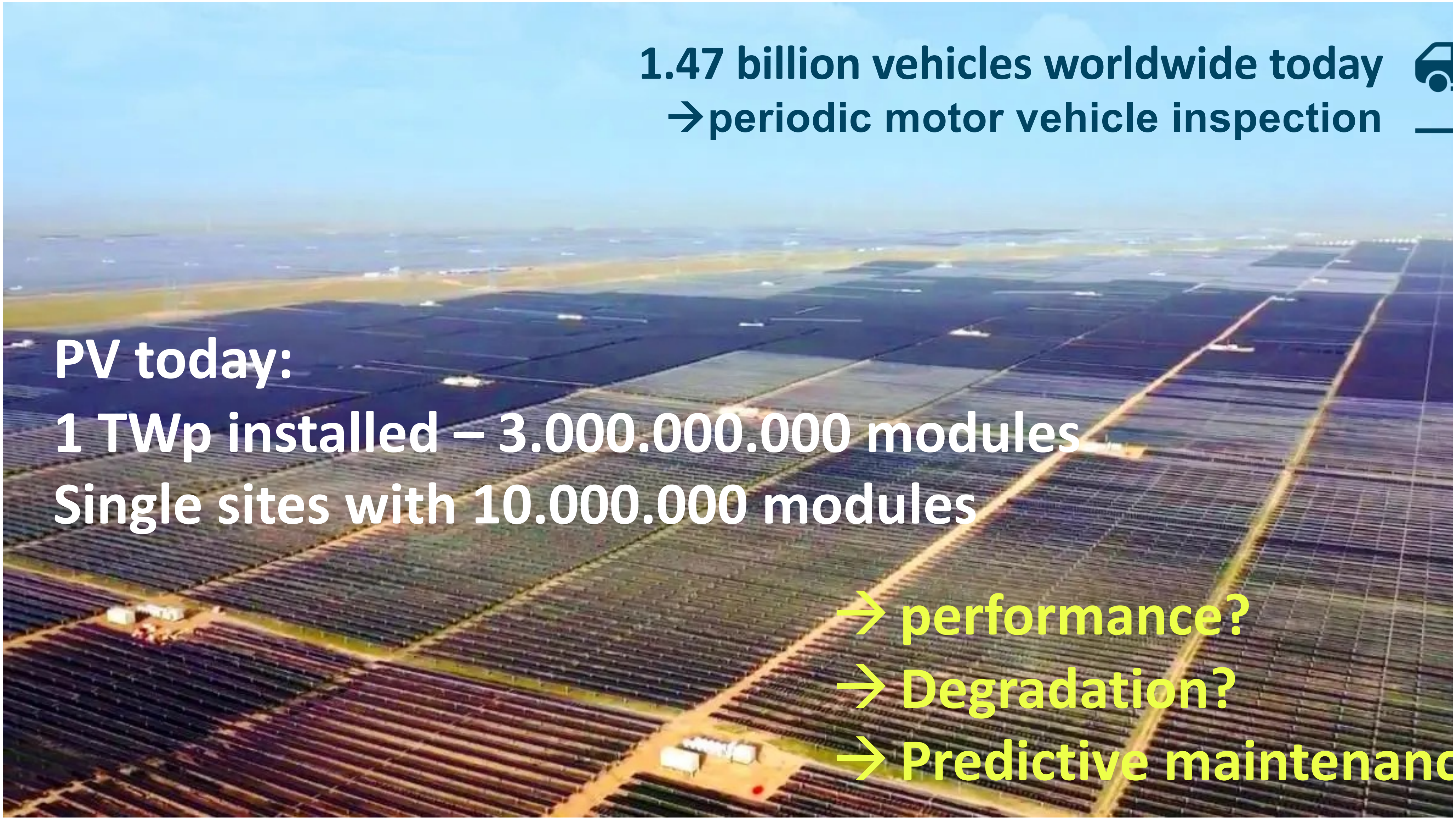
PVPMC Mendrisio, CH

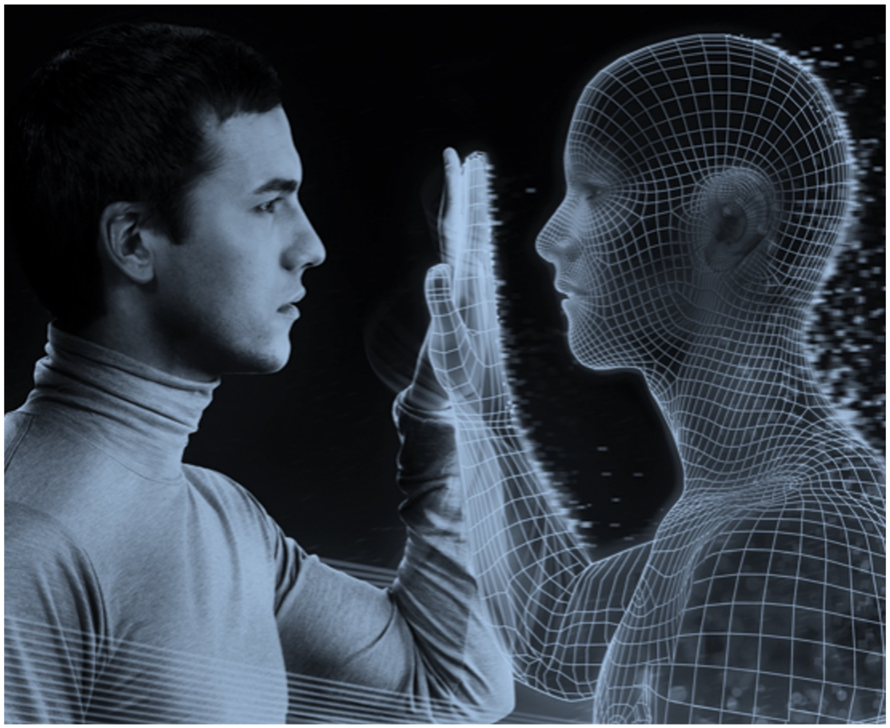
HI ERN Helmholtz Institut Erlangen Nürnberg, D-91058 Erlangen, Immerwahrstraße 2
Team High Throughput Characterization and Modelling

part of
in cooperation with


1.47 billion vehicles worldwide today
→periodic motor vehicle inspection
PV today:
1 TWp installed – 3.000.000.000 modules
Single sites with 10.000.000 modules
→ performance?
→ Degradation?
→ Predictive maintenanc

The digital twin of a PV installation

How it *should* be



