

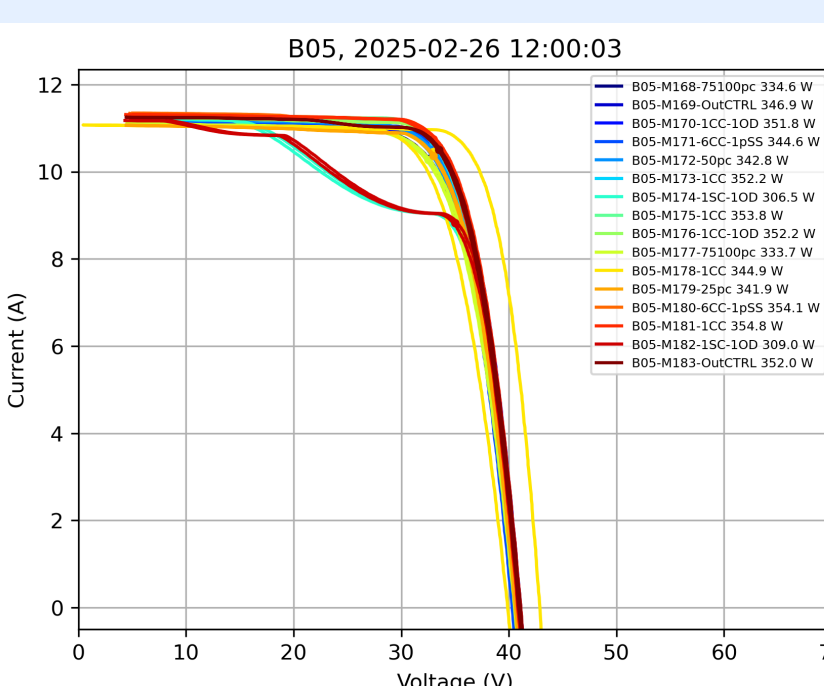
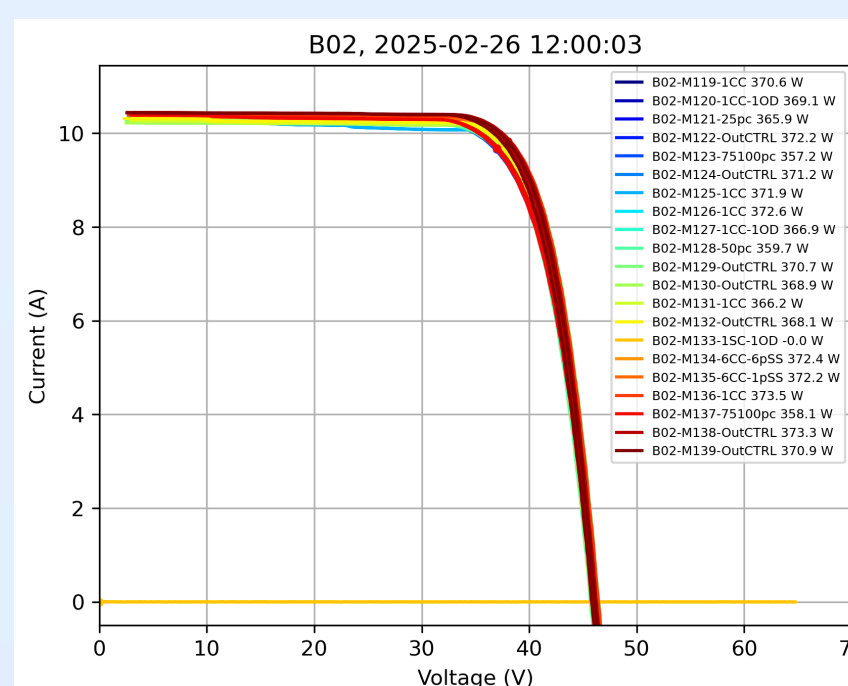
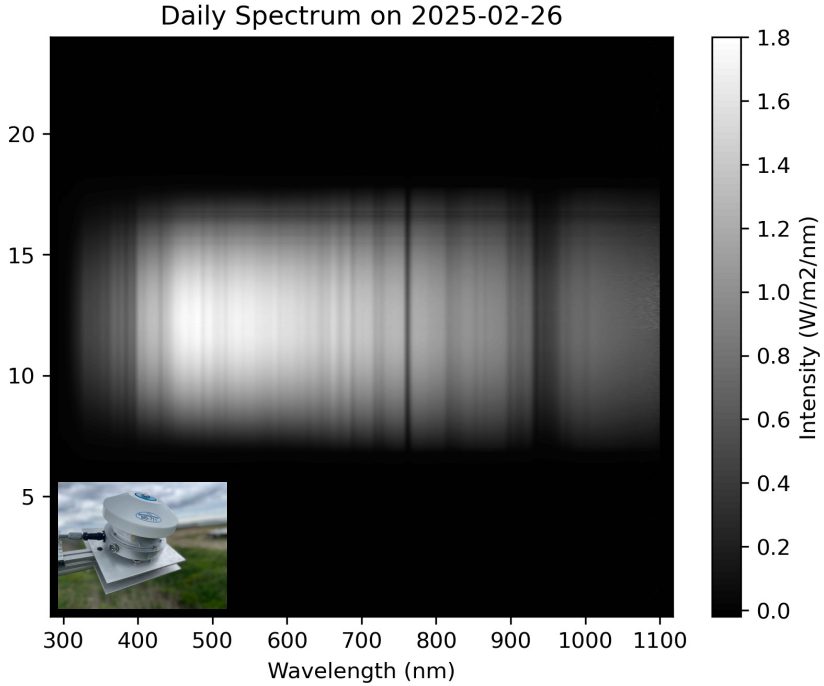
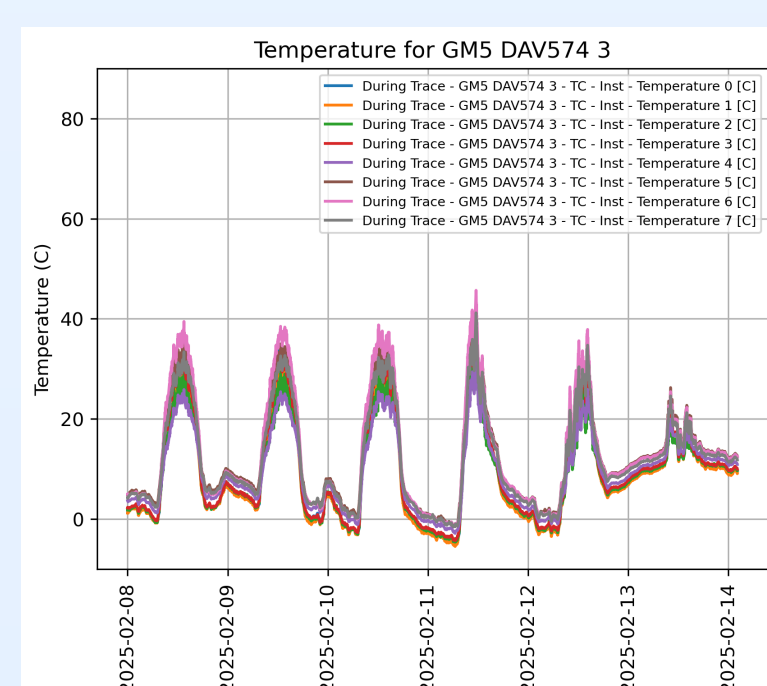
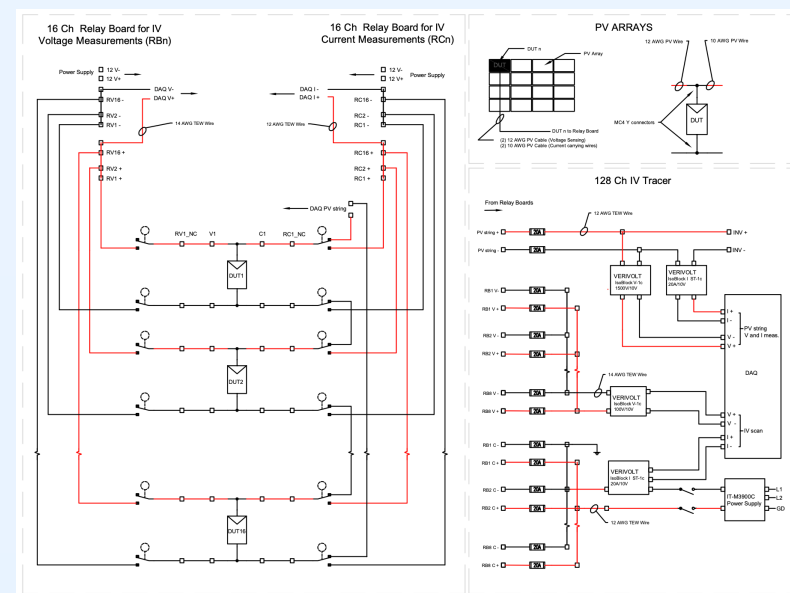
INTRODUCTION

