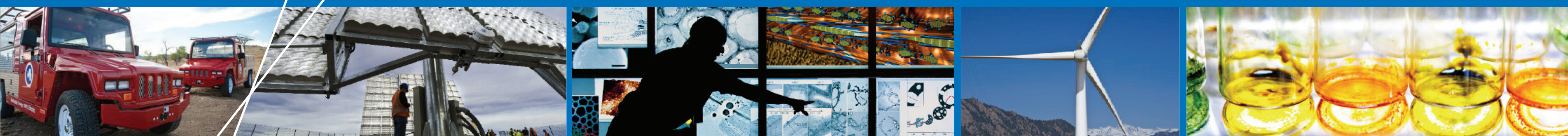
Changes in Field ~~Failure~~ Degradation Modes Over Time



Duramat Workshop

Stanford, CA

Dirk Jordan, Tim Silverman, Sarah Kurtz, John Wohlgemuth, Kaityln VanSant

5/23/2017

Outline

- Definitions: failure - degradation
- Failure rates
- Degradation modes
- Changes in the last 10 years
- “New” degradation modes

Why study literature?

Great overview of the aggregated knowledge of the PV community
but determination of trends from literature can be difficult:

1. Unknown quality of modules/systems/installation
2. Many factors may influence failure/degradation modes and often they are not clearly documented
3. Inconsistent use of reporting terminology
4. Misidentification
5. Synergy of degradation modes: often multiple modes can be seen in single module/system

Failure ↔ Degradation

Definition of failure: IEC 60050-191

"Failure is the termination of the ability of an item to perform a required function"

What does that mean for PV module?

Failure ↔ Degradation

Definition of failure: IEC 60050-191

"Failure is the termination of the ability of an item to perform a required function"

What does that mean for PV module?

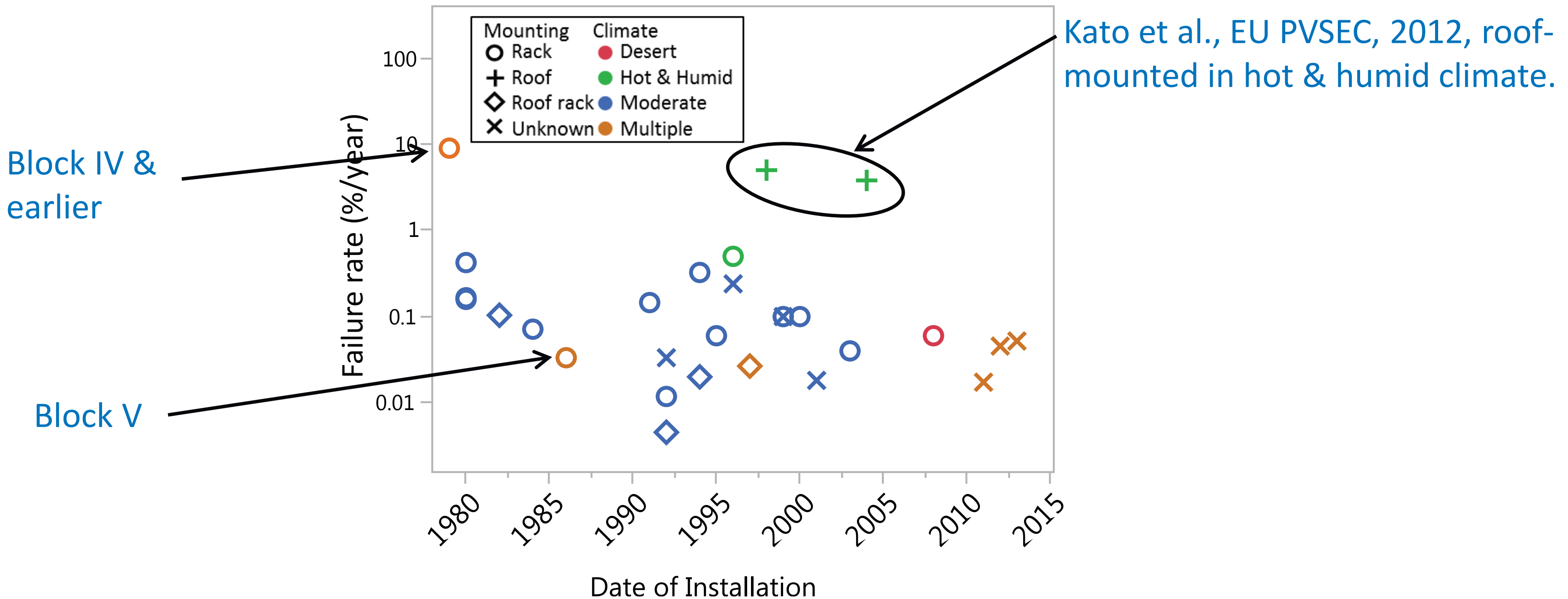
Several different definitions of PV "failures" have been used!!

1980: JPL Block Buy Program "failure < 75% of short-circuit current (Isc)
1993: EPRI: power decline > 50% that cannot be repaired in field
2014: IEA: modules undergoing irreversible changes
Maybe: Modules that default on warranty, which warranty?

Failure rates need to take into account field exposure

Failure rates are typically not reported, failure ratios are reported.

Define failure as modules that required replacement.



