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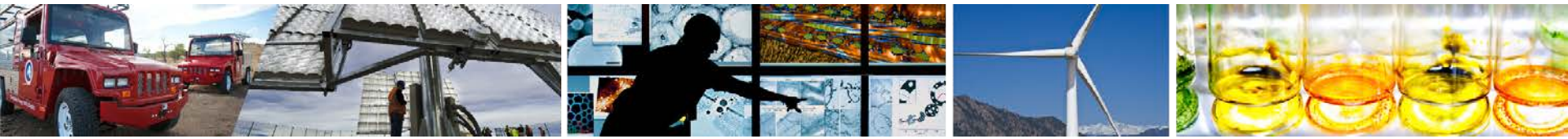
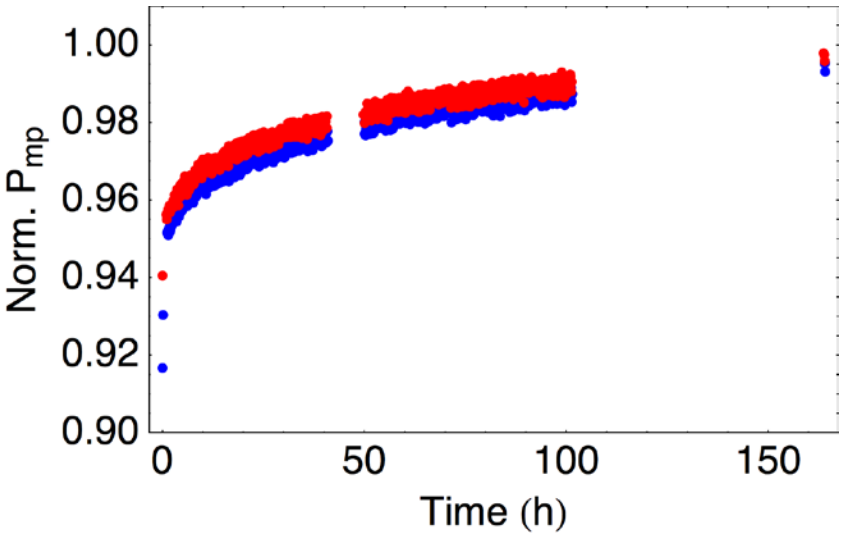
Transient Behavior in Thin-Film Modules

Michael Deceglie
Timothy Silverman
Bill Marion
Sarah Kurtz

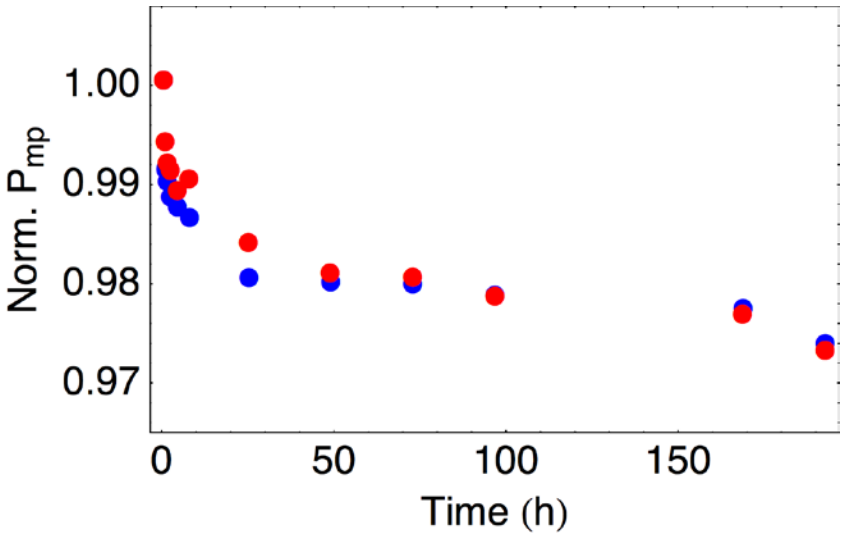


Metastable performance in thin-films

Light exposure (1000 W m^{-2}, 55°C)



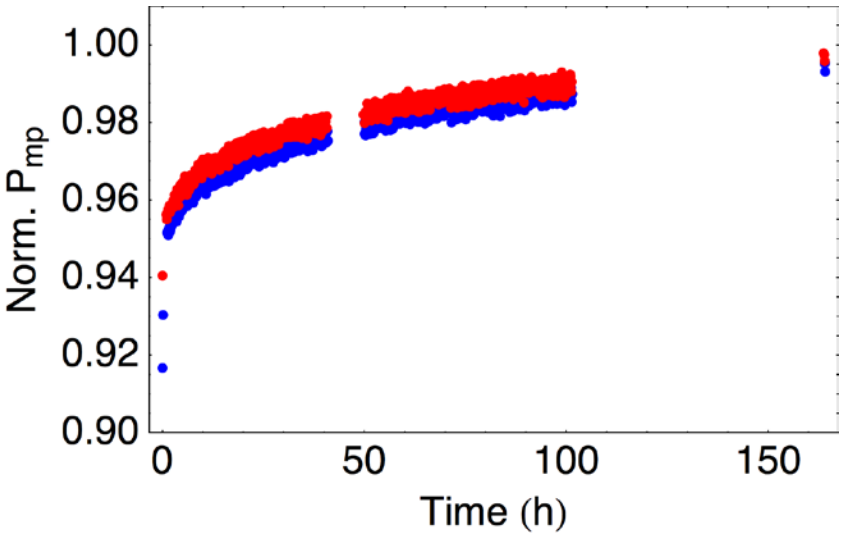
Storage at room temp.



Thin-film modules change performance upon exposure to light and storage in the dark

Metastabilities vs. permanent changes

Light exposure (1000 W m^{-2}, 55°C)



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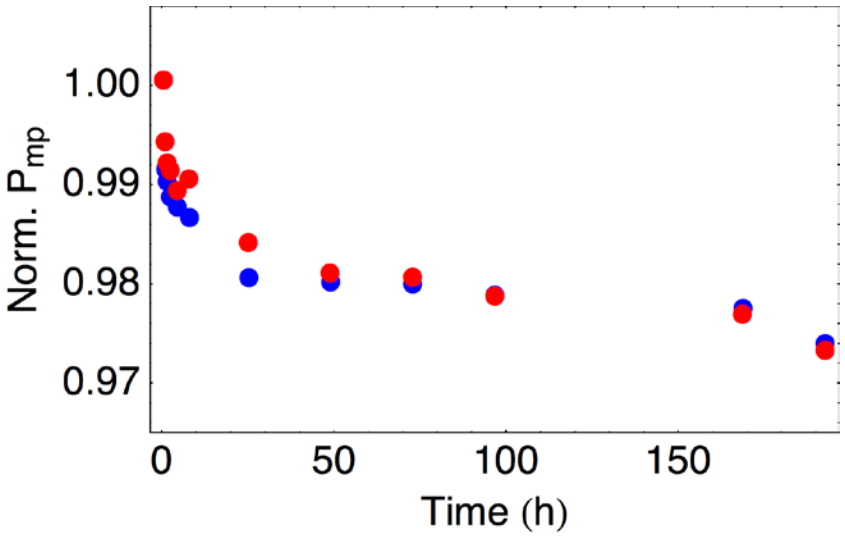

