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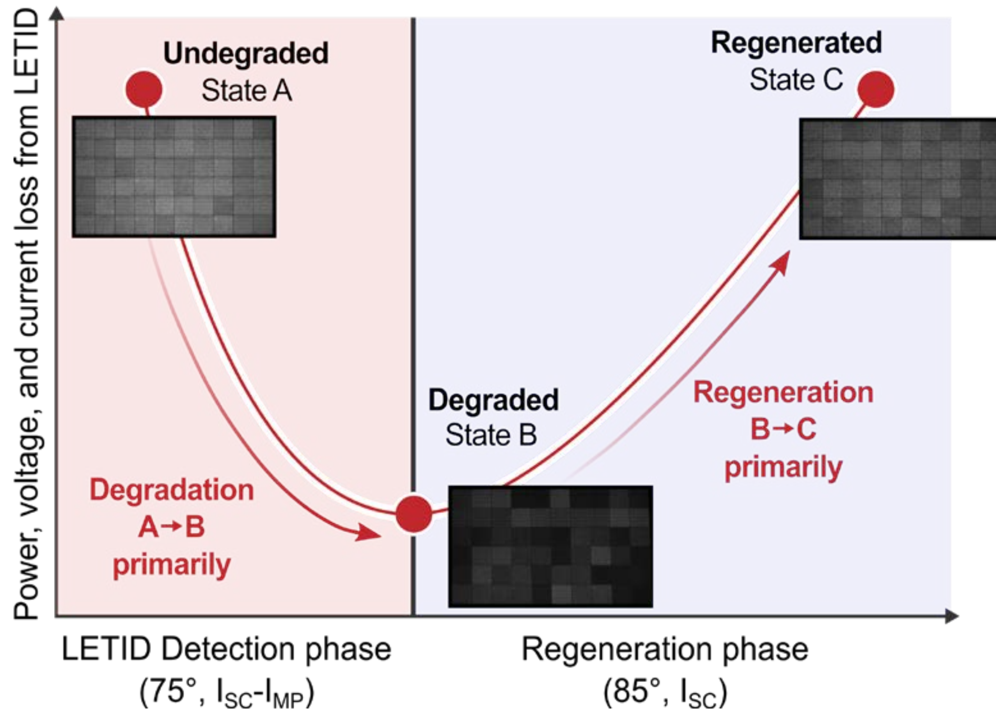

Results from an international interlaboratory study on light- and elevated temperature-induced degradation (LETID) in solar modules

Joseph Karas*, Ingrid Repins, Karl A. Berger, Bernhard Kubicek, Fangdan Jiang, Daqi Zhang, Jean-Nicolas Jaubert, Ana Belén Cueli, Tony Sample, Bengt Jaeckel, Matthias Pander, Esther Fokuhl, Max B. Koentopp, Friederike Kersten, Jun-Hong Choi, Birinchi Bora, Chandan Banerjee, Stefan Wendlandt, Tristan Erion-Lorico, Kenneth J. Sauer, Jon Tsan, Mauro Pravettoni, Mauro Caccivio, Giovanni Bellenda, Christos Monokroussos, Hamza Maaroufi

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PV Reliability Workshop, 21-25 February 2022

Much of this work has recently been submitted for publication:

J. Karas, et al., "**Results from an international interlaboratory study on light- and elevated temperature-induced degradation in solar modules**," Submitted to **Progress in Photovoltaics**, December 2021

In the meantime, also see my presentation from this workshop last year:

J. Karas, I. Repins, M.B. Koentopp, F. Kersten, J-N. Jaubert, D. Zhang, F. Jiang, C. Monokroussos, L. Jakisch, M. Pravettoni, S. Wendlandt, M. Caccivio, G. Bellenda, A.K. Tripathi, *et al*., "First Results from the International Round Robin Study of Light- and Elevated Temperature-Induced Degradation (LETID)", 2021 PV Reliability Workshop.