- We present approx. 1 year of outdoor testing data on new PV modules with and without cell cracks.
- A variety of modern modules (8 unique BOMs) were admitted to the study.
- Emphasis on acquiring n-type TOPCon and HJT modules. PERC also included for comparison.
- Samples received a variety of cracking stress, from 0% to 100% cracked cells.
- 104 modules deployed outdoors, starting in April 2024.

BOM	Cell Technology	Back glass (BG) Back sheet (BS)	Number of Busbars	Number of Cells	Nameplate Pmp W	Number of Samples
B01	n-HJT	BS		20	80	410
B02	n-TOPCon	BS		6	144	415
B03	n-TOPCon	BG		6	144	565
B04	n-TOPCon	BG		16	144	570
B05	p-PERC	BS		12	132	400
B06	n-TOPCon	BS		6	144	445
B07	n-TOPCon	BS		10	144	535
B08	p-PERC	BS		6	144	545

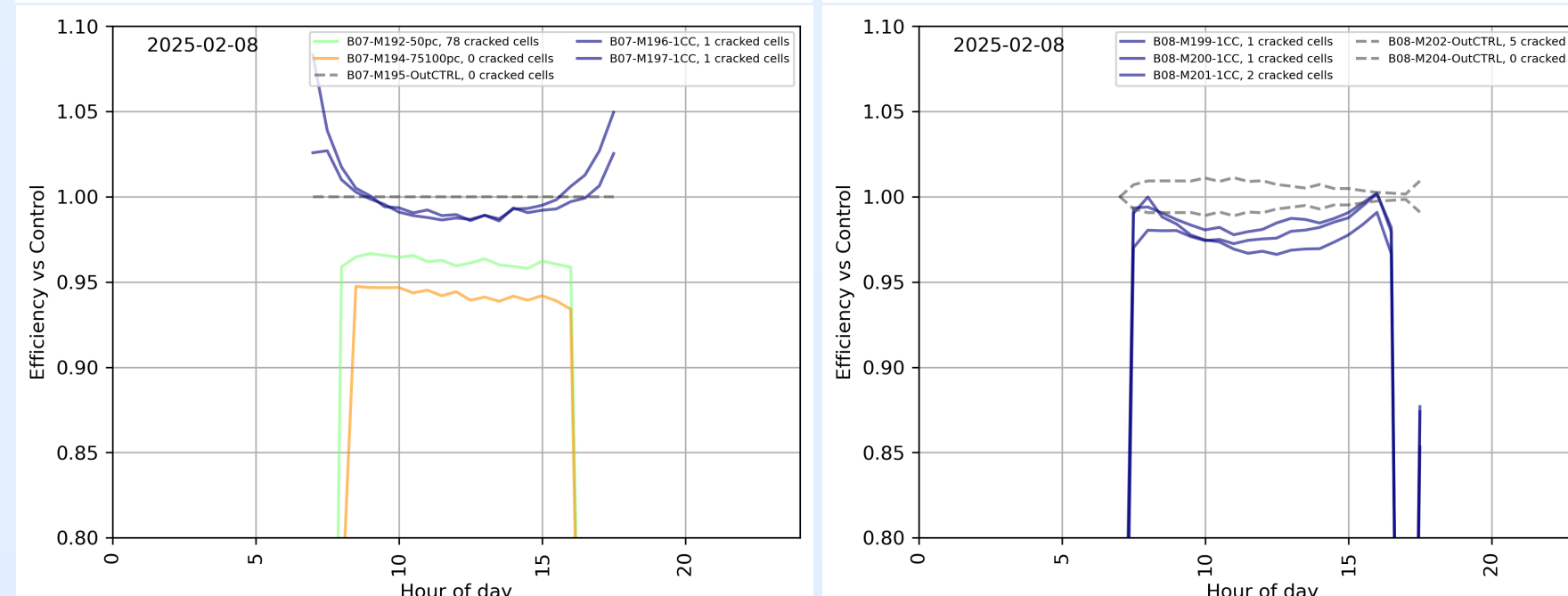
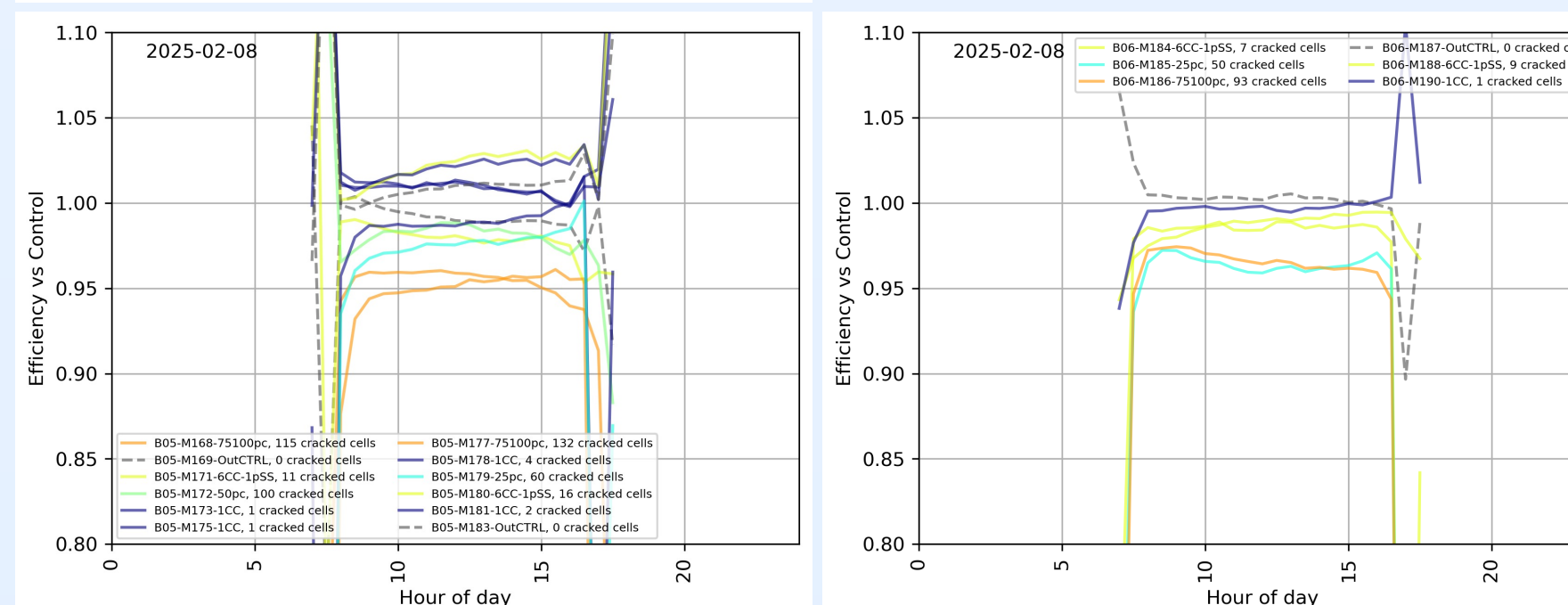
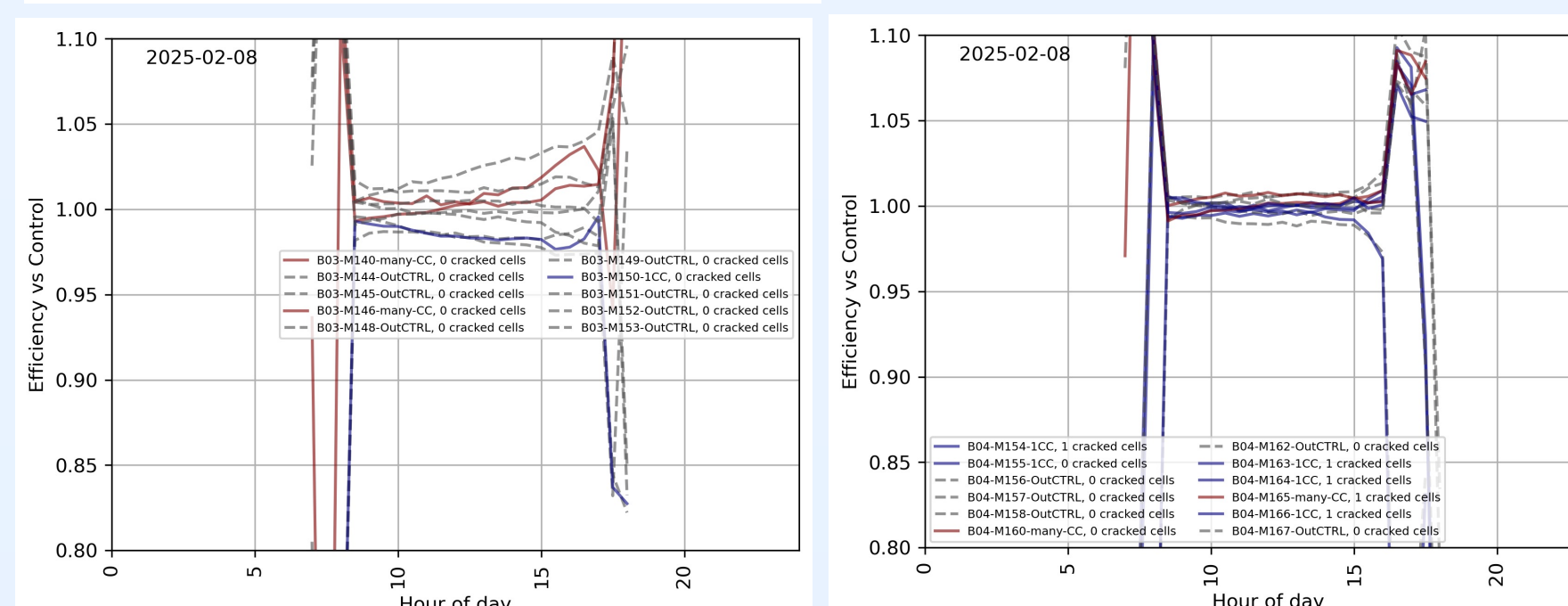
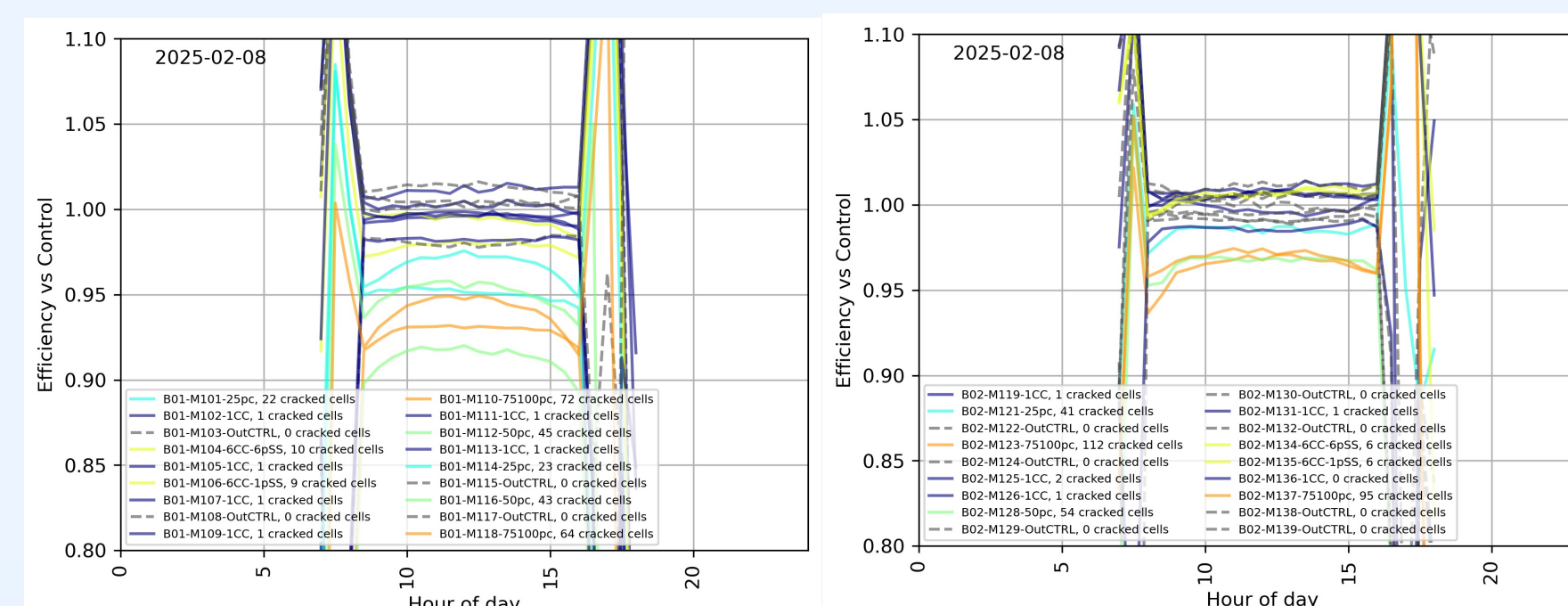
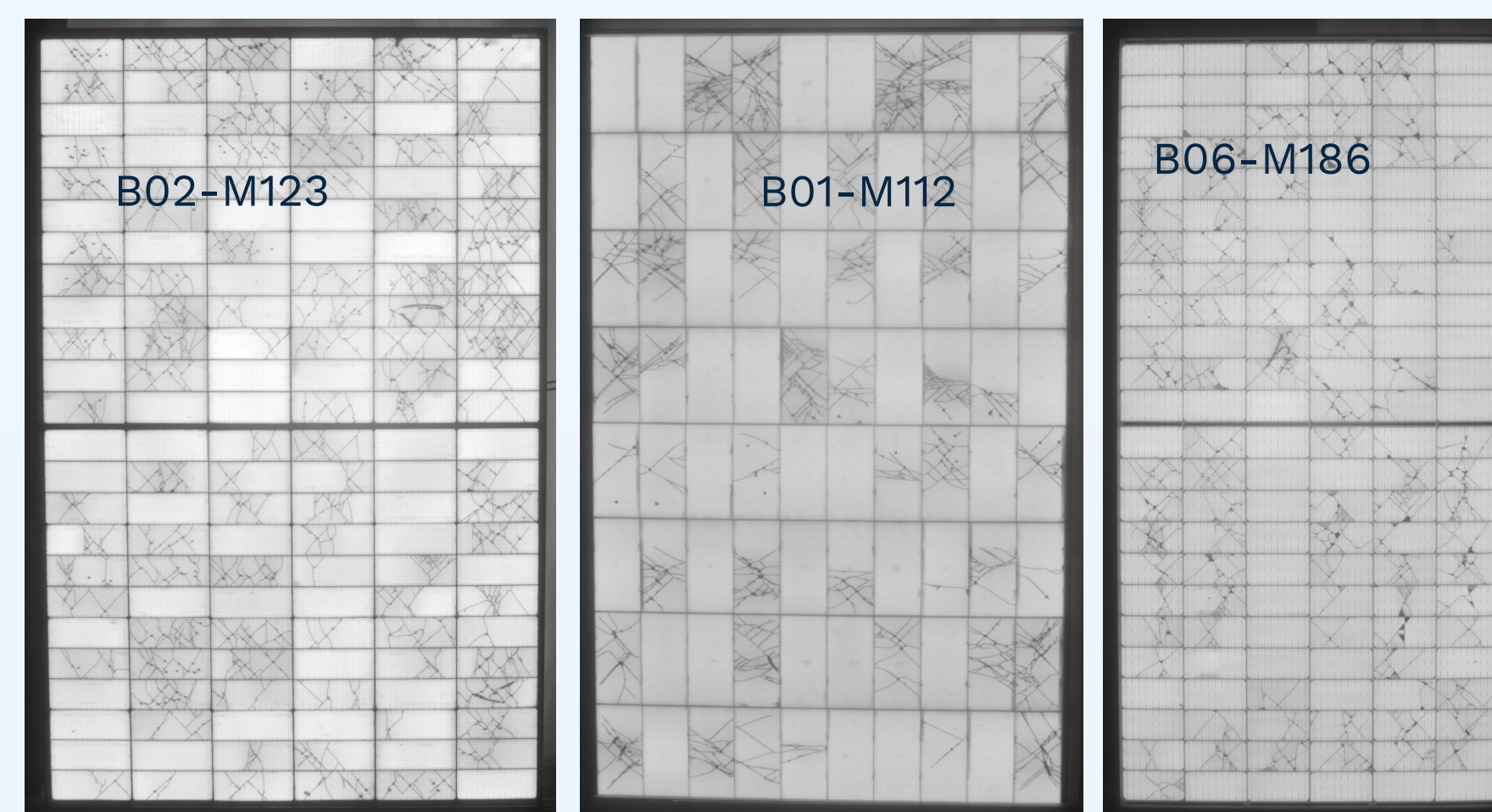
INSTALLATION AND DATA COLLECTION