Changes are at often at least partially reversible, especially upon exposure to elevated temperatures

- Initial Norm. P_{mp}: 0.88
- After 165 hours at 55°C: 0.91

Metastabilities vs. permanent changes

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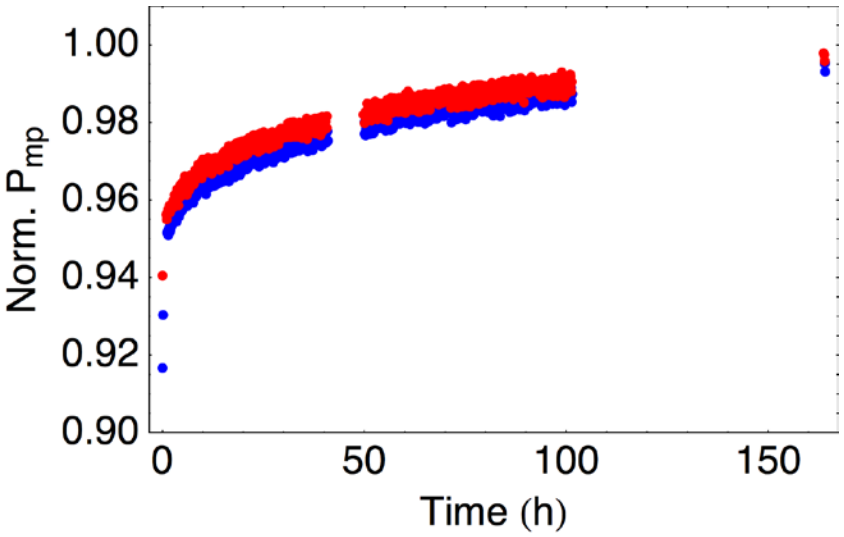
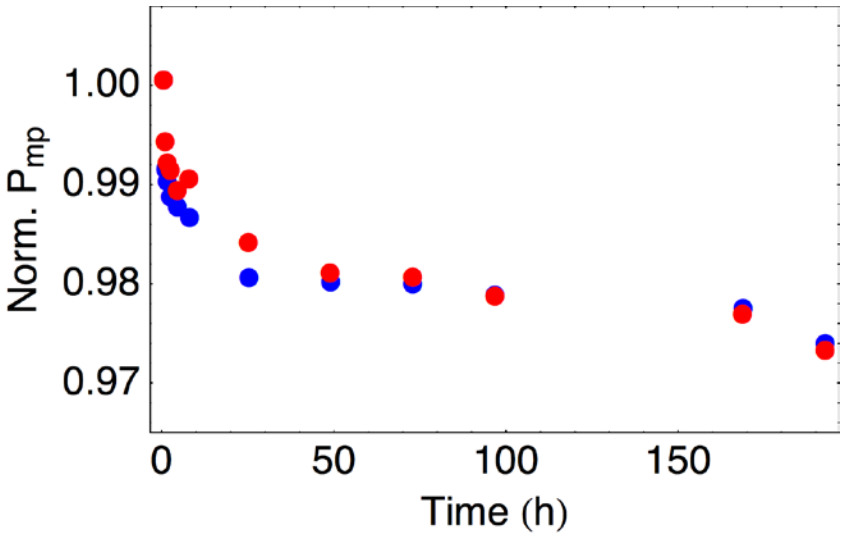


Storage at room temp.



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- Initial Norm. P_{mp}: 0.88
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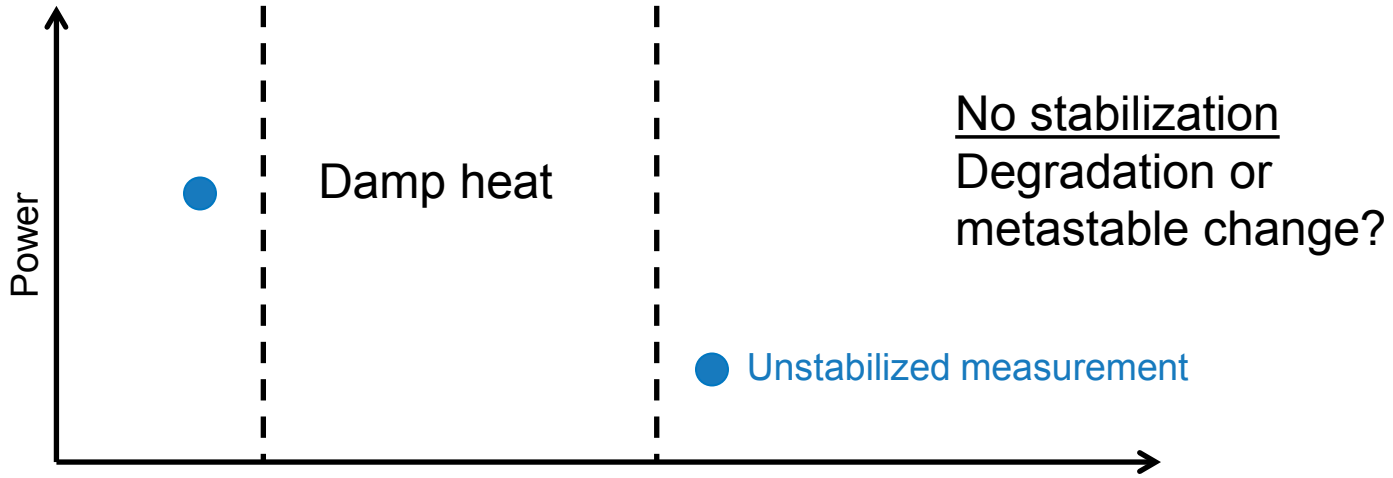
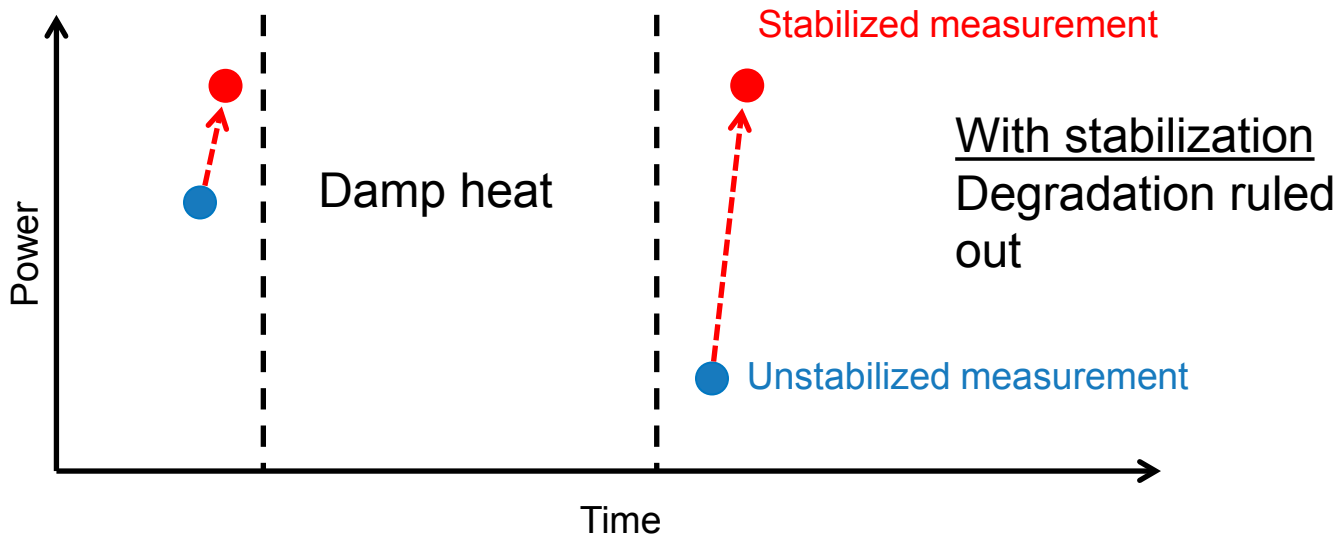
Metastabilities: reversible changes
Stabilization: Repeatedly achieving metastable state