Proceedings available online at https://www.nrel.gov/pv/pvrw.html

Rationale for this study & study details

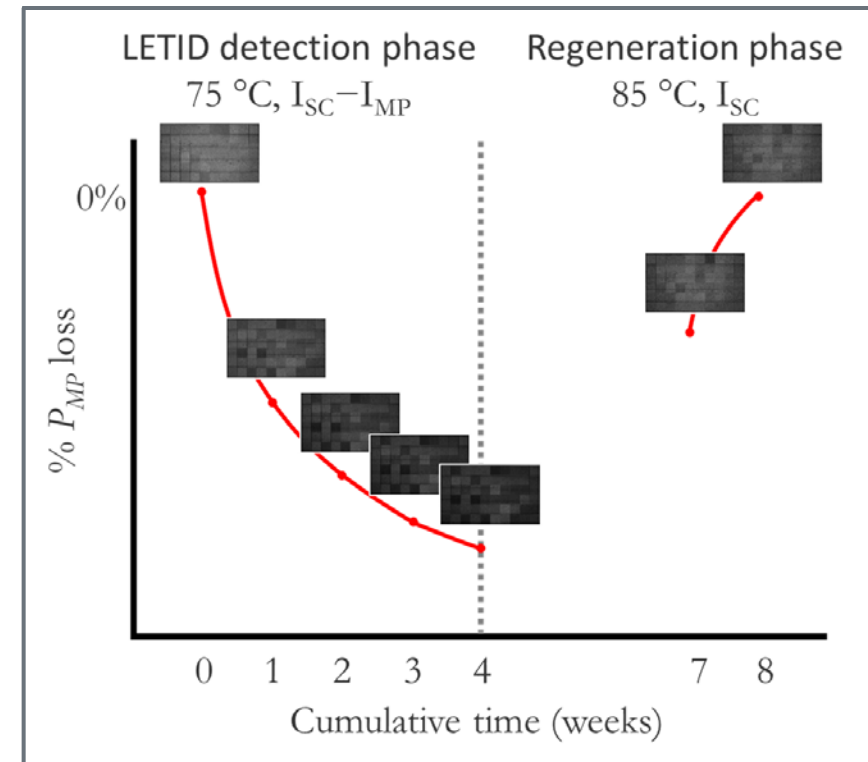
- In 2018, **two parallel efforts:**
  - Quickly draft a LETID test to include in the then-upcoming edition of IEC 61215
  - Perform an interlaboratory cross-comparison of an early version of the test ← (**this work**)
    - Main goals: Evaluate **effectiveness and reproducibility** across labs
- The LETID test **wasn't included in the new 61215**, which is now published
- **But a revised version of the test now exists as the forthcoming IEC TS 63342** (likely to be published in 2022)
  - See Max Koentopp's poster at this workshop

This work:
Two phases: LETID detection and Regeneration

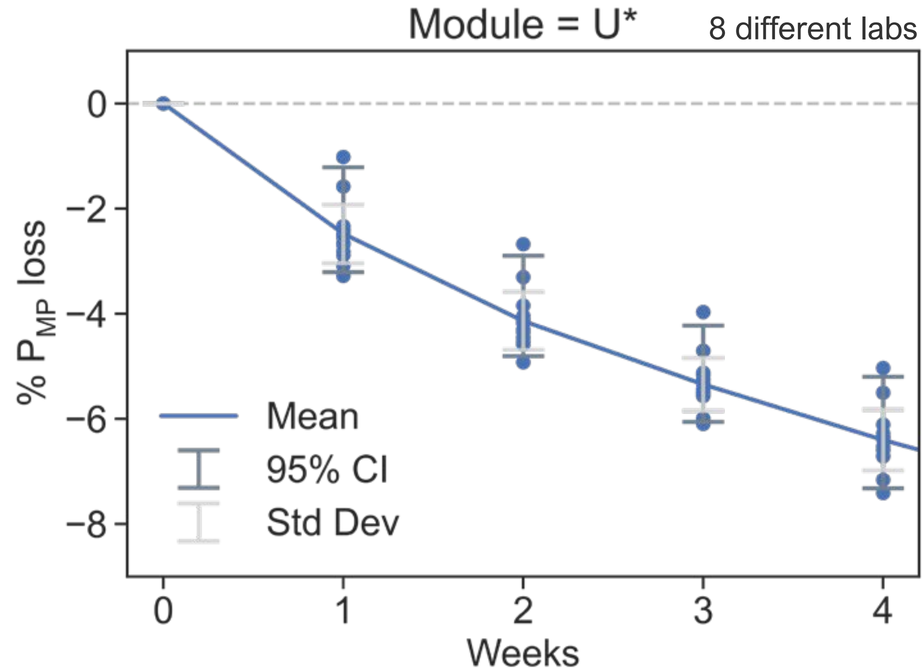
- LETID detection:
  - ($I_{SC} - I_{MP}$) at 75°C for steps of 1 week (~162h), up to 4 weeks
- LETID regeneration:
  - I_{SC} at 85°C for 3 weeks (~500h), then up to 1 more week