- Giant 128 -> 1 switchboard uses a single IV tracer to cycle through and trace each module individually.



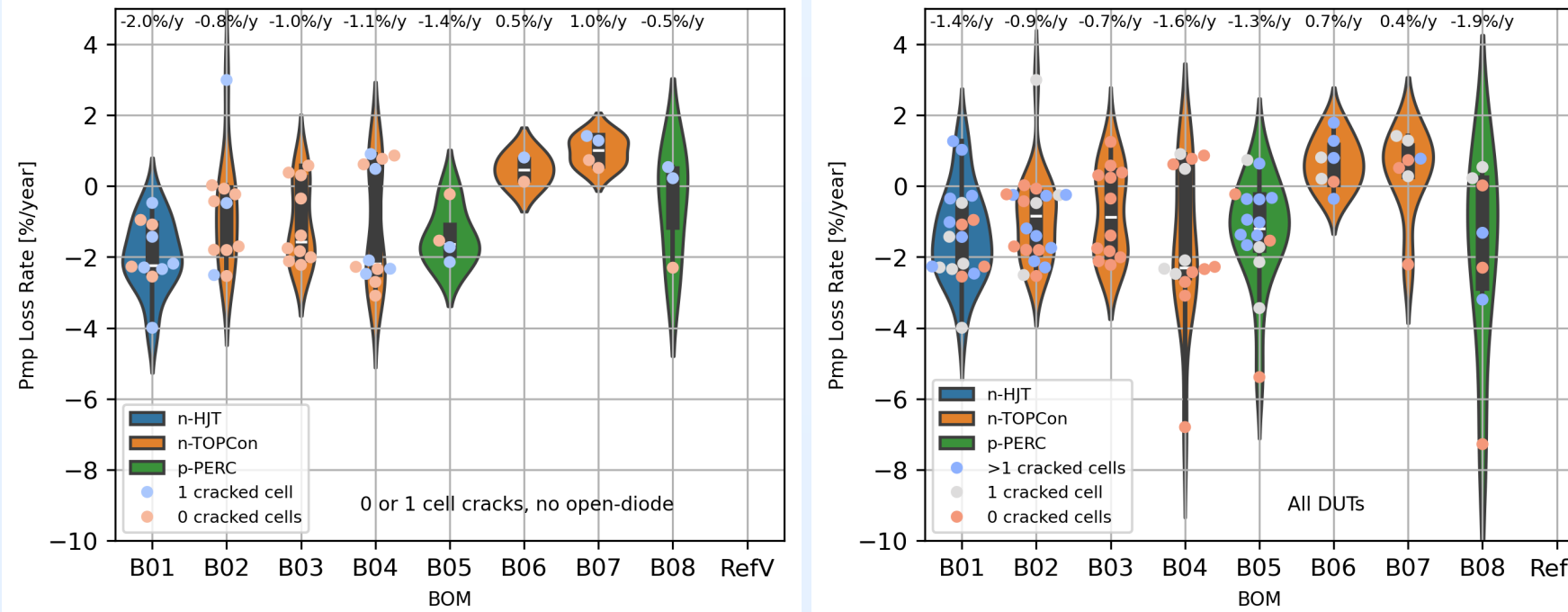