Differentiating degradation

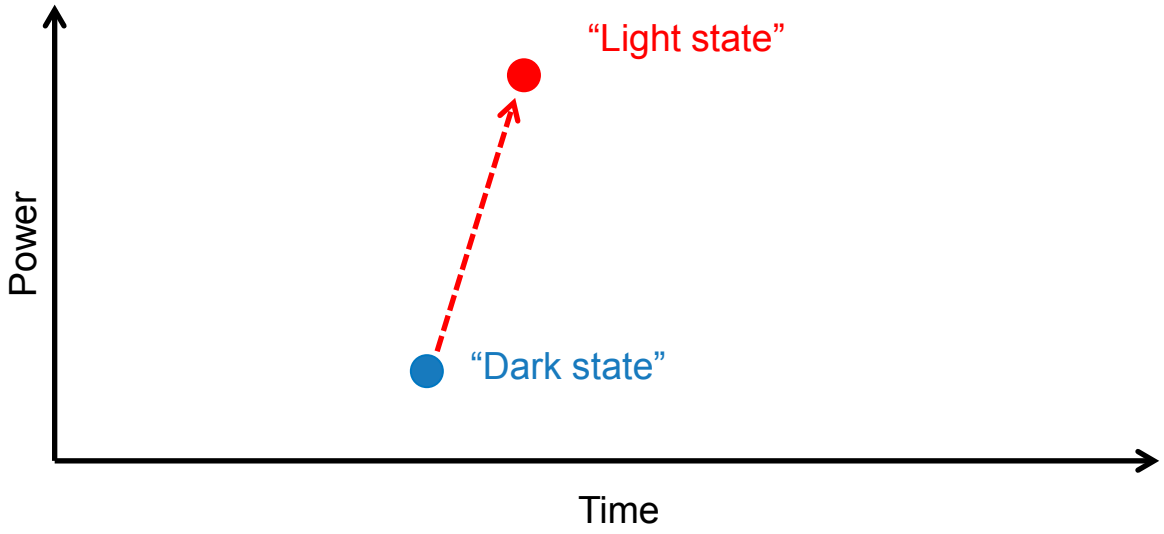


Differentiating degradation

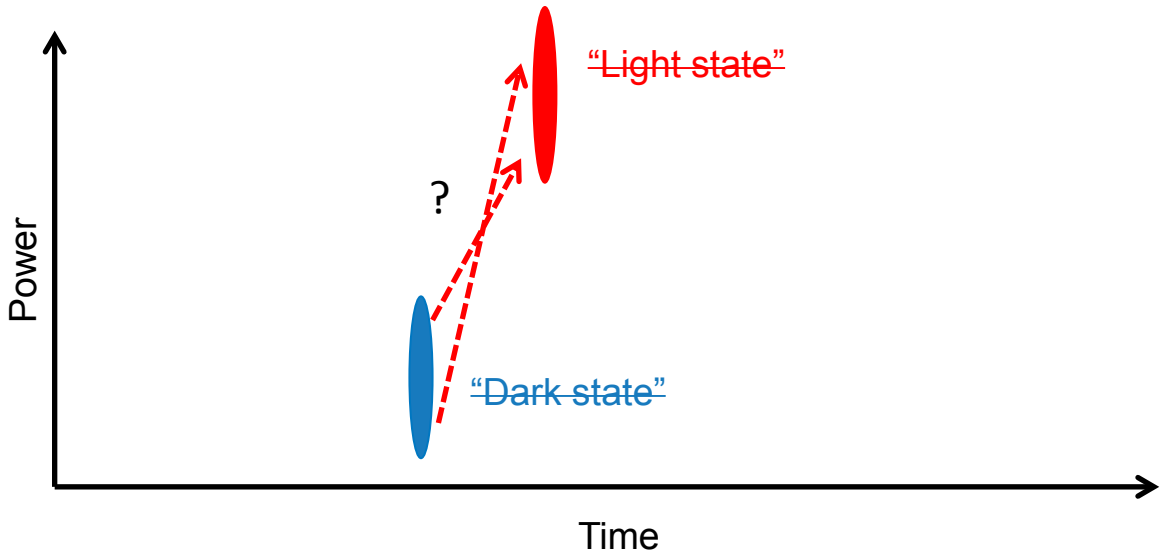


Repeatable stabilization procedure needed before and after reliability test

“The light state”