Expected failure rate 5 out of 10,000 modules annually

Jordan et al., *Progress in PV*, 2017

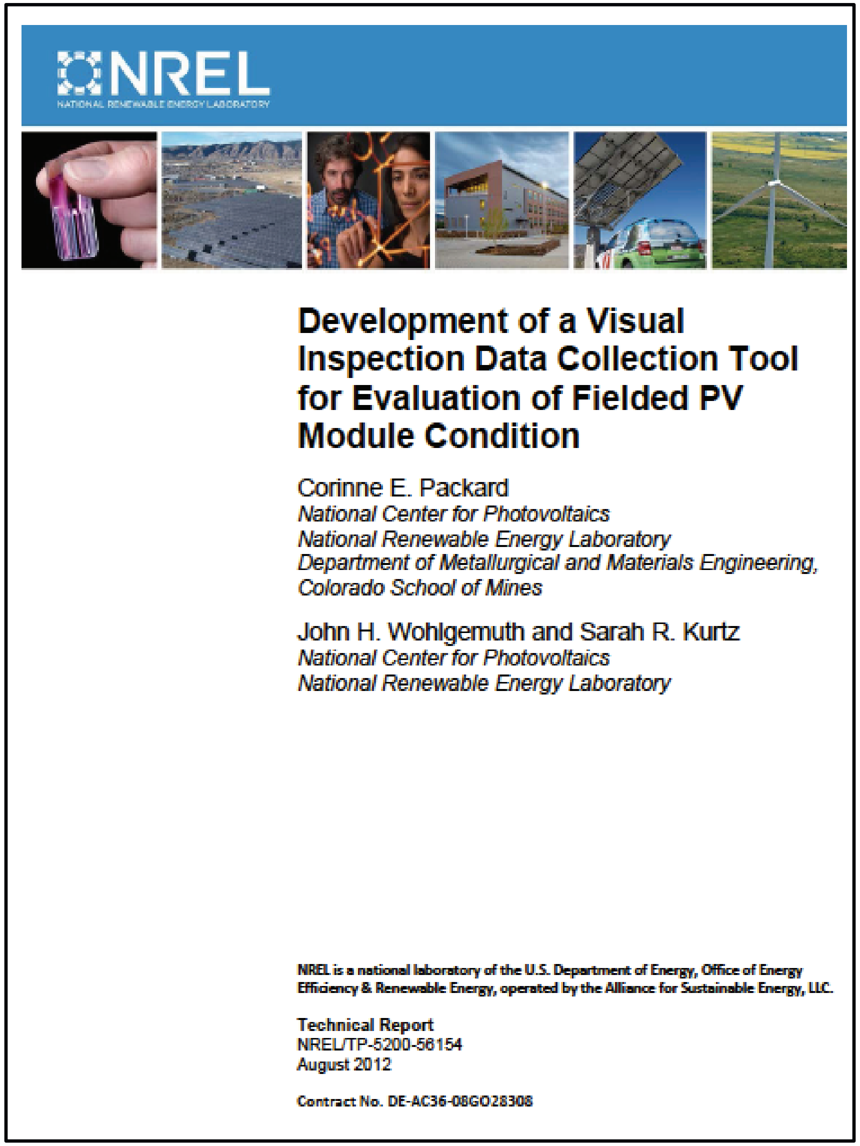
Visual Inspection Tool is not as widely used as we'd like

- Uses IEC/UL standard terminology
- Balance collection of sufficient detail for degradation mode evaluation against minimizing recording time per module
- Consists of 14 sections- based on module component
- Short & long version available

Example: front glass

Polverini et al. , Prog in PV, 2012.

Visual inspection could help discriminate between these cases



NREL
NATIONAL RENEWABLE ENERGY LABORATORY

Development of a Visual Inspection Data Collection Tool for Evaluation of Fielded PV Module Condition

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NREL is a national laboratory of the U.S. Department of Energy, Office of Energy Efficiency & Renewable Energy, operated by the Alliance for Sustainable Energy, LLC.

Technical Report
NREL/TP-5200-56154
August 2012

Contract No. DE-AC36-08GO28308

How can we be more quantitative?

Risk priority number (RPN) = No. reports*No. affected modules * Severity * ~~Detectability~~

Severity	Rating
Major impact on power & safety	10
Major impact on power	8
Significant impact on power	5
Slight deterioration of performance	3
No effect on performance	1

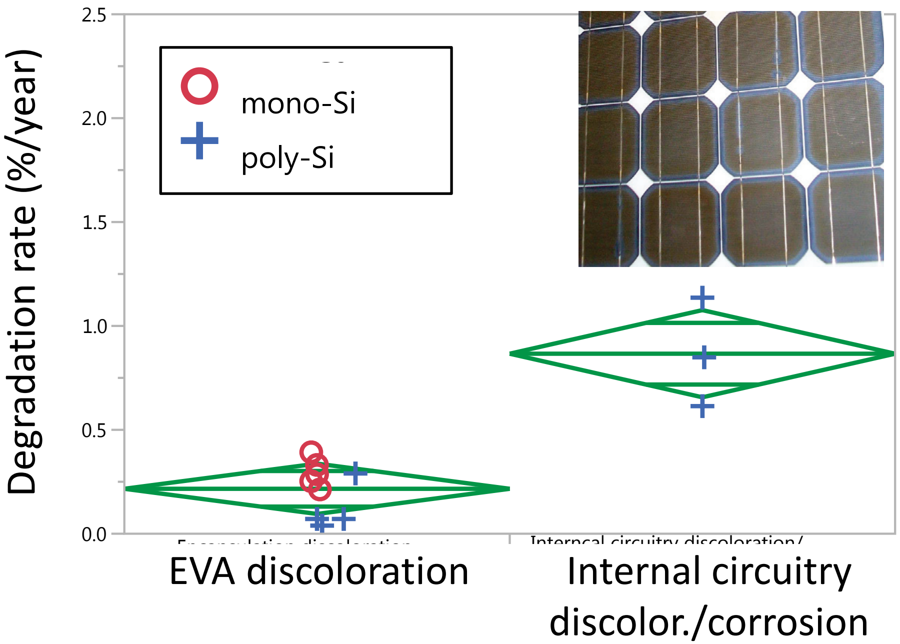
For better discrimination the scale is not continuous