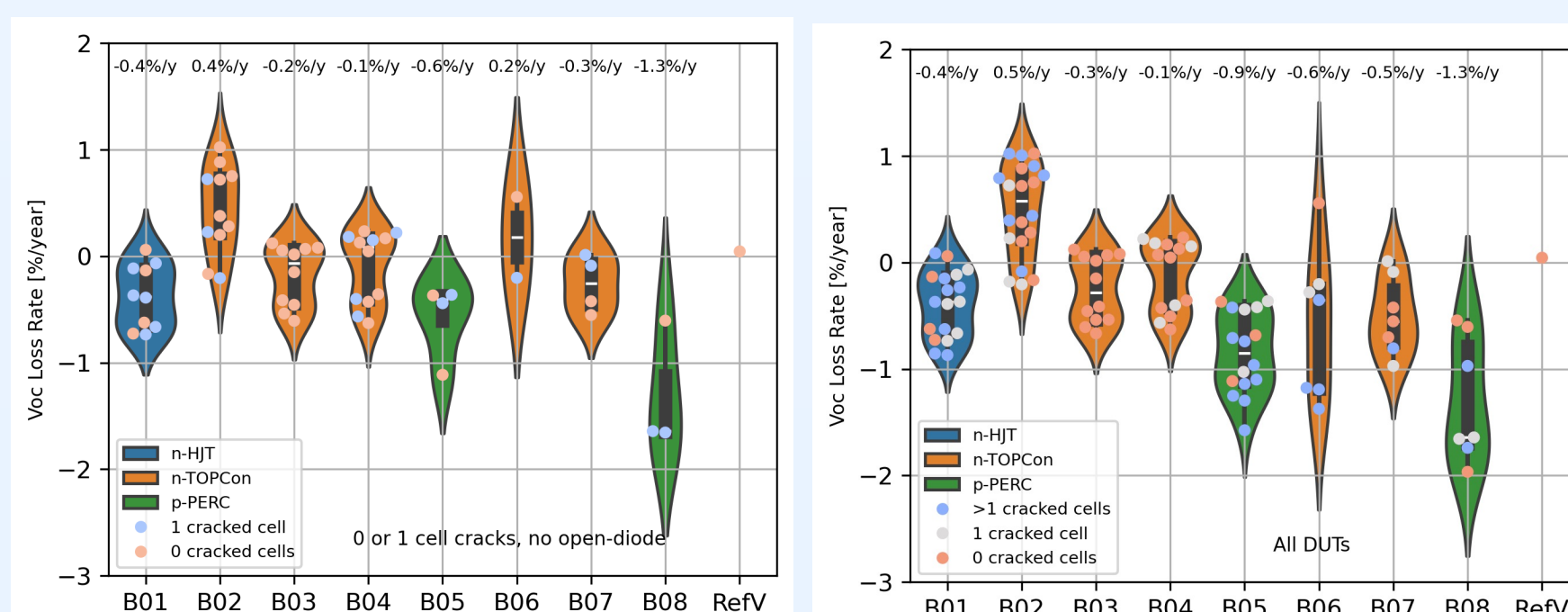
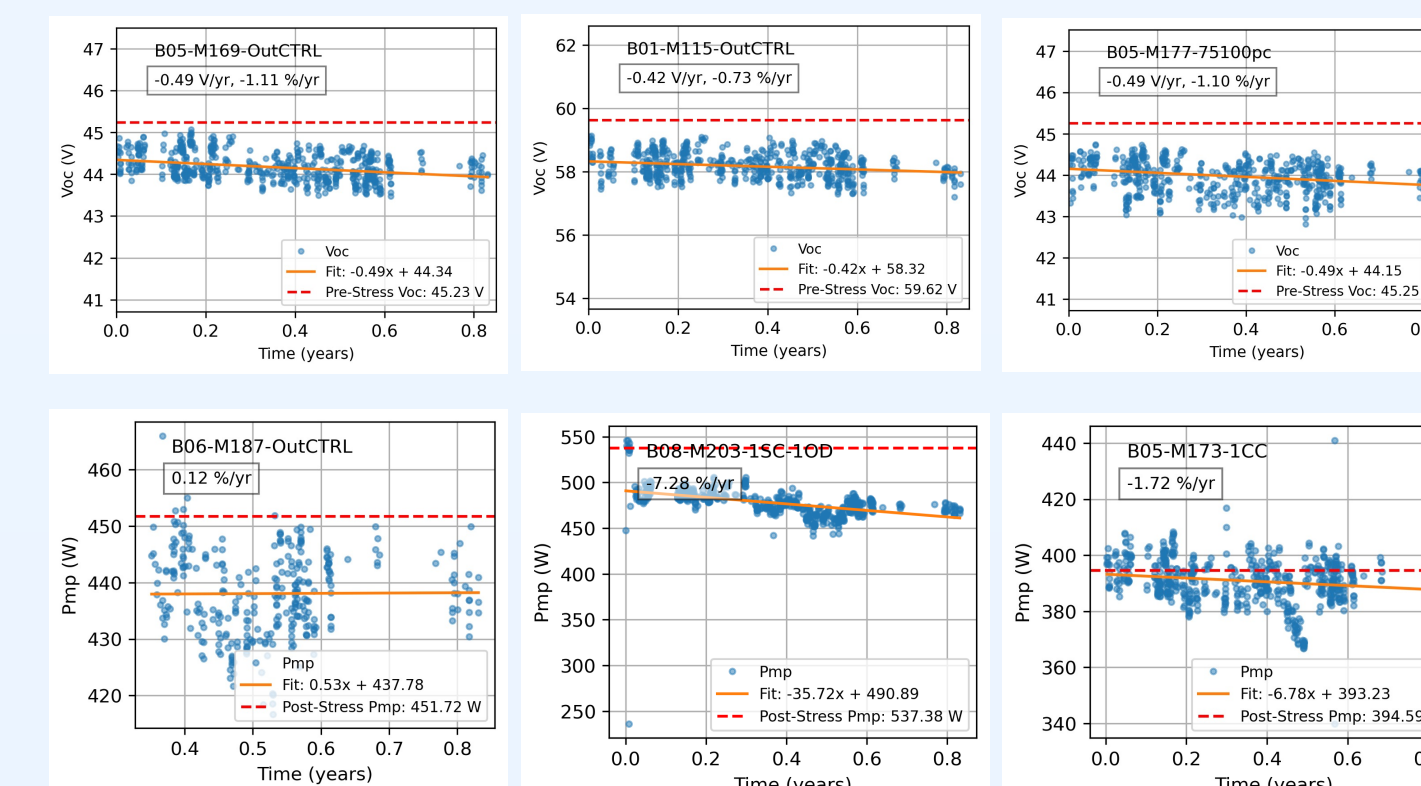
EFFECT OF CRACKS ON POWER