- Layout / Maps the world coordinate and orientation of each element in the plant (module, inverter,..) correctly.
- Stores information for each element (BOM!) and all measurements ever performed.
- Correctly documents changes in the plant, reports.
- Historic monitoring data of adequate quality
- *As a rule, we do not find sufficient documentation.*
- **How do we get there, especially with older installations?**

Motivation

What do we need from field characterization methods?

Good & reliable, fast & affordable

Contact free

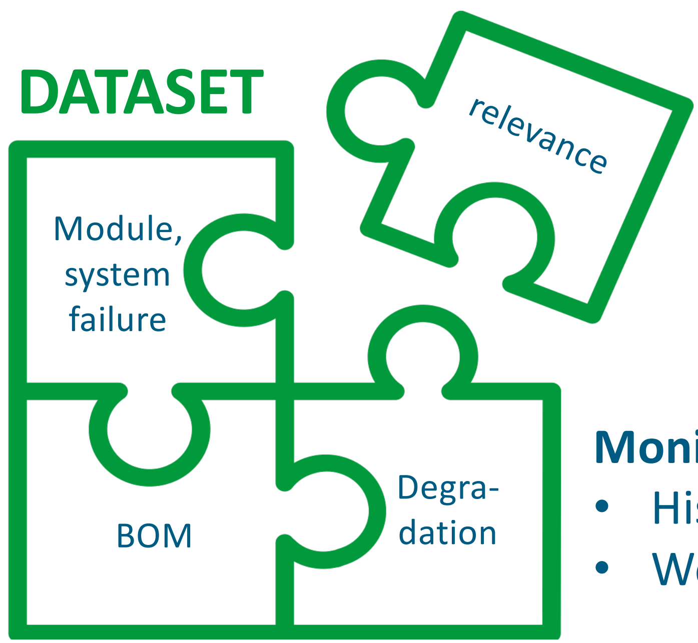
Auto-mation

Imaging methods:

- thermography –IR- + drone,
- Photoluminescence
- UV-fluorescence
- Visual inspection

optical methods:
Near-infrared spectroscopy – NIRA-

DATASET



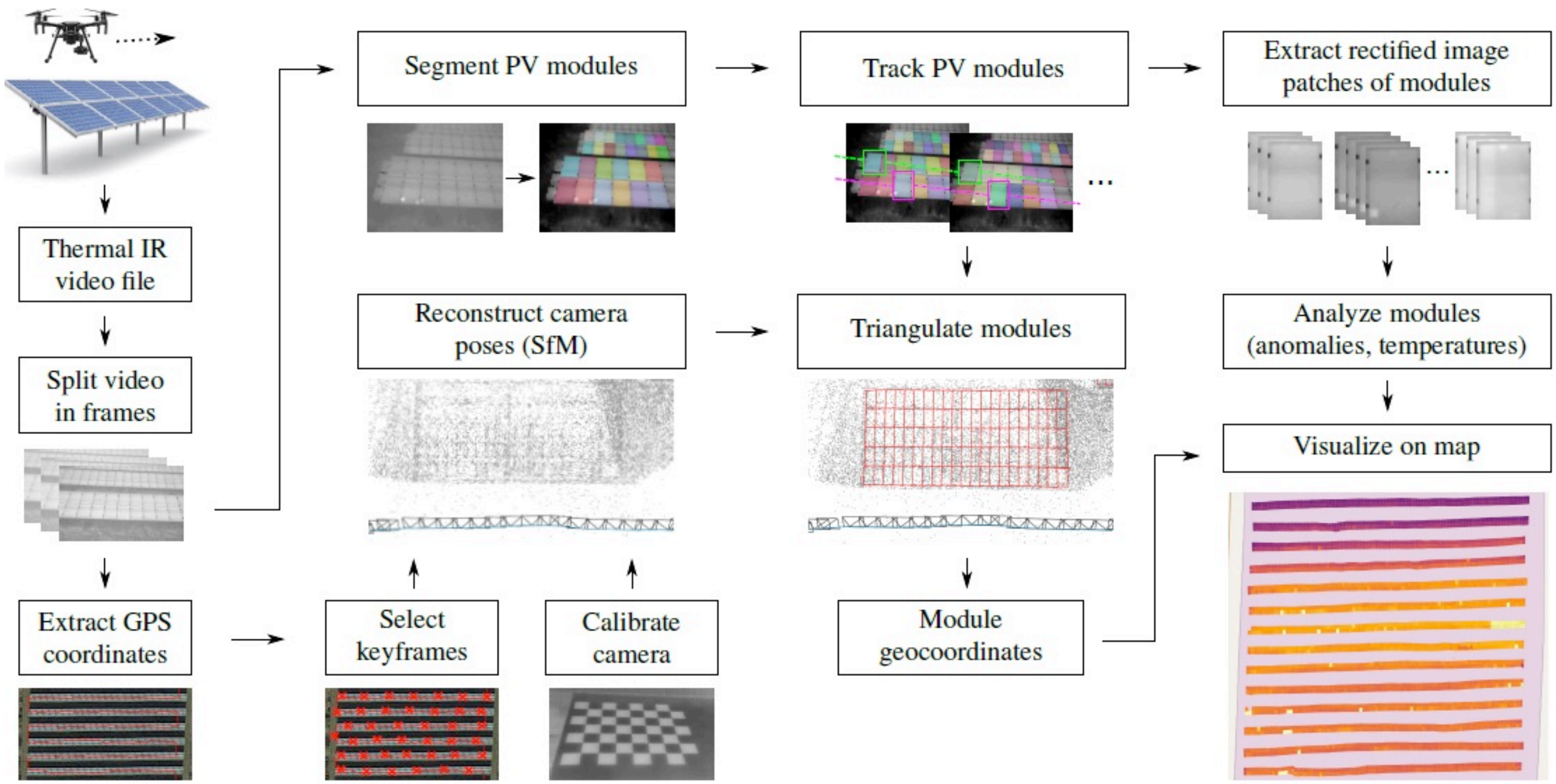
electrical methods (for verification, quantification):