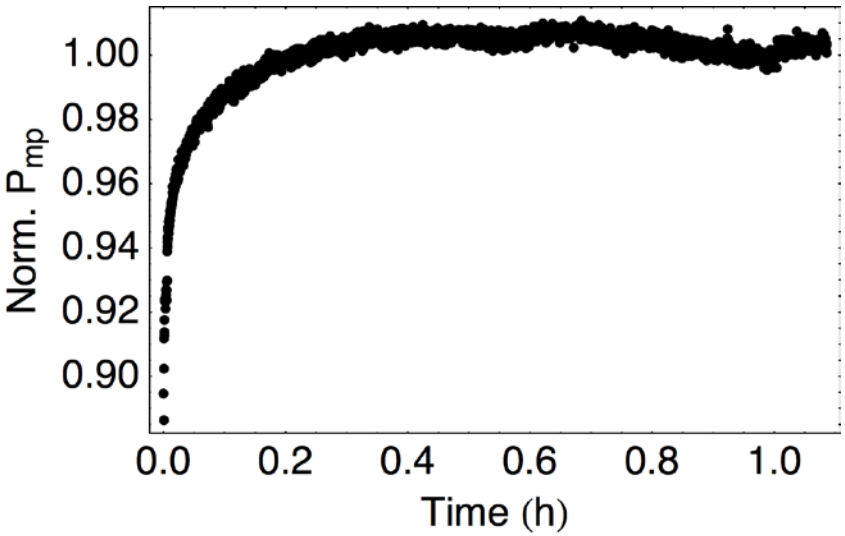
“The light state”