- Do cracks cause underperformance? *Yes but it's smaller than you'd think!*
- Worst case seems to be around 8% under-performance in Pmp for a single module (does not take into account effect on large arrays). Most cracked modules under-perform by less than 4%.
- Analyze by comparing irradiance-corrected Pmp to the irradiance-corrected Pmp of the outdoor controls (with no cracks).
- Examples of highly cracked modules.



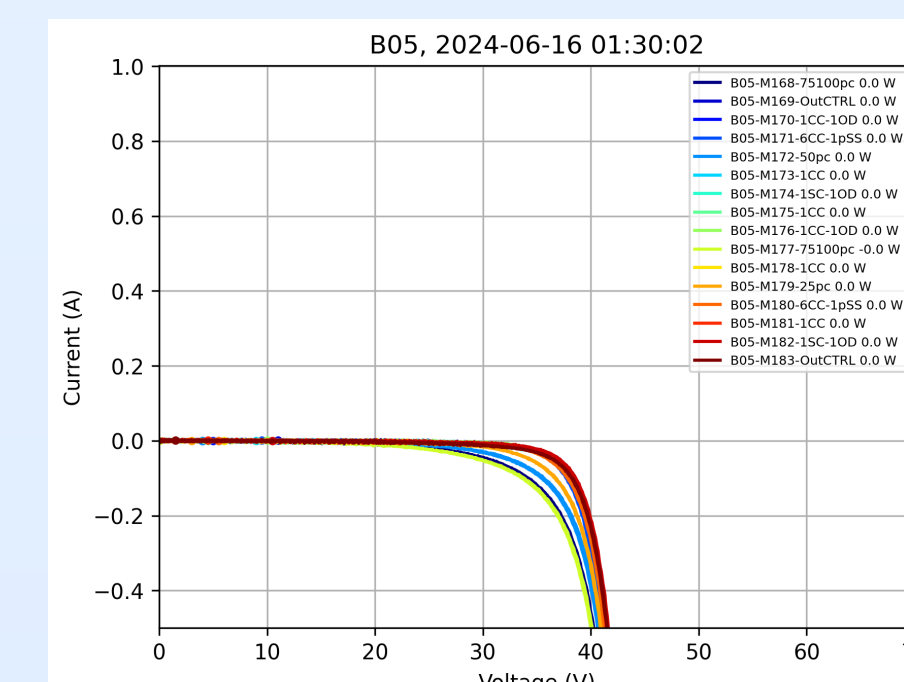
DEGRADATION

- Calculated voltage and power degradation rate.
- Used a single temperature and irradiance sensor to correct all DUTs.
- Voc loss is less sensitive to soiling and irradiance errors, thus more robust to making yearly trends compared to Pmp.
- Voc and Pmp loss rates are similar for cracked and un-cracked modules.
- Voc loss rate for TOPCon and PERC BOMs is better than -0.5%/yr,
- Note: typical warranty for TOPCon: <1% first year, <0.4%/year after.
- Highest mean Pmp loss rate for TOPCon BOMs is around -1% for first year.
- However, many DUTs (even control samples) exceed -2% power degradation in first year.



DARK IV – EFFECT OF CRACKS

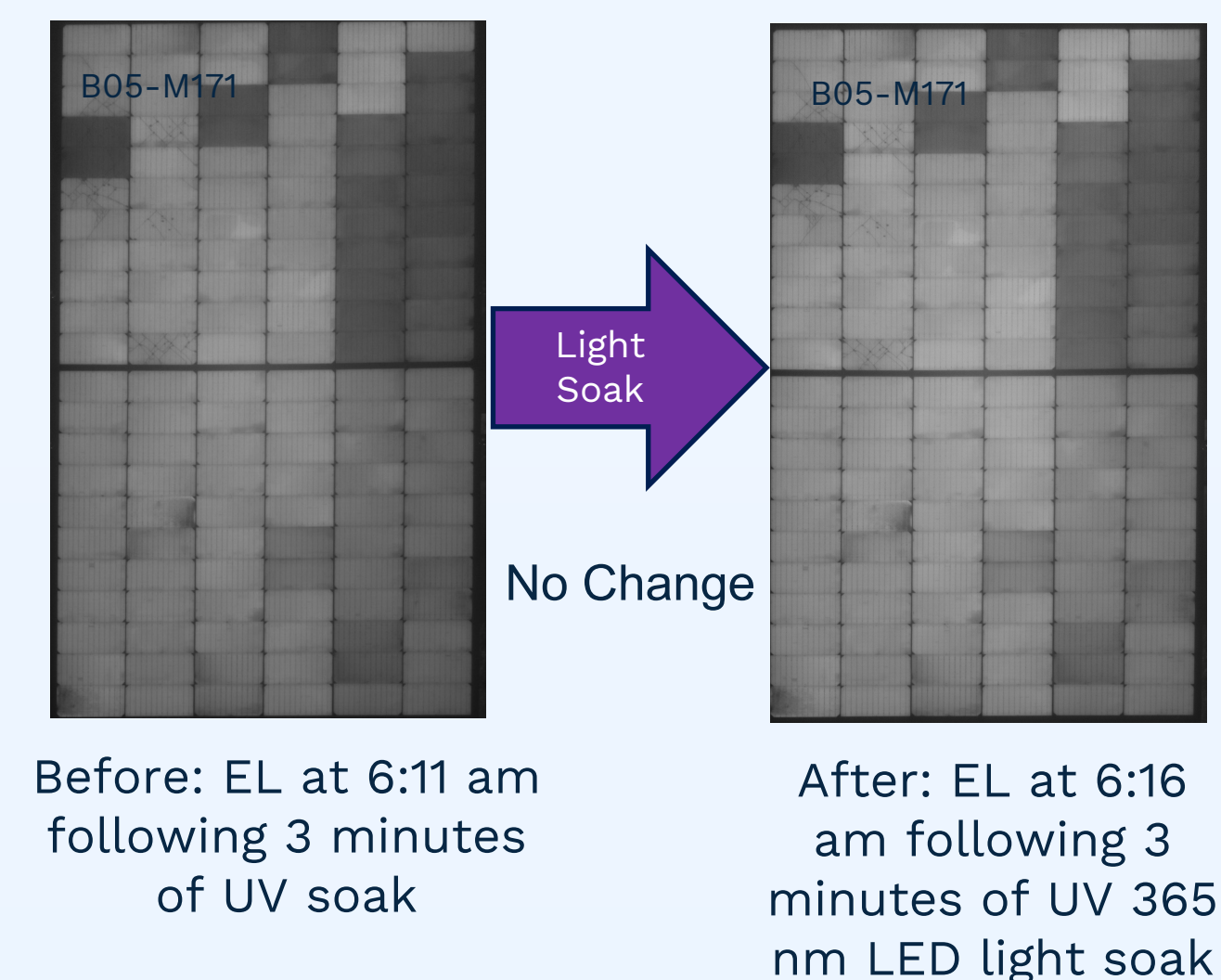
- More cracks -> more “FF” loss in dark IV.
- What's the best way to quantify?