- Riso
- IV-curve

Monitoring data:

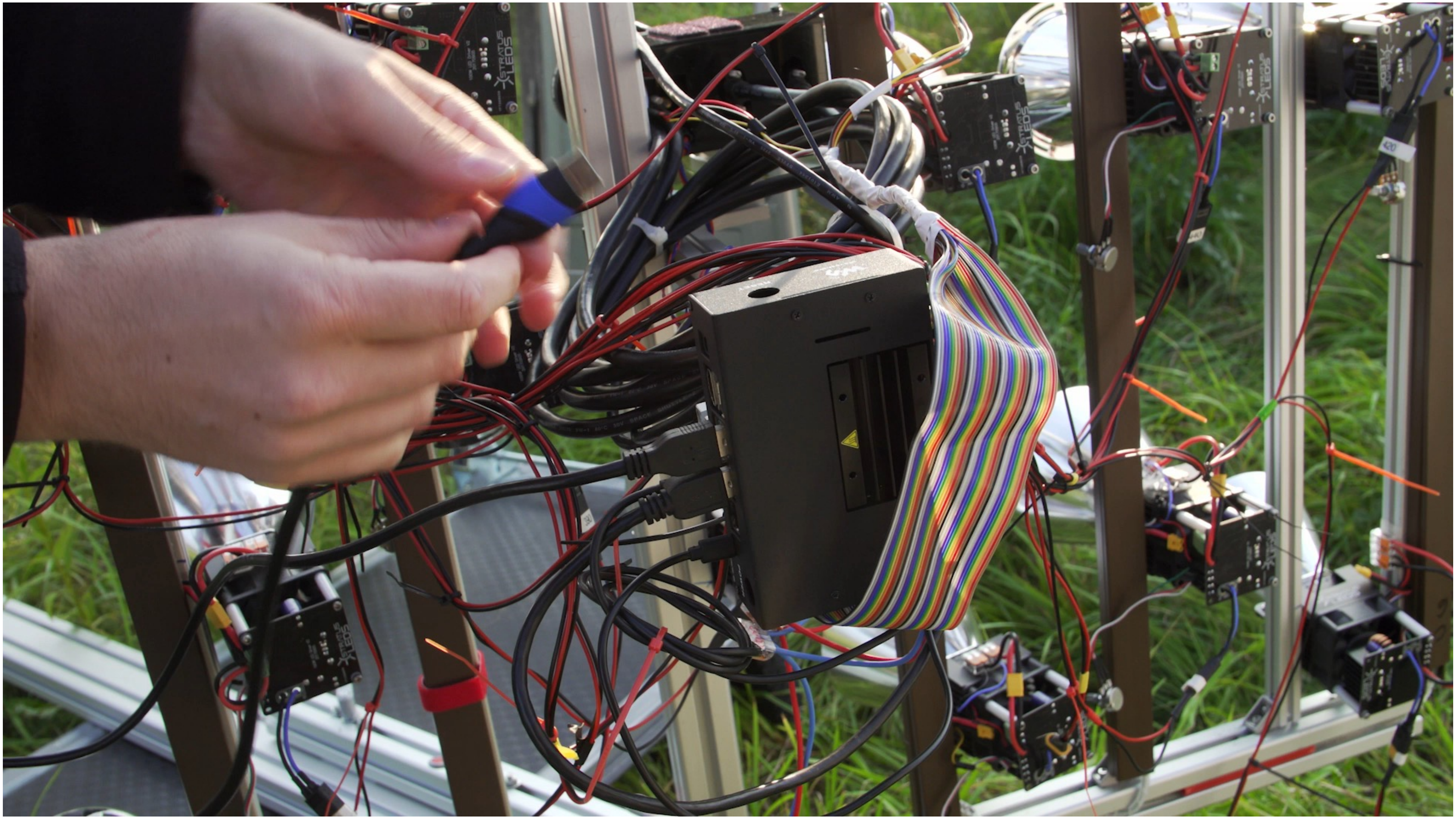
- Historic data
- Weather data

I – Localizing and identifying defects



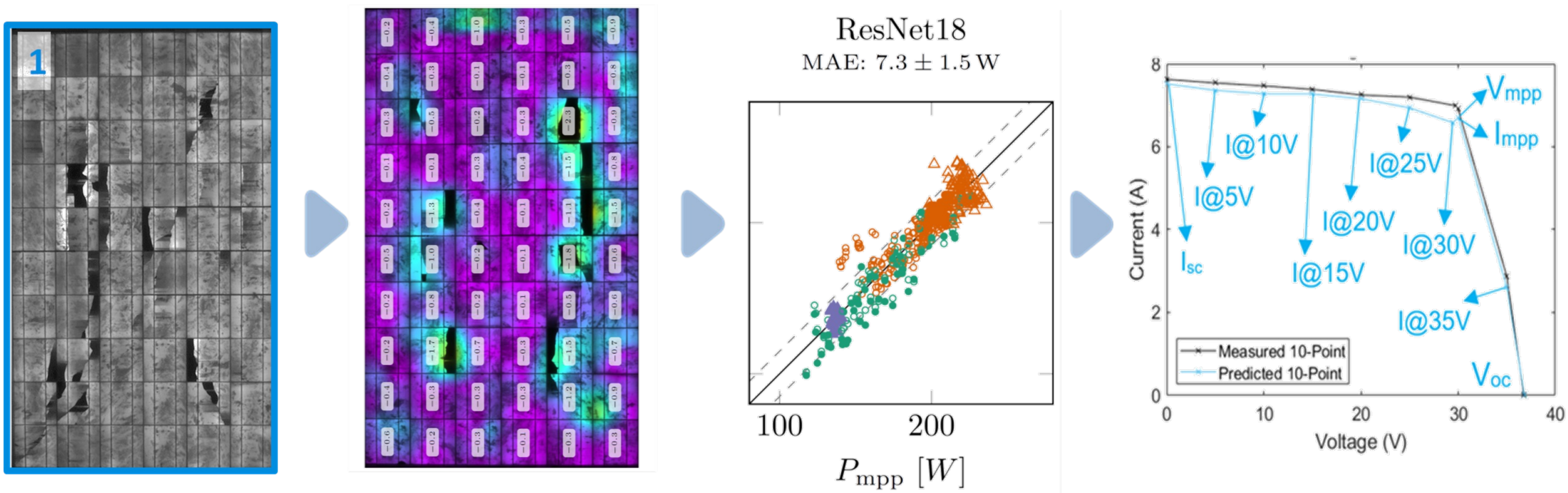
L. Bommes et al., *Georeferencing of Photovoltaic Modules from Aerial Infrared Videos using Structure-from-Motion,* minor revisions**, Progress in Photovoltaics** (2021).

https://lukasbommes.github.io/PV-Hawk/



Predicting power from luminescence images

The power of Images



The power of a module with fractured cells (EL / PL)

M. Hoffmann et al. *Deep-learning-based pipeline for module power prediction from electroluminescence measurements,* **Progress in Photovoltaics: Research and Applications** 29 (2021), 920-935.

PROGRESS IN PHOTOVOLTAICS

Bill of material –BOM-
Importance of polymers for performance and lifetime?