Mode	Severity
Backsheet insulation compromise	10
Hot spots	10
Internal circuitry (IC) failure	8
PID	8
Major delamination	5
Internal circuitry (IC) discoloration	5
Fractured Cells	5
Diode/J-box problem	5
Glass breakage	5
Encapsulant discoloration	3
Frame deformation	3
Permanent soiling	2
Minor delamination	1
Backsheet other	1

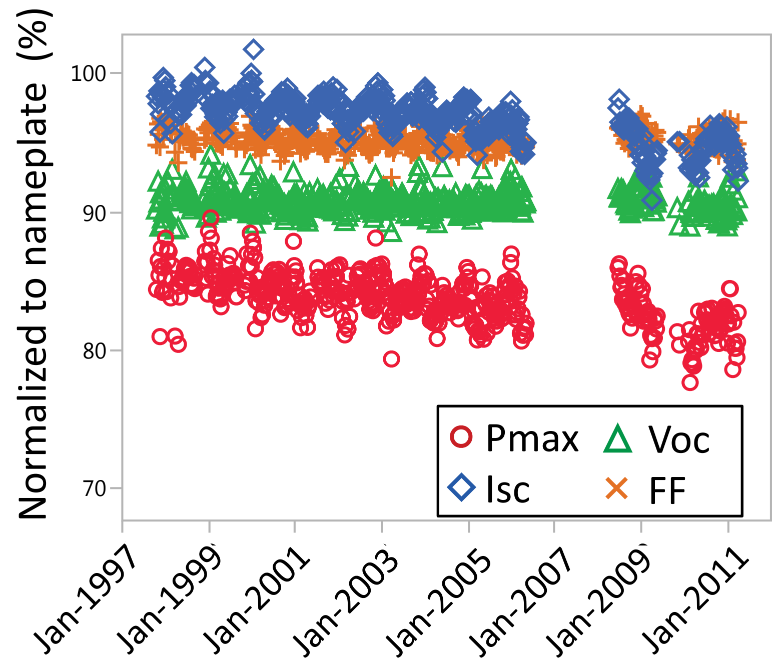
Synergy of degradation modes often make it difficult to determine the power impact of a specific degradation mode.

Kuitche et al., *JPV*, 2014

Encapsulation discoloration associated with small power loss



Jordan, et al., 35th PVSC, Honolulu, HI, USA, 2010.



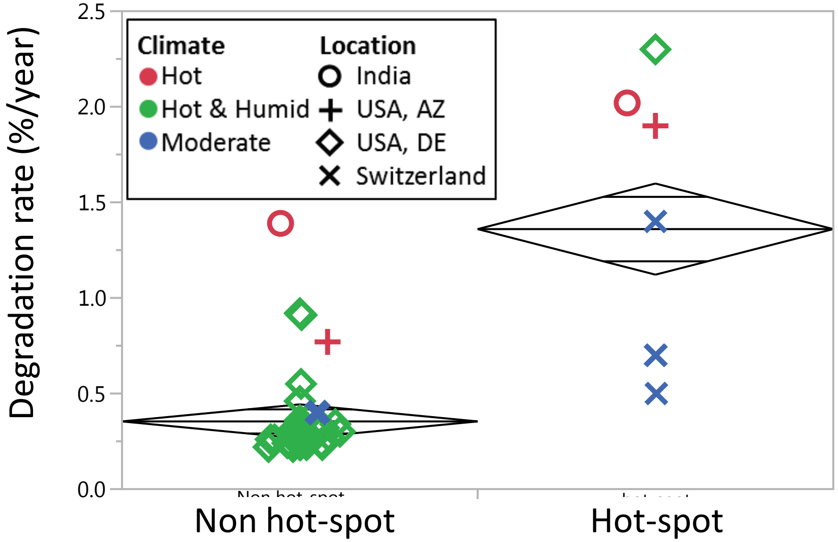
Date

Encapsulant discoloration associated with lower power loss in direct comparison.