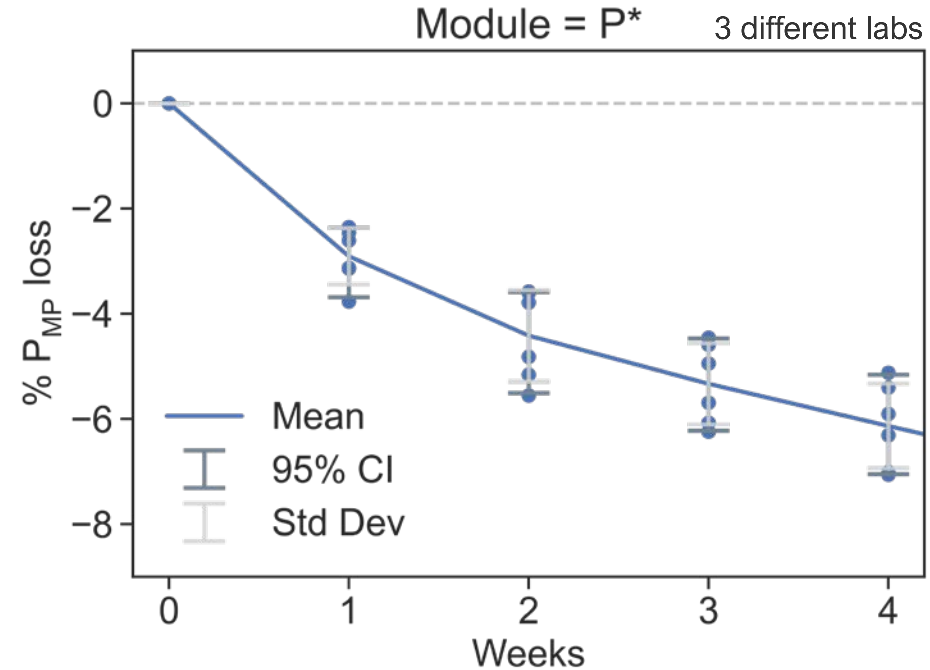
- 10 different module types, 64 total modules
- 14 different labs

- Several types of module were **intentionally-engineered for LETID-sensitivity**



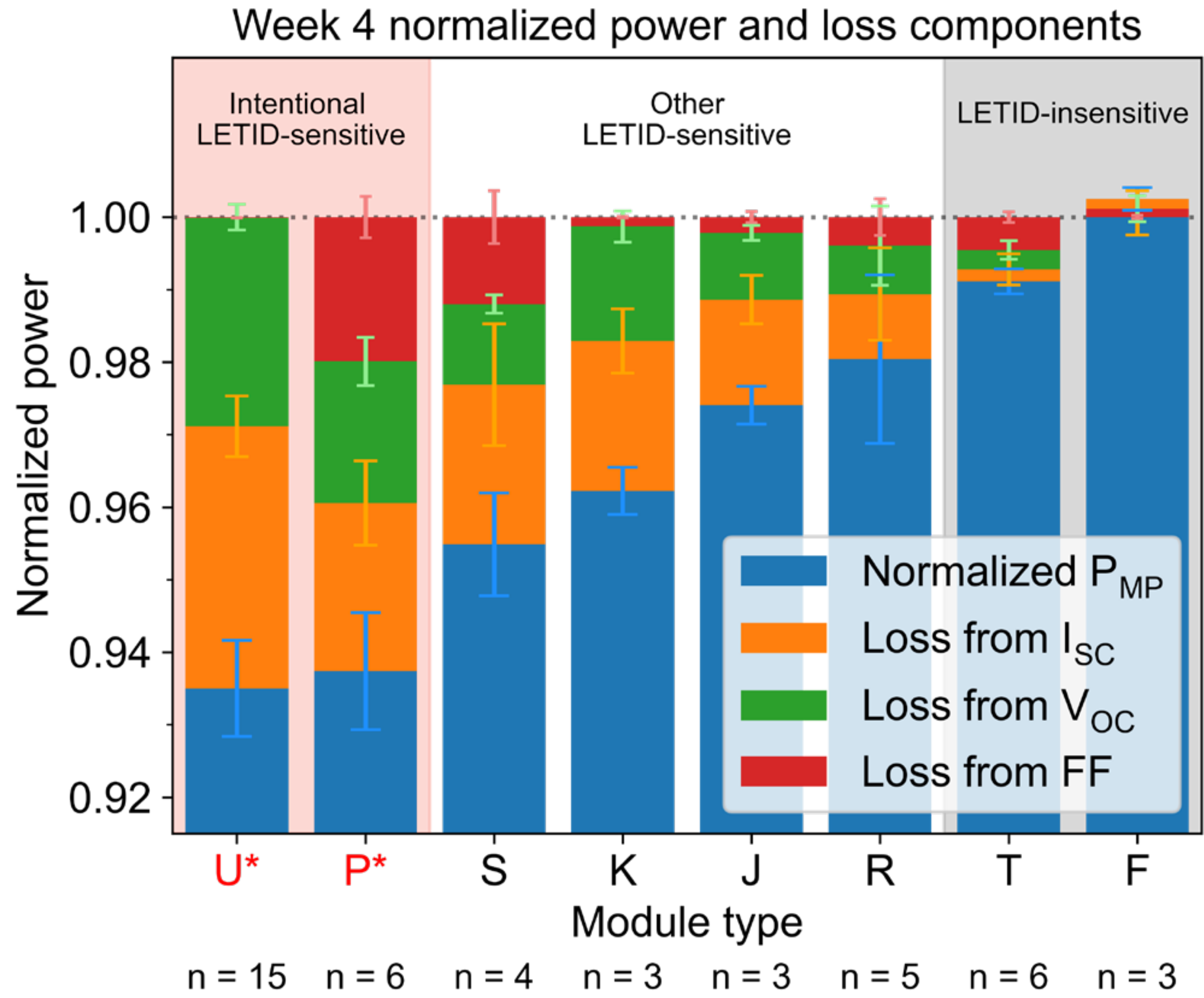
Reproducibility across labs is likely within ±1% P_{MP}