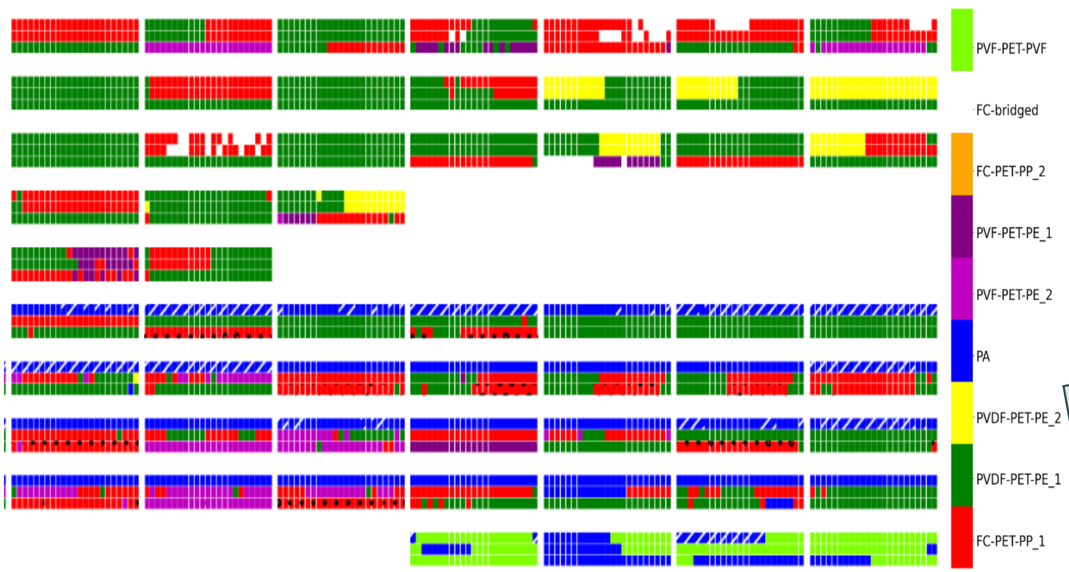
Inspection method / Module failure	*IR*	*EL/PL*
BS-type	-	-
EVA	-	-
IV-curve, Riso	-	-
PV module failure, e.g. PID	x	x
Degradation e.g. coloration, corrosion	-	-

BS: backsheet, EVA: encapsulant, PID: potential induced degradation

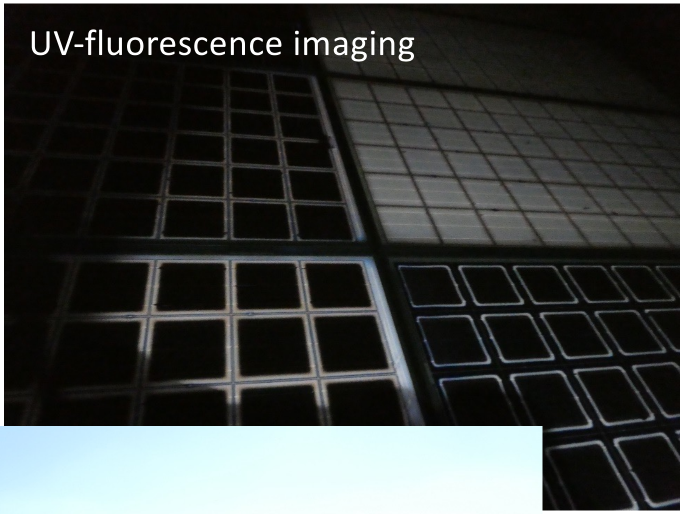
Imaging or optical methods ? → datamix

III – Field analysis of polymers

variety of polymers – backsheet and encapsulant



Map of BS-variety in a PV power station, approx 500 kWp, ca. 2200 PV modules

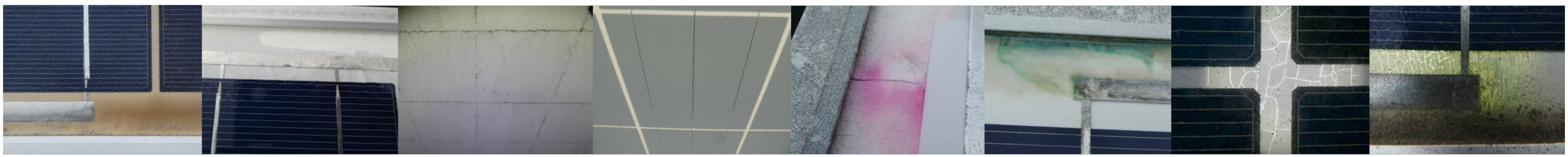


C. Buerhop-Lutz et al., *PV modules and their backsheets-A case study of a Multi-MW PV power station*, **Solar Energy Materials and Solar Cells** 231, 111295 (2021).