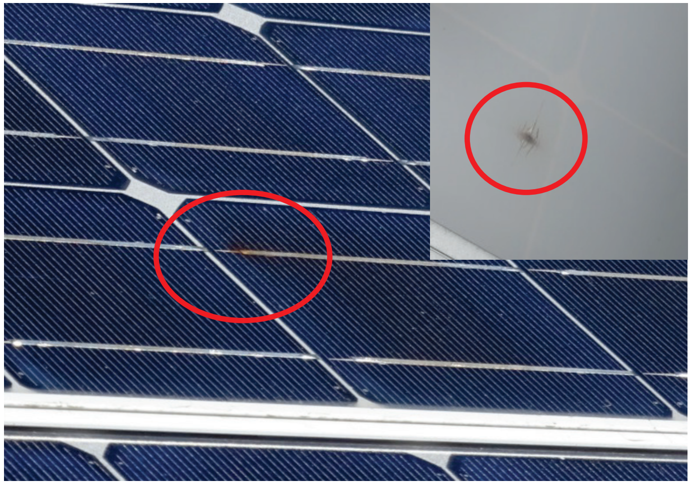
Encapsulant discoloration shows linear decline below 0.5 %/year, dominated by Isc losses.

Smith et al., *WREF* 2012

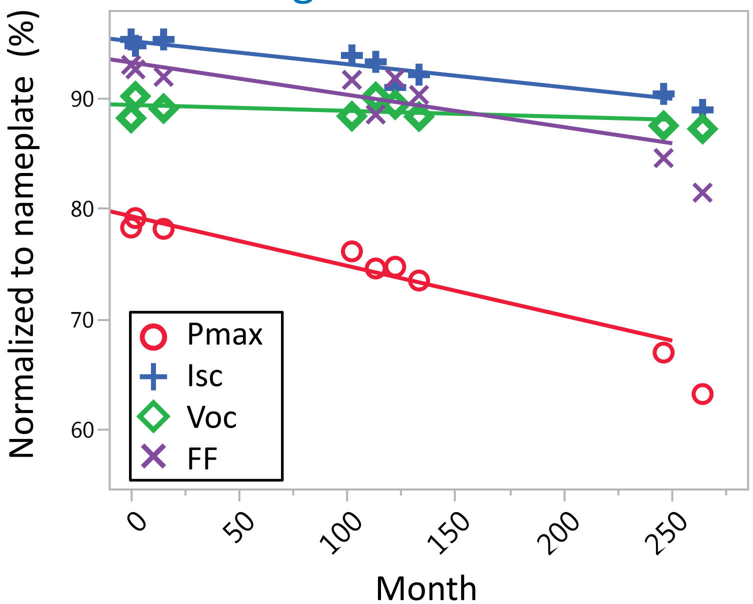
Hot-spots lead to larger power loss & pose safety issue