Module type	Week	# of modules	# of labs	Mean % P_{MP} loss	Standard deviation	95% CI high	95% CI low
U*	4	15	8	-6.4%	0.6%	1.2%	0.9%
P*	4	6	3	-6.1%	0.8%	1.0%	0.9%
S	4	4	2	-4.5%	0.7%	0.8%	0.8%
K	4	3	2	-3.8%	0.3%	0.3%	0.2%
J	4	3	2	-2.5%	0.3%	0.2%	0.3%
R	4	5	3	-2.0%	1.1%	1.3%	1.5%
T	4	6	3	-0.9%	0.2%	0.2%	0.2%
F	4	3	2	0.3%	0.2%	0.1%	0.2%

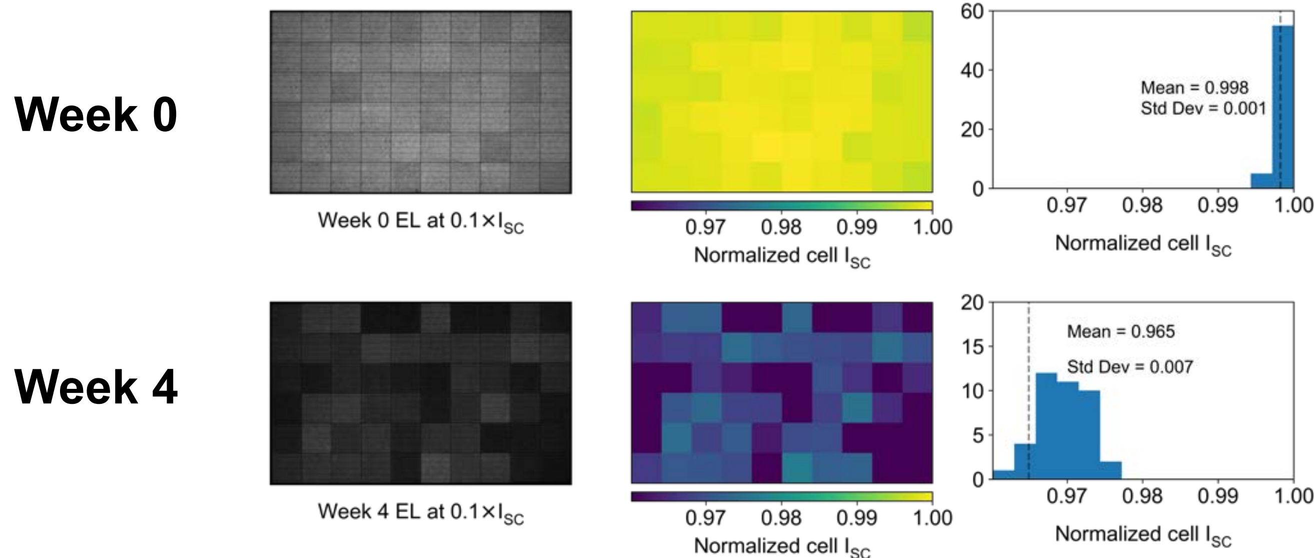
I-V parameter loss contributions: power loss driven by **voltage AND current** loss