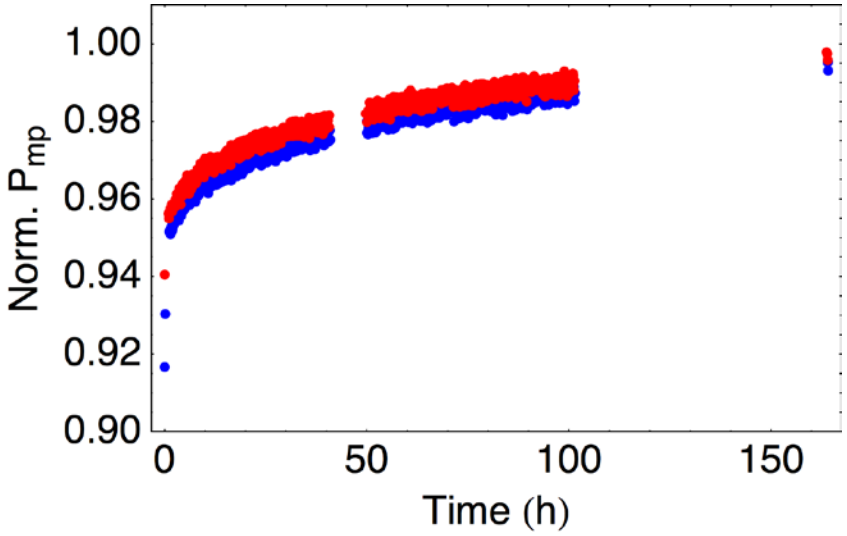


There is not a singular, well-defined light state

Time scales of change

Transient changes in performance of two different types of CIGS modules

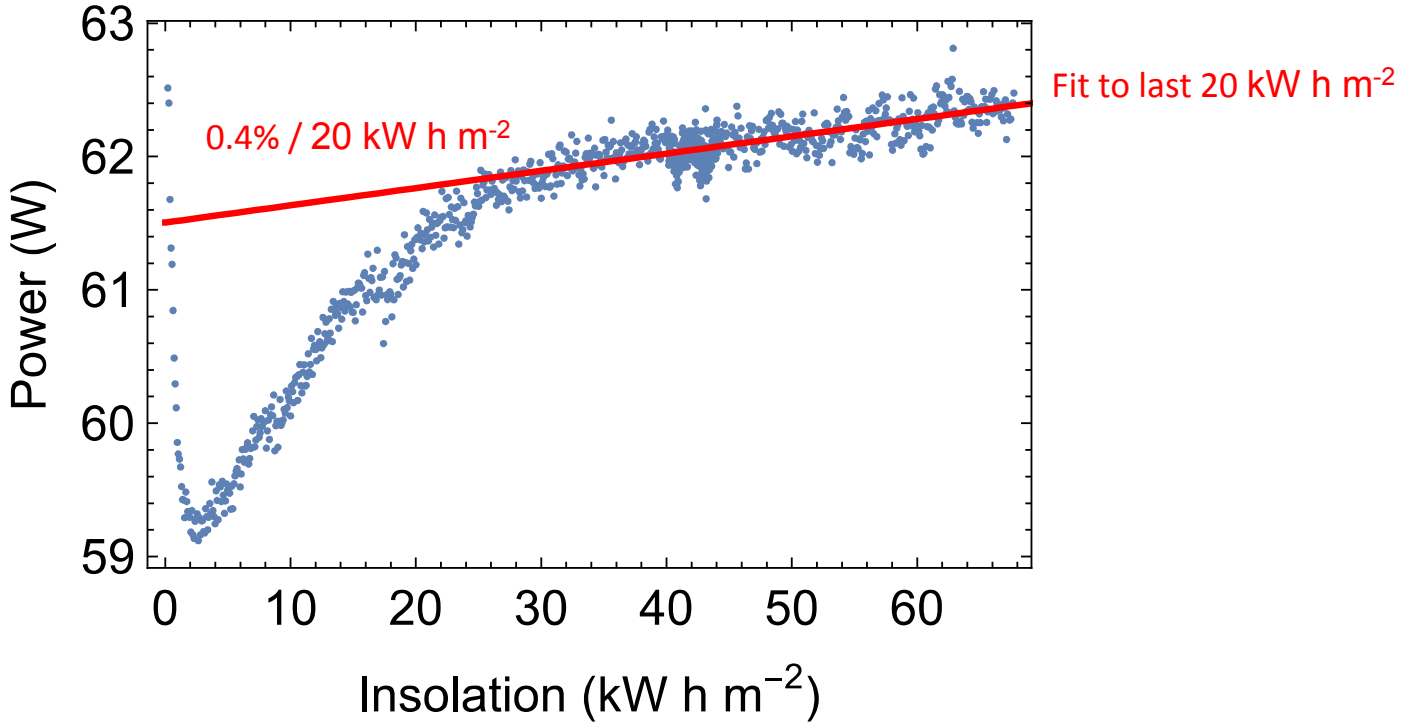




Changes can occur on different timescales for different modules

Must define relevant timescale

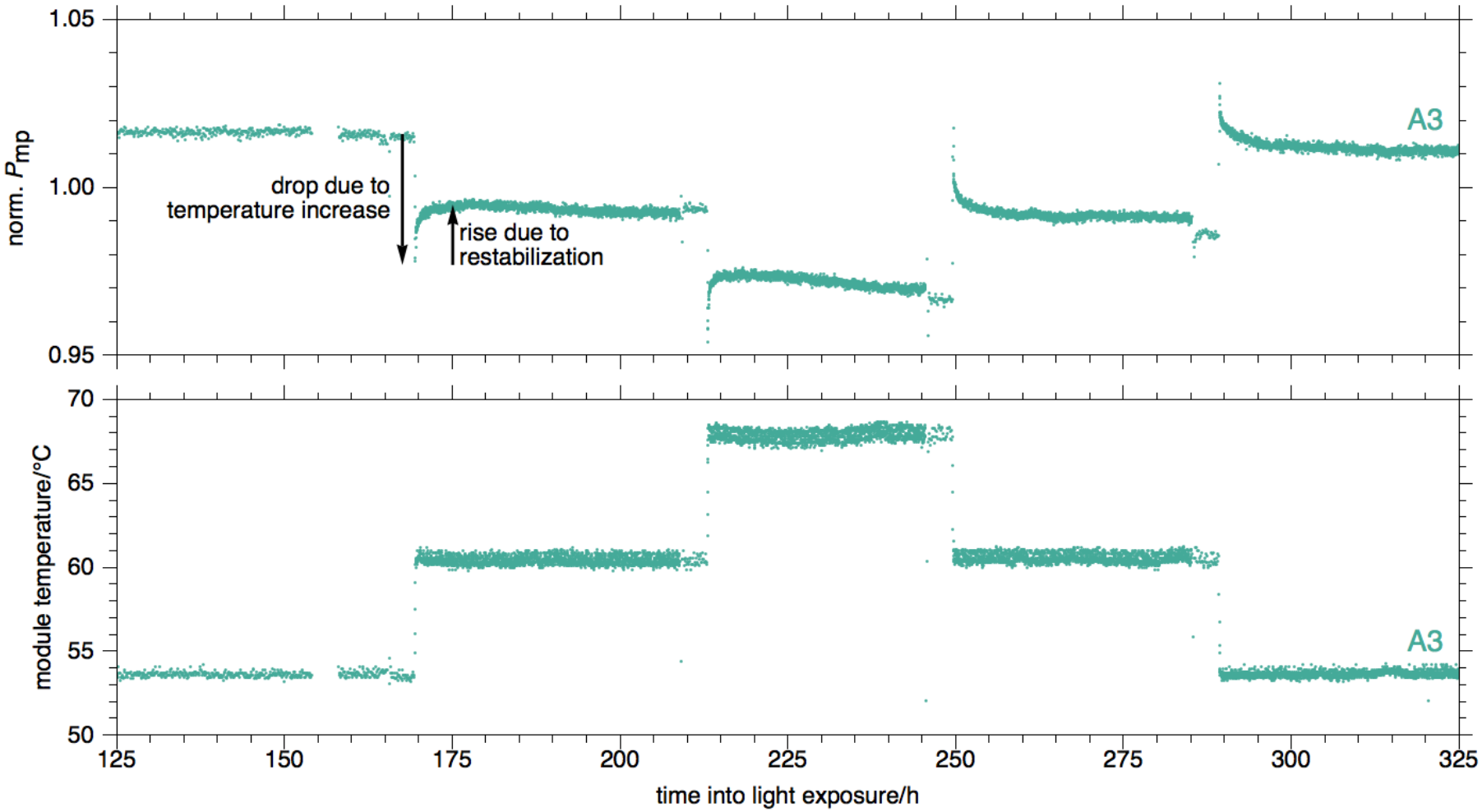
Transient change in CdTe module exposed at 1000 W m^{-2}, constant temperature



We use: <1% per 20 kW h m^{-2}

IEC 61646: <2% in two intervals of 43 kW h m^{-2}

Temperature dependent states



CdTe module exposed to light at different temperatures

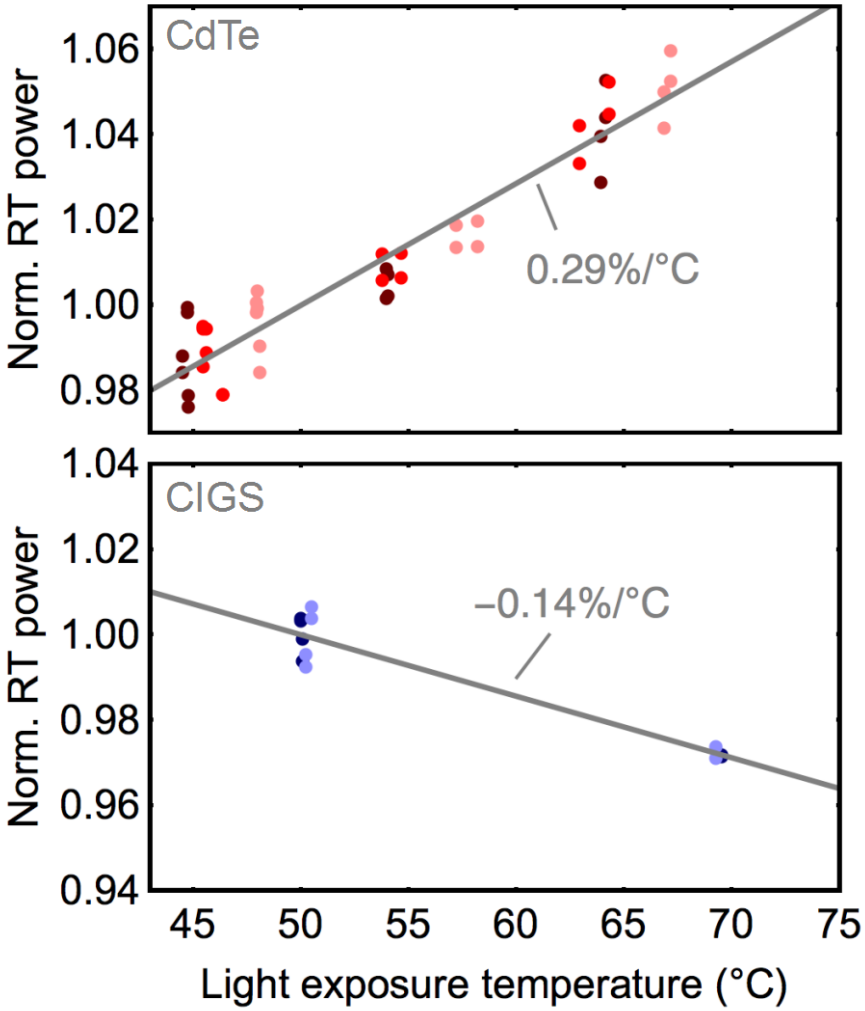
Silverman et al., J. PV 5:1 p. 344, 2015