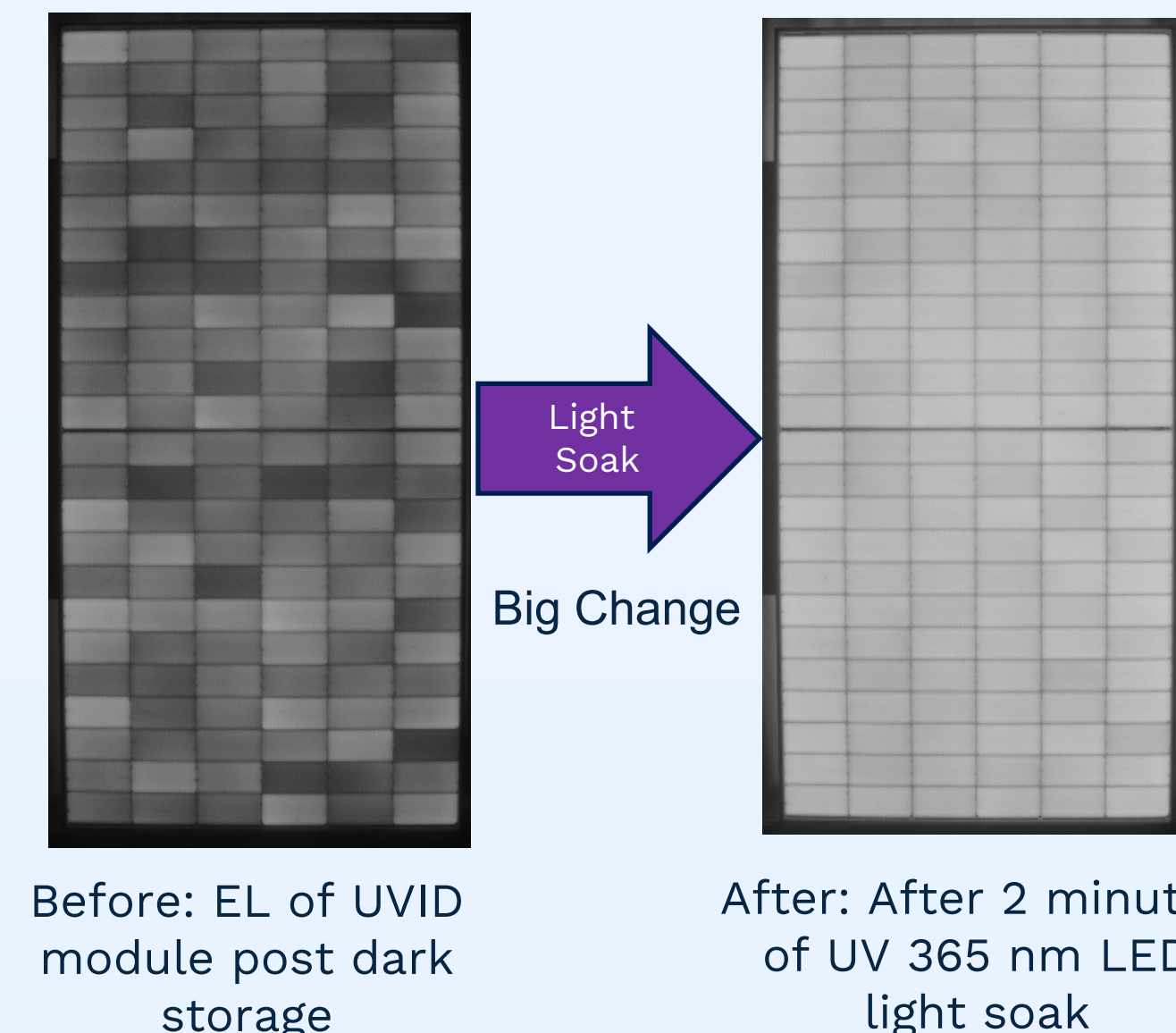
OUTDOOR RECOVERY

- Early in morning (before dawn), perform EL -> UV LED exposure -> repeat EL.
- Do not see any recovery of EL signal after UV exposure, in contrast to post-UVID modules.
- Implies that if UVID is occurring in these BOMs, there is not enough dark-storage metastability to cause a noticeable recovery signal in EL.

12 hours dark storage on outdoor fielded module



Compare: Weeks of dark storage on post-UVID module



SUMMARY & FUTURE WORK

- We will continue to acquire high quality data and provide to the PV community.
- Even highly cracked modules typically have less than 5% power loss.
- Yearly degradation rates are outside warranty bounds on many modules (even without cracks).

ACKNOWLEDGMENT

Funding provided by the Durable Module Materials Consortium 2 (DuraMAT 2), an Energy Materials Network Consortium funded by the U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, Solar Energy Technologies Office agreement number 38259. The views expressed in the article do not necessarily represent the views of the DOE or the U.S. Government. The U.S. Government retains and the publisher, by accepting the article for publication, acknowledges that the U.S. Government retains a nonexclusive, paid-up, irrevocable, worldwide license to publish or reproduce the published form of this work, or allow others to do so, for U.S. Government purposes.