III – Field analysis of polymers

visual anomalies

any	any	PA	PA	PA	PA, FC	FC	FC



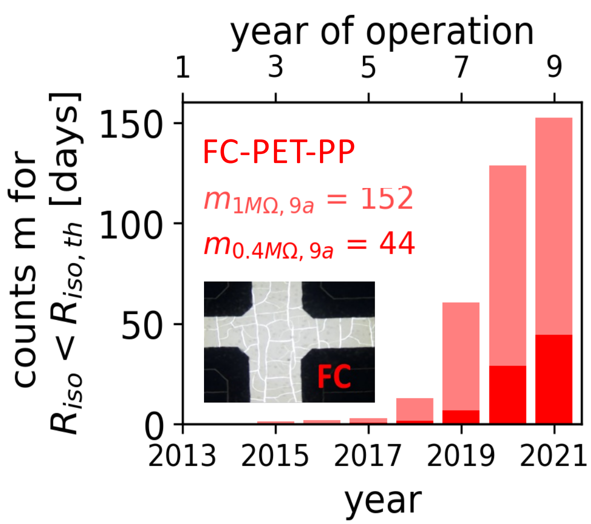
coloration	delamination	square cracks	open cracks	corrosion	corrosion	Inner cracks	Inner cracks +corrosion

- ➢ Power loss
- ➢ Safety issues
- ➢ Inverter tripping
- ➢ Module failures

?!

III – Field analysis of polymers

relevance – insulation resistance, ground impedance

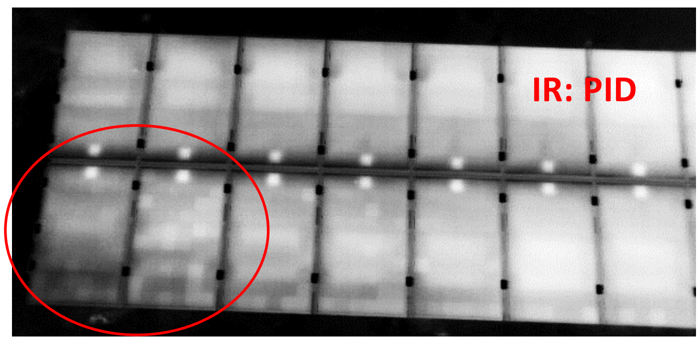


$R_{iso} < R_{iso,th} = 0.4\ M\Omega \rightarrow$ inverter tripping, no connection to grid, no feed-in

C. Buerhop-Lutz et al., *Evolution of inverter ground impedances for PV modules with various backsheet types* **Progress in Photovoltaics** (2022).