Quantifying the temperature effect

- Light soak in chamber until stable
  - <1% / 20 kWh m^{-2} change based on in situ IV curves
- Measure IV at room temperature at 30 & 60 minutes after end of light soak
- Repeat light-soak at different back-of-module temperature
- Example:
  - Light soak at 50°C
  - Measure RT IVs
  - Light soak at 70°C
  - Measure RT IVs
  - Light soak at 50°C
  - Measure RT IVs

Discriminates permanent vs. reversible changes

Temperature-dependent “light states”



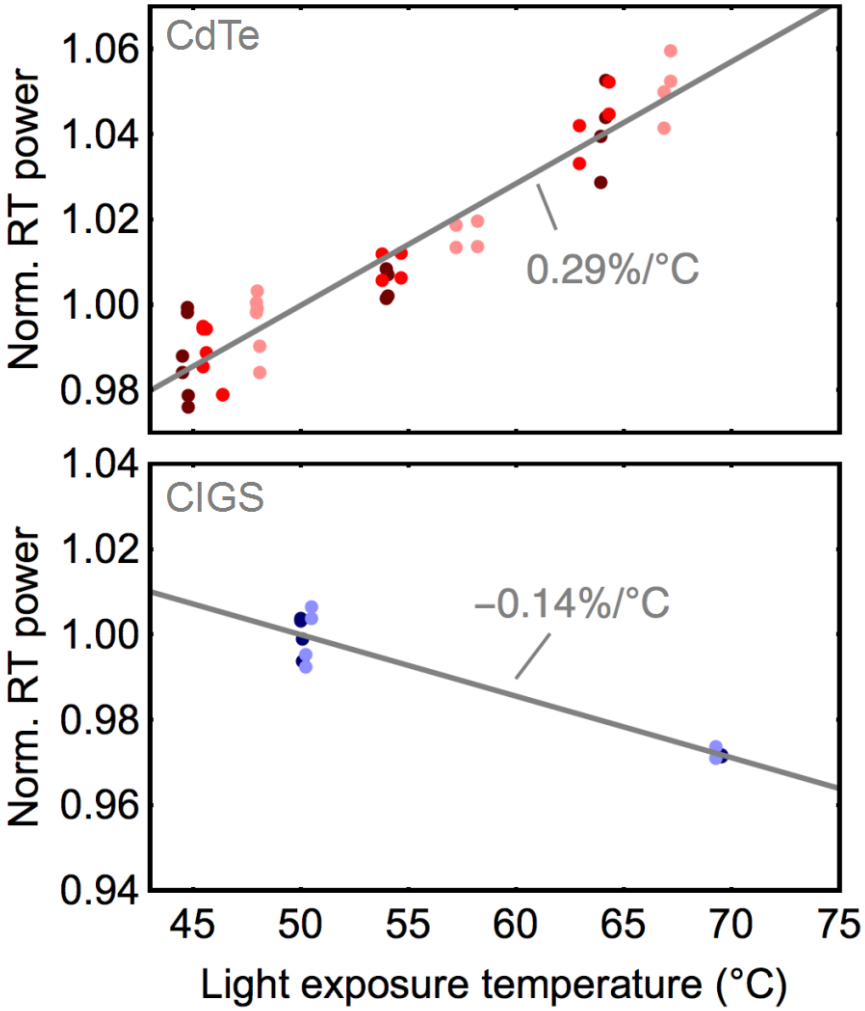
Variations in light-soak temperature affect the final metastable state.

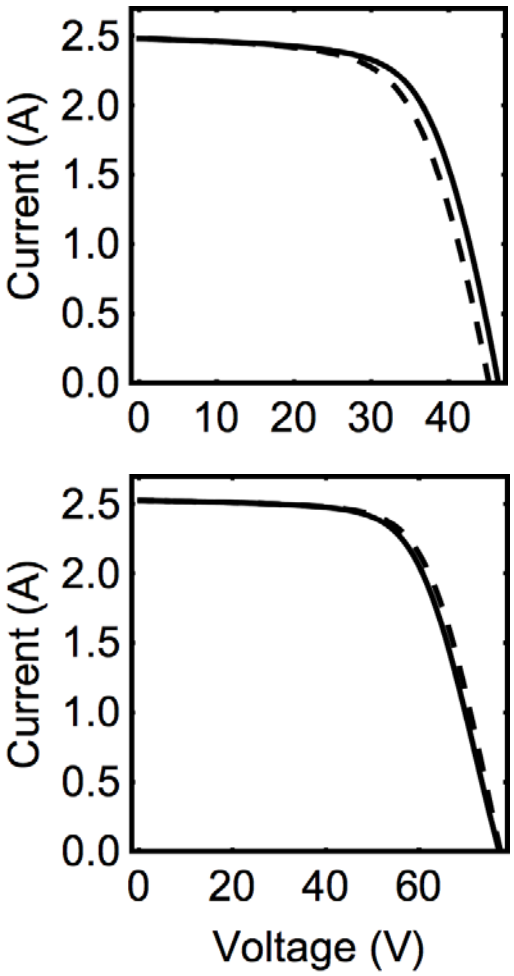
For a 20°C discrepancy:
2.8% change in CIGS
5.8% change in CdTe

(Effects not universal)

Different shades indicate different samples.
Both 30 min and 60 min measurements shown.