Internal circuitry (IC) failure due to solder bond



String IV measurements

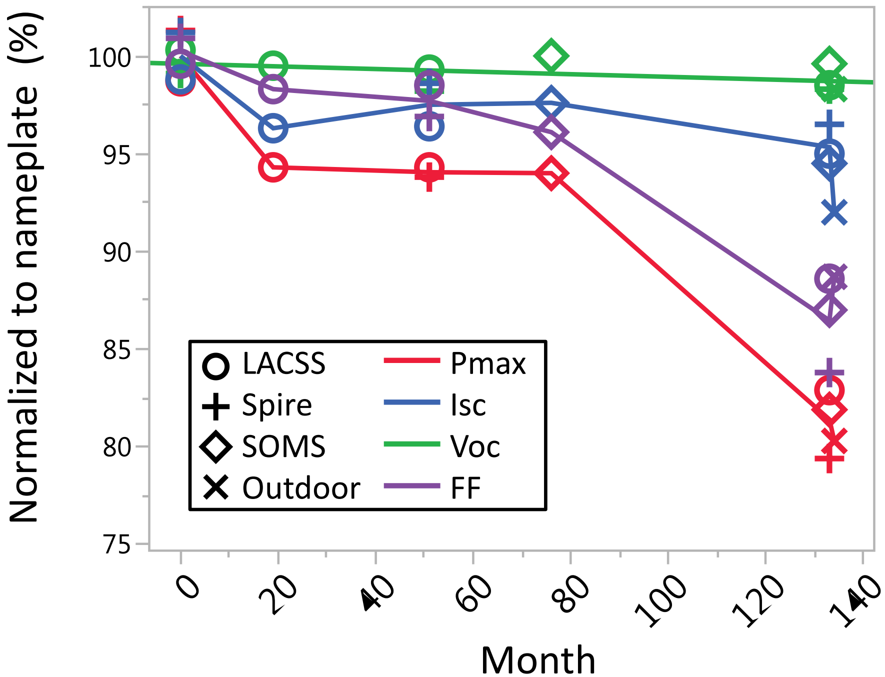


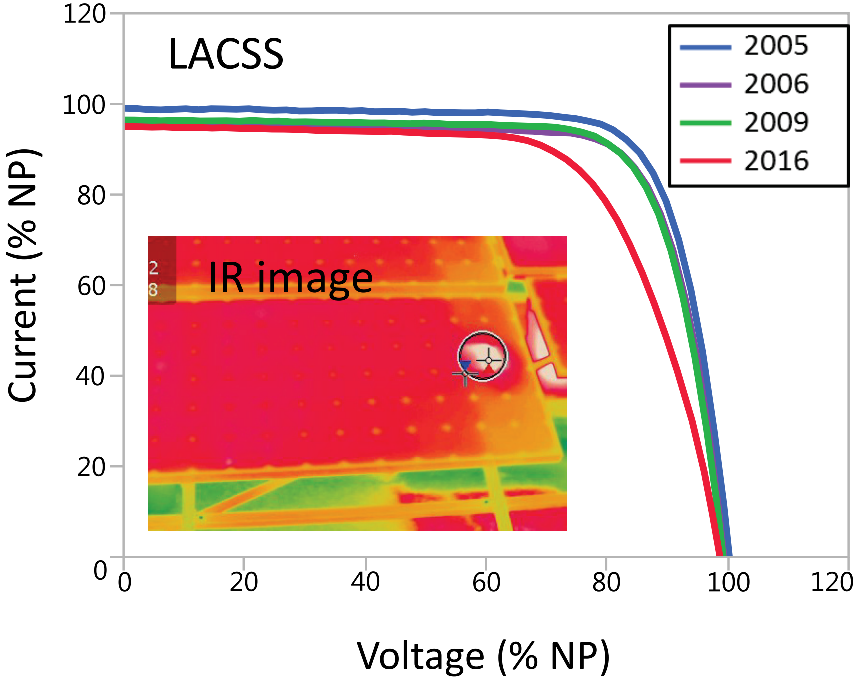
The first 20 years decline appears to be around 0.5 %/year.

More rapid decline associated with FF loss.

Hot spot because of cracked cell causing non-linearity

I-V measurements



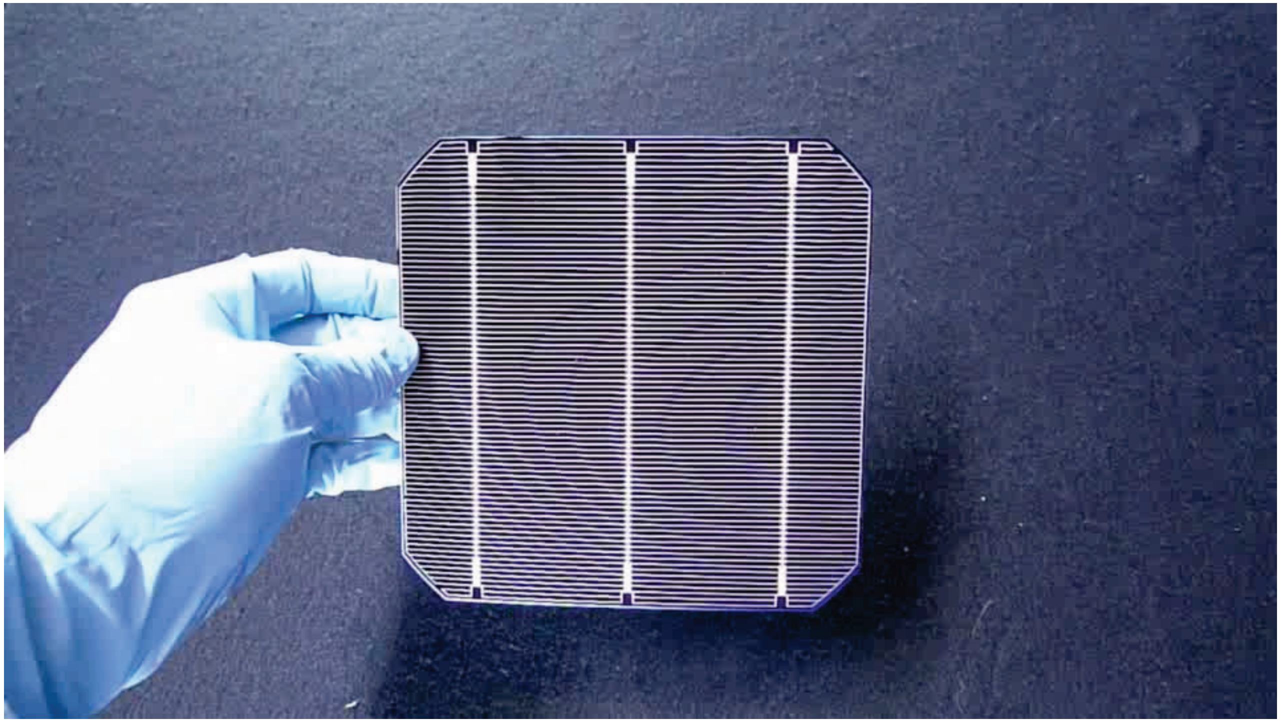


LACSS: large area solar simulator
Spire: indoor flash tester
SOMS: standard outdoor measurement system
Outdoor: Daystar field measurements

- Module was stable for several years
- Now we see more precipitous decline associated with FF losses, Rs increase

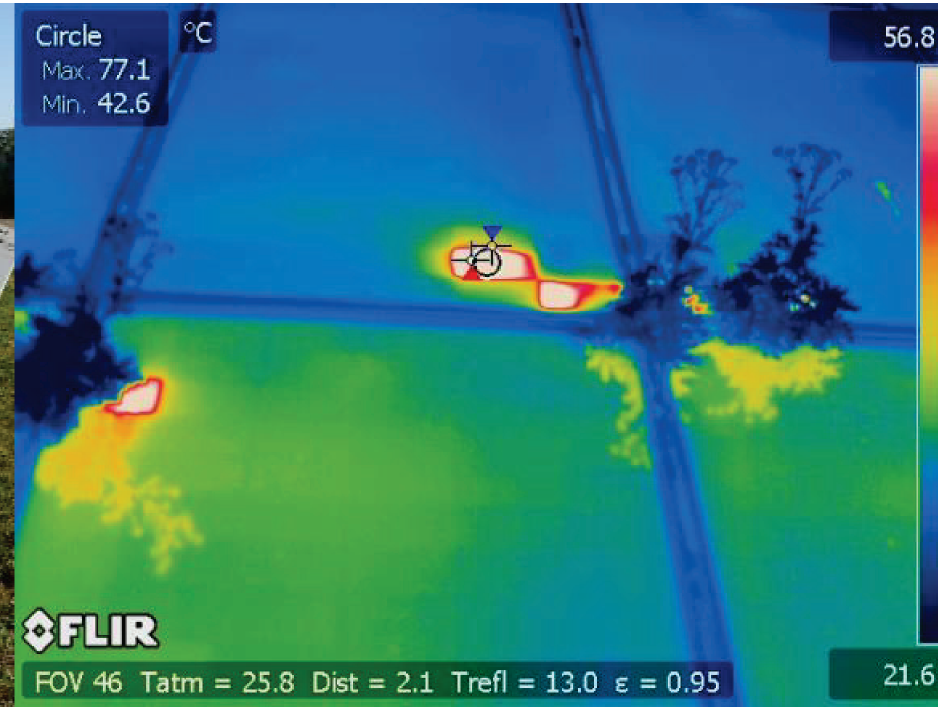
Jordan et al., *Progress in PV*, 2016

Cracked cells can easily be induced



https://www.youtube.com/watch?v=-qdyxIybmoc

Other reasons for hot spots



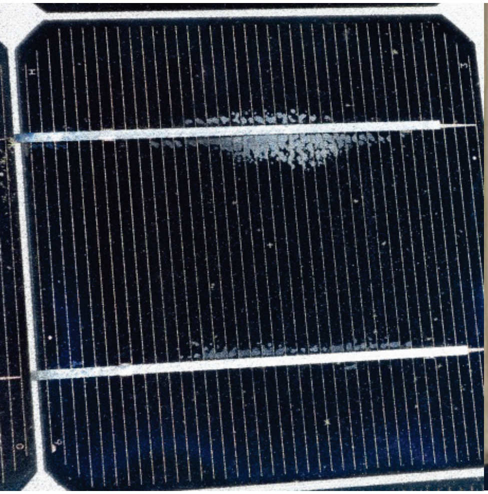
Constant shading stresses bypass diodes and may eventually lead to diode failure

Delamination can have different impact

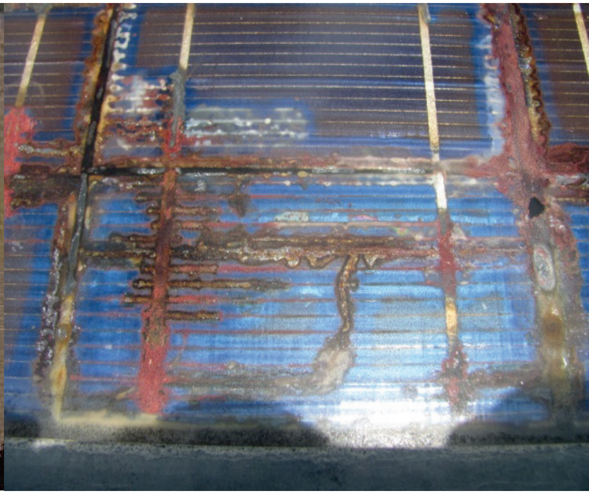
Initial stages

More advanced stages

Encapsulant/Si

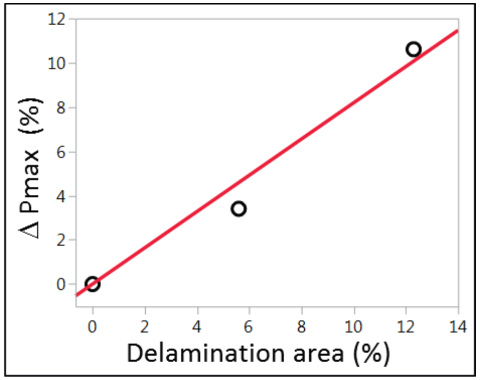


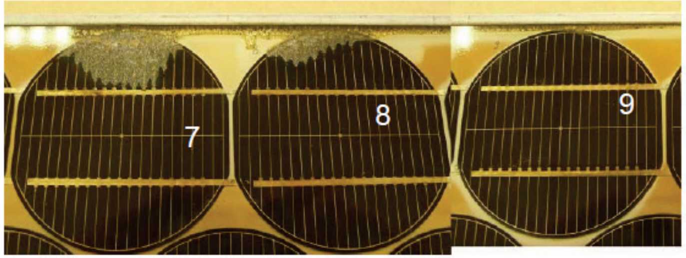
Glass/encapsulant



Skoczek et al., *Progress in PV*, 2009

Before moisture ingress & corrosion delamination appears to scale with affected area, dominated by Isc losses

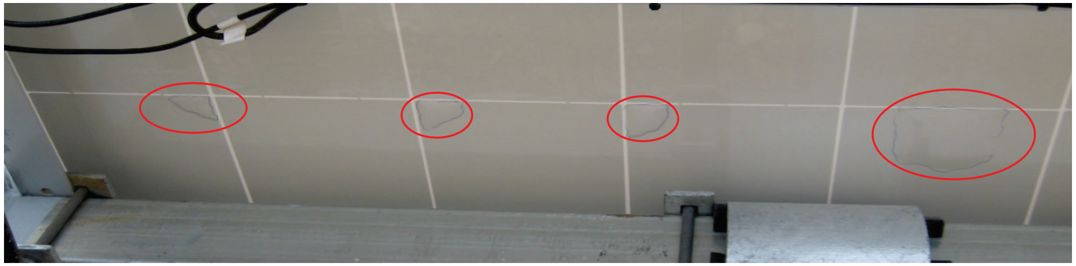




Friesen et al., PVMR, 2011

Backsheet issues can have different impact

Minor issues

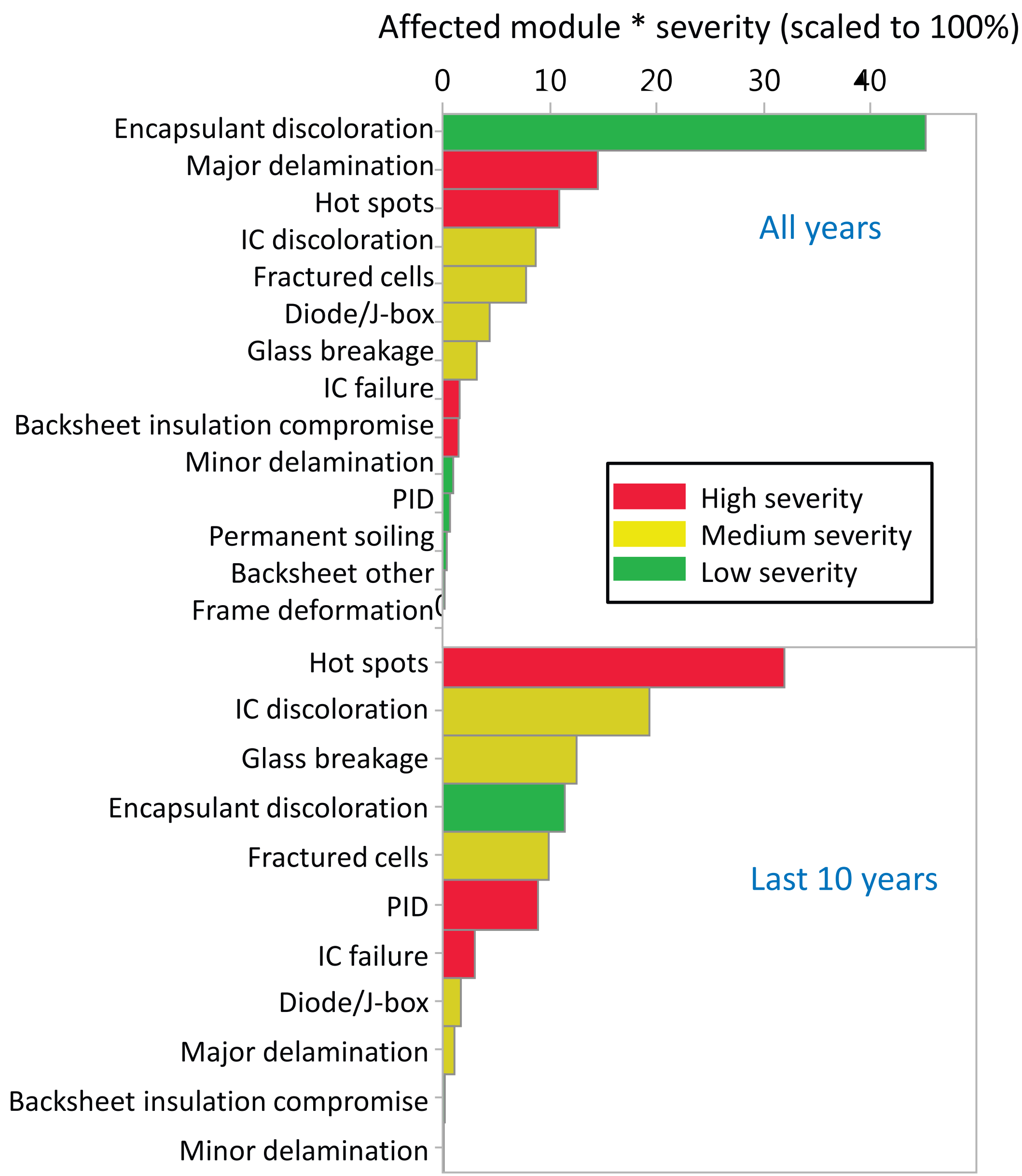


deGraaff et al. , PVMR, 2011

Major problem

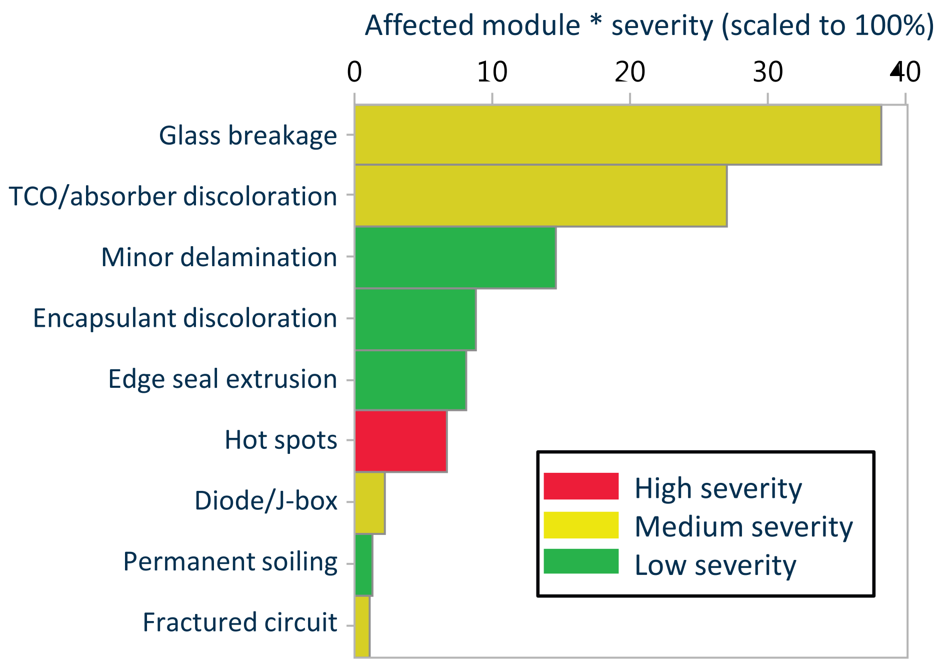
Mani et al. , PVSC, 2014

Hot-spots most common degradation mode in recent years



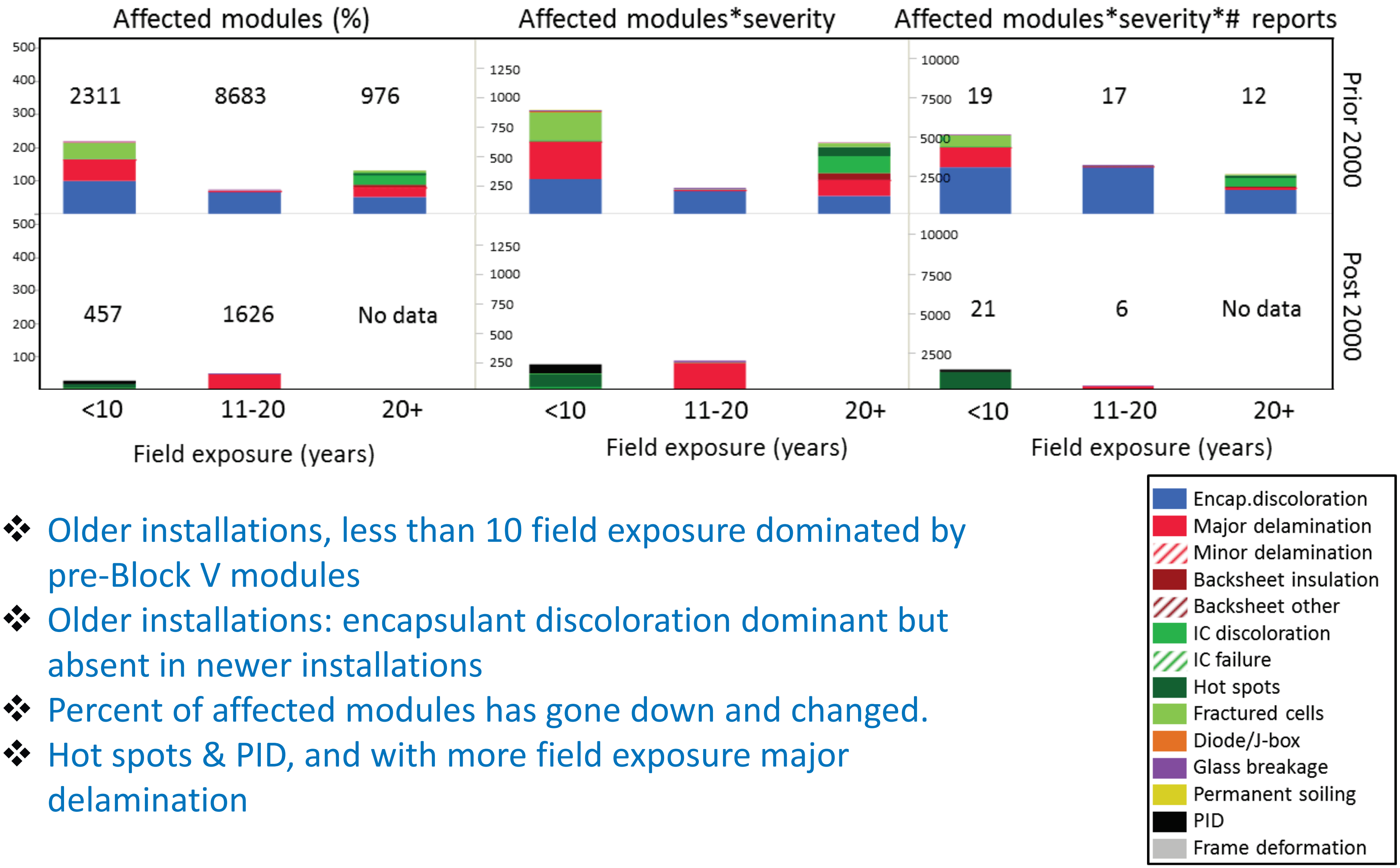
Thin-films: glass breakage most important

Don’t have a lot of data on thin-film degradation modes



Percent of affected modules has gone down in newer installations