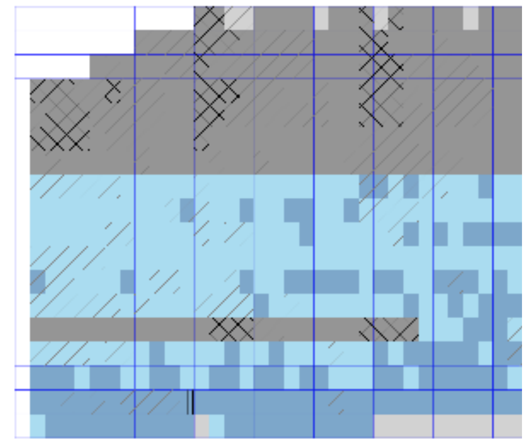
Multi-dimensional dataset

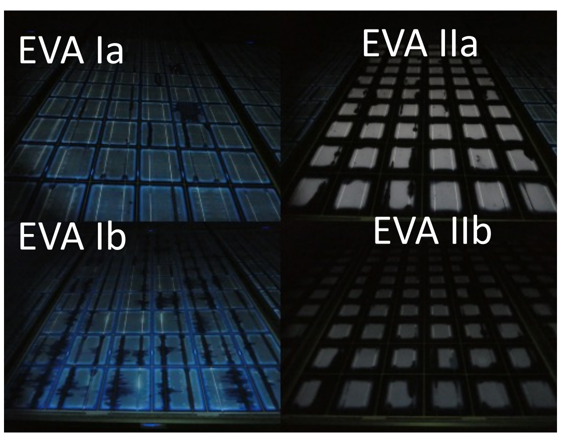
module failure – formation of PID



Backsheet: PET-PET-PE
UV-imaging: 4 EVA types
PCA:
EVA IIa → PID (2% modules, 20% strings)
EVA IIb → coloration
EVA Ia+b → nothing
Map: distribution of EVA types

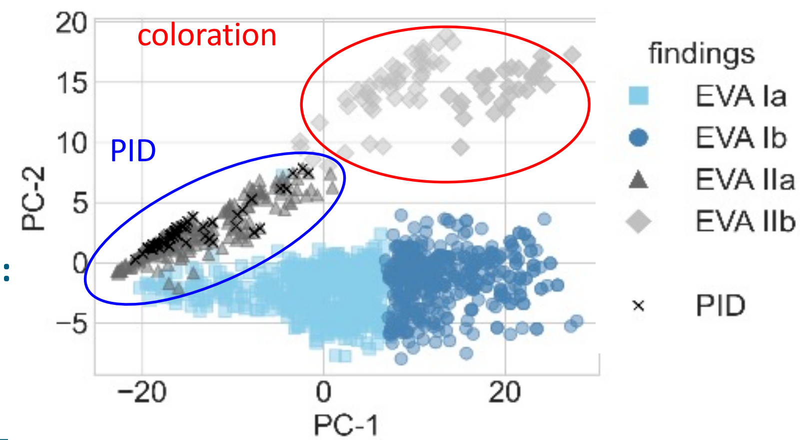
Map of EVA type and PID





UV:
EVA types

PCA analysis of UV-images: EVA types vs. observations



C. C. Buerhop*, T.P., O. Stroyuk*, et al: Energy Science & Engineering, 2023, doi: 10.1002/ese3.157_.,

Imaging methods → dataset of various data

Inspection method / Module failure	*IR*	*EL/PL*	*Visual inspection*	*NIRA*	*UV-imaging*	*Riso measurement*
BS-type	-	-	(x)	x	(x)	-
EVA	-	-	-	x	x	-
Riso	-	-	-	-	-	x
PV module failure, e.g. PID	x	x	-	-	(x, cell cracks)	-
Degradation e.g. coloration, corrosion	-	-	x	-	-	-

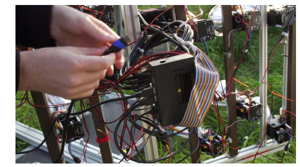
BS: backsheet, EVA: encapsulant, PID: potential induced degradation

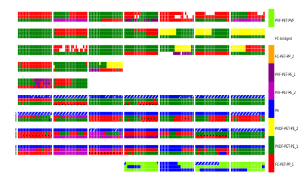
SUMMARY

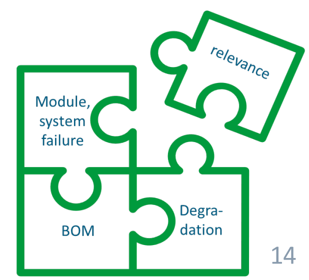
De-risking PV installation for high performance and long lifetime

- Dataset of optical methods (independent of availability of reports or historic data)
  - Digitalization of PV fields down to module level,
  - Identification, localization of anomalies in PV fields
  - Evaluation and quantification using ML-algorithms
  - Identification of anomalies before they may cause an issue in the future

Predictive maintenance: data → decision-making → action







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Thank you for your attention!

Contact:
Dr. Claudia Buerhop-Lutz
at FZJ, HI ERN, Erlangen, Germany,
email: c.buerhop-lutz@fz-juelich.de

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