Temperature-dependent parameters





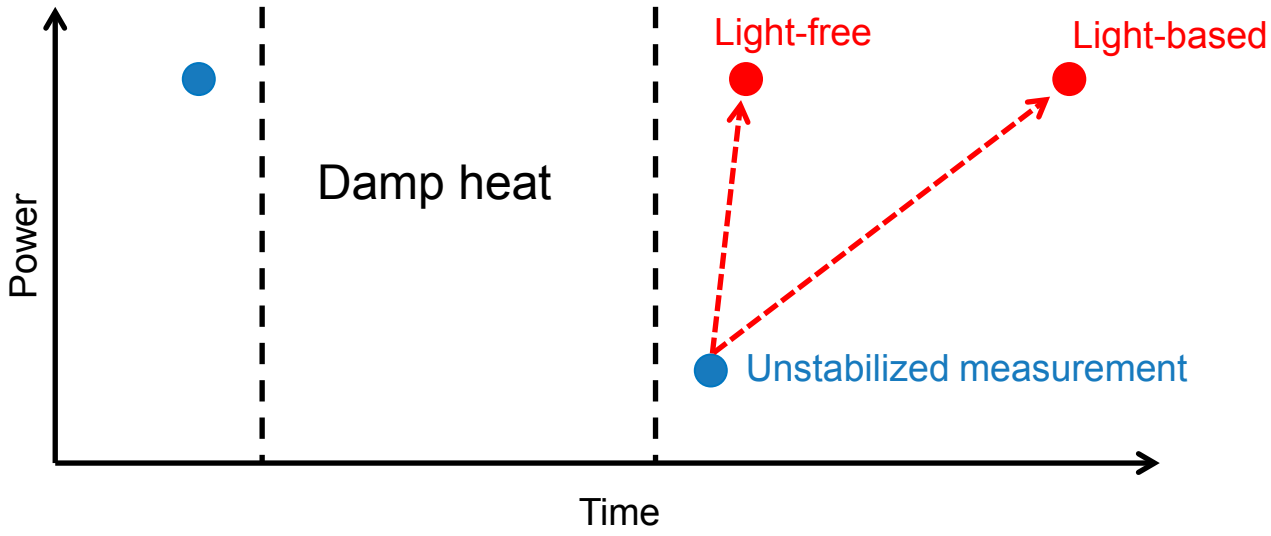
Differences

V_{oc} 3.6 %
FF 3.1%

V_{oc} 0.3%
FF 2.3%

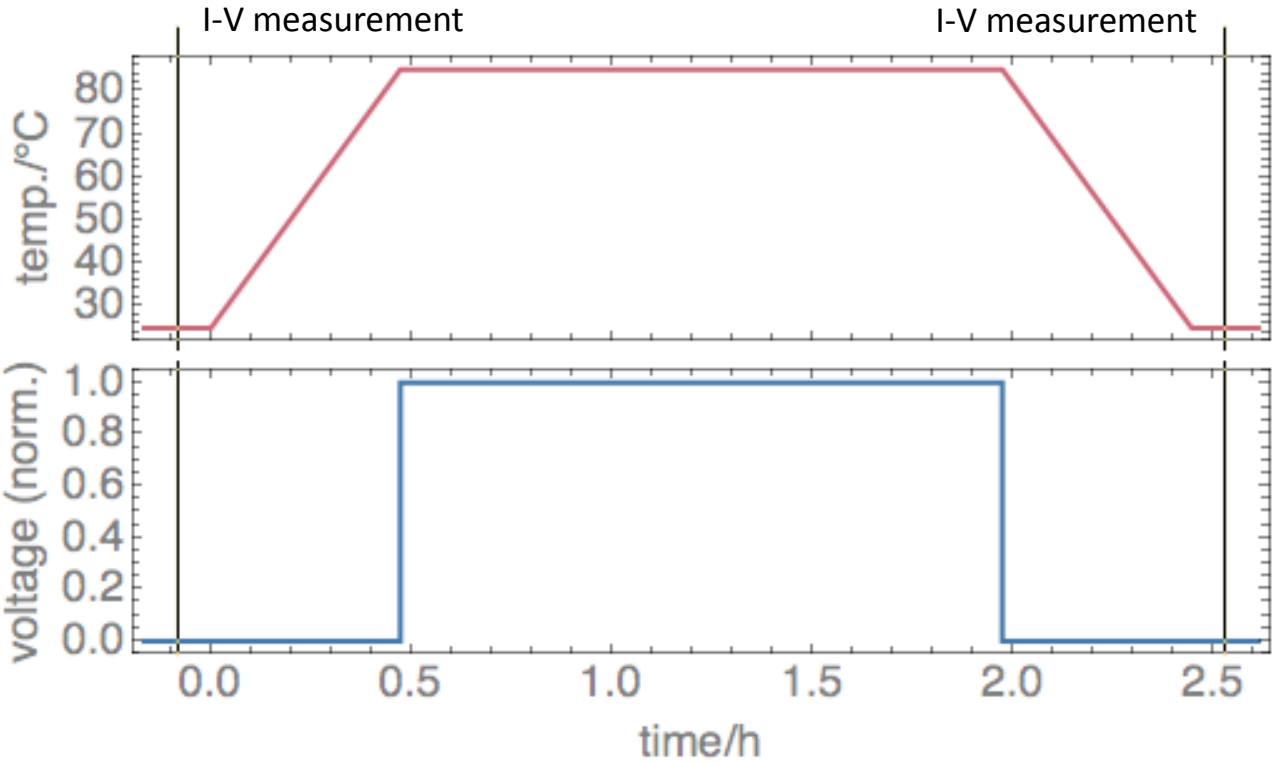
Hot light soak
Cool light soak

Light-free stabilization



- Can be **quicker** and **cheaper**
- Must produce **relevant state**

Bias at elevated temperature (BET)

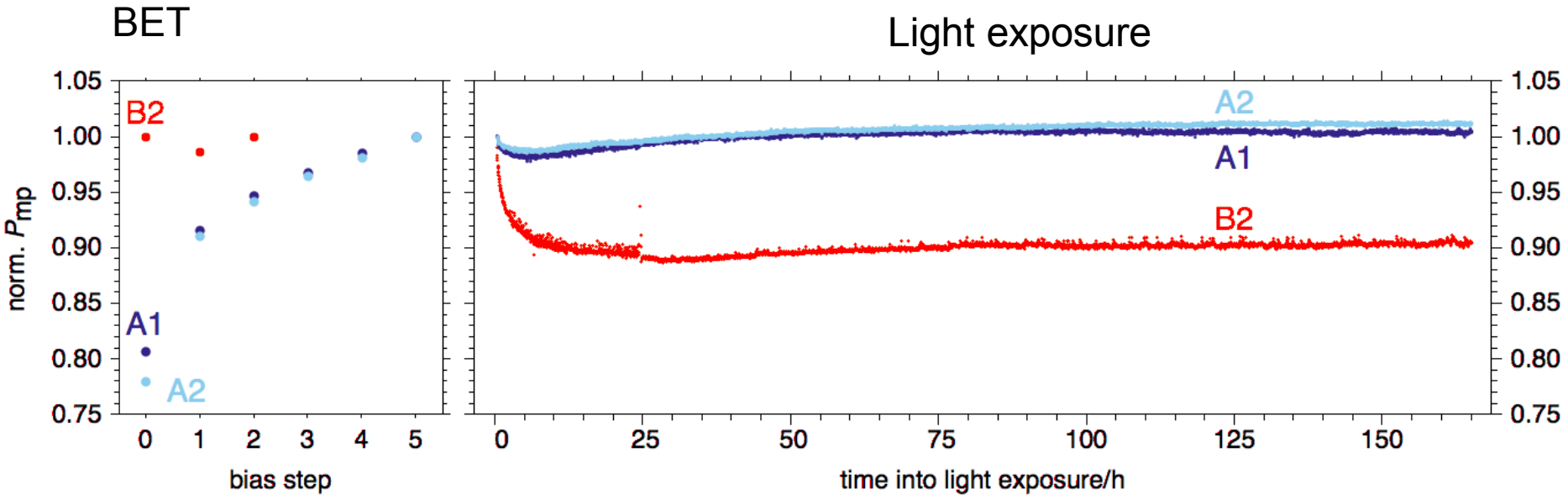


Method based on proposal in draft IEC 61215 update:

- Collect light I-V curve
- Heat to 85°C
- Apply forward bias (0.6 to 0.7) × V_{oc}
- Cool to room temperature
- Collect light I-V curve
- Repeat until power is stable

BET results

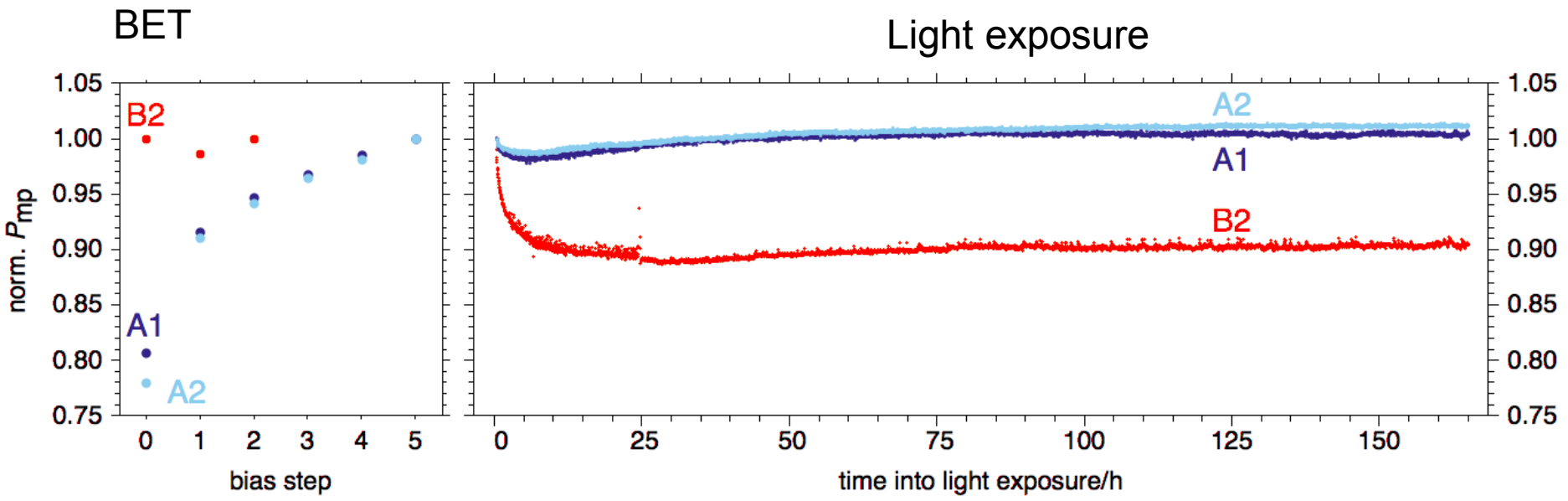
Two types of CdTe module were stabilized with the bias at elevated temperature (BET), then placed in light-soak chamber



For some modules, BET does not produce a light-stable state

Silverman et al., J. PV 5:1 p. 344, 2015

BET results

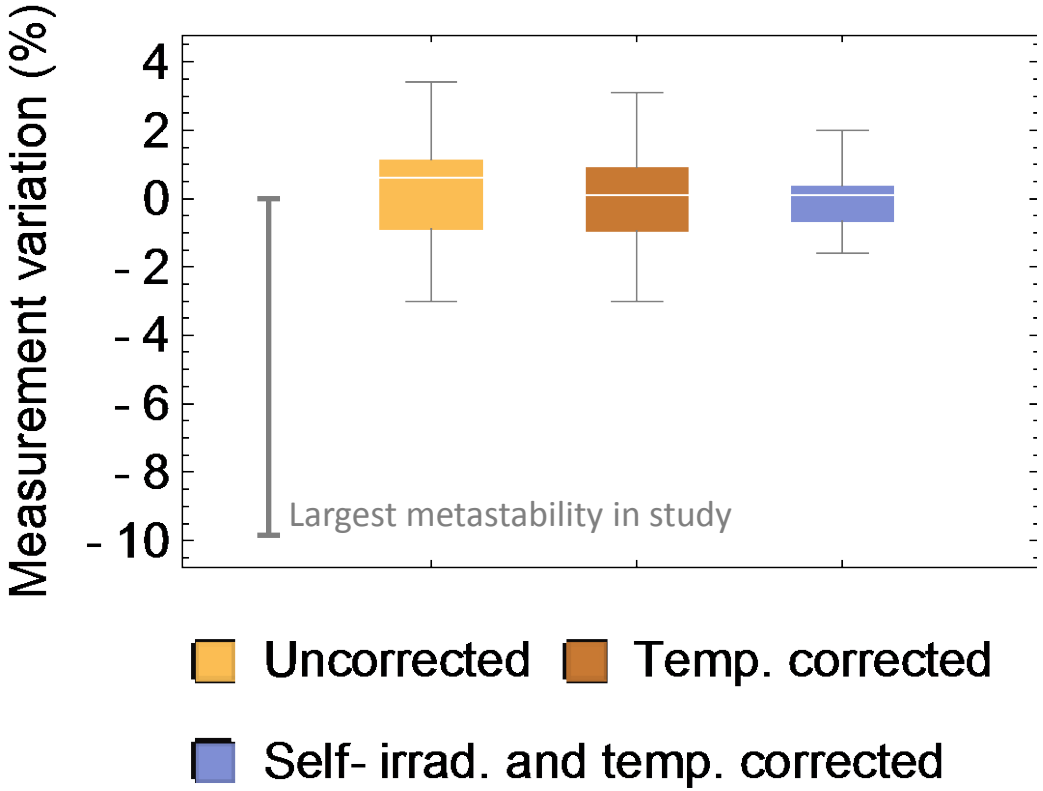


Validation is critical

Silverman et al., J. PV 5:1 p. 344, 2015

Reproducible measurements are possible

- Round robin
  - 5 labs
  - 4 CIGS module types
- Uninterrupted 5 hour light soak
- Module forward biased while cooled
- Prompt IV measurement (within 1 minute)



Deceglie et al., J. PV 5:2 p. 607, 2015

Conclusion

- “Light state” and “Dark state” are ill-defined
  - Timescale
  - Temperature
  - Stimulus (alternate methods)
- Best practices
  - Define the timescale of interest
  - Tightly control the temperature
  - Validate light-free methods
  - Control and minimize the delay between light exposure and measurement

Acknowledgments

Thank you:

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