Mismatch loss calculated from EL parameter extraction suggests **mismatch doesn't play a significant role**

Week 0

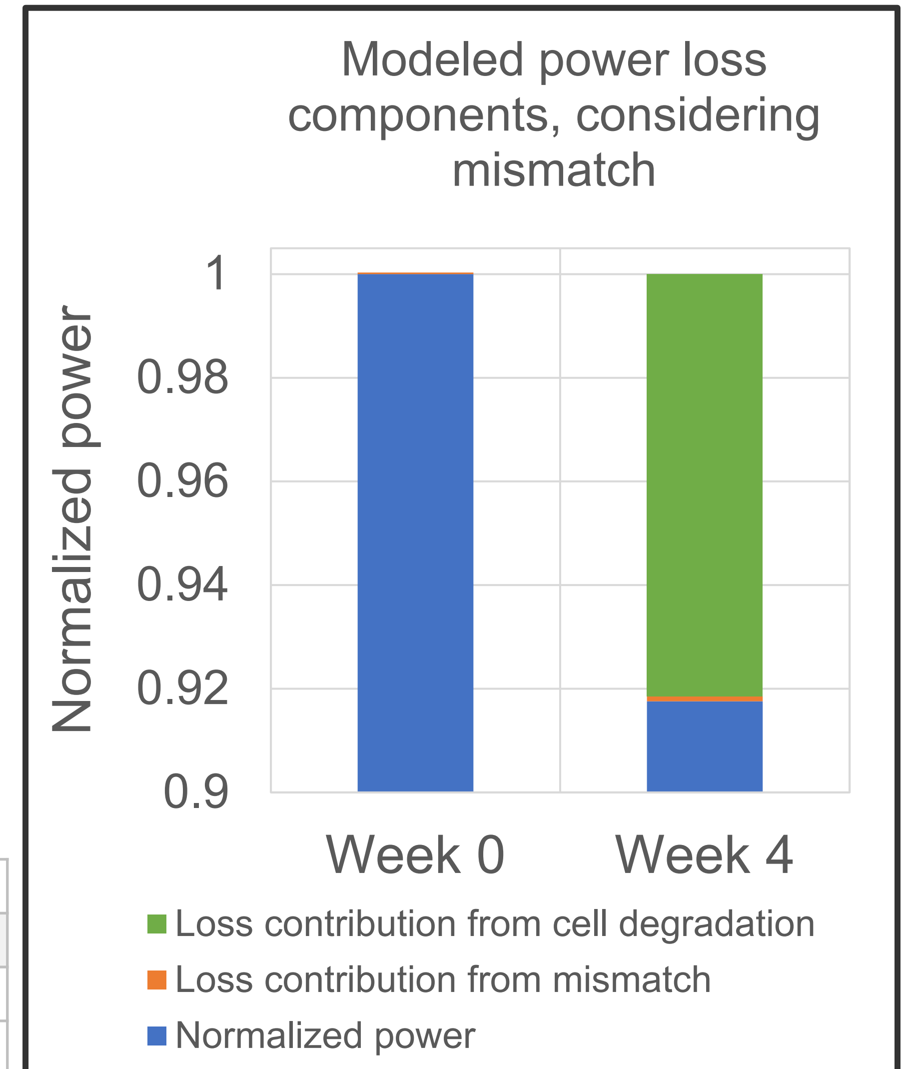
Week 4



Mismatch loss →

$$L = \frac{\sum_{i=1}^{n} p_i - P_{MP}}{\sum_{i=1}^{n} p_i}$$

	Normalized P_{MP}	Normalized $\sum p_i$	Mismatch loss L
Week 0	1	1.0003	0.0003
Week 4	0.9176	0.9184	0.0009
Percentage power loss	8.24%	8.19%	0.06%



Conclusions

- In general, the **cross-lab reproducibility of LETID testing appears to be pretty good**, standard deviation results across labs in agreement to within ±1% P_{MP} even in heavily LETID-sensitive samples. In samples with less LETID sensitivity, the reproducibility appears to be better than ±1%.

- Power losses in LETID-sensitive modules were driven by **roughly similar-magnitude losses in voltage and current**. In some modules, but not all, FF also degrades and recovers in a manner that seems consistent with LETID. In other modules, FF seems to be unaffected by LETID stress.

- **The degradation varies cell-to-cell**. This is readily visible in EL images.

- We found that **mismatch seems to play an inconsequential role**, and most module-level current loss comes from the cumulative degradation of cells' current. The origin of cell-to-cell variation and a more robust mismatch measurement in degraded modules could be a topic for future work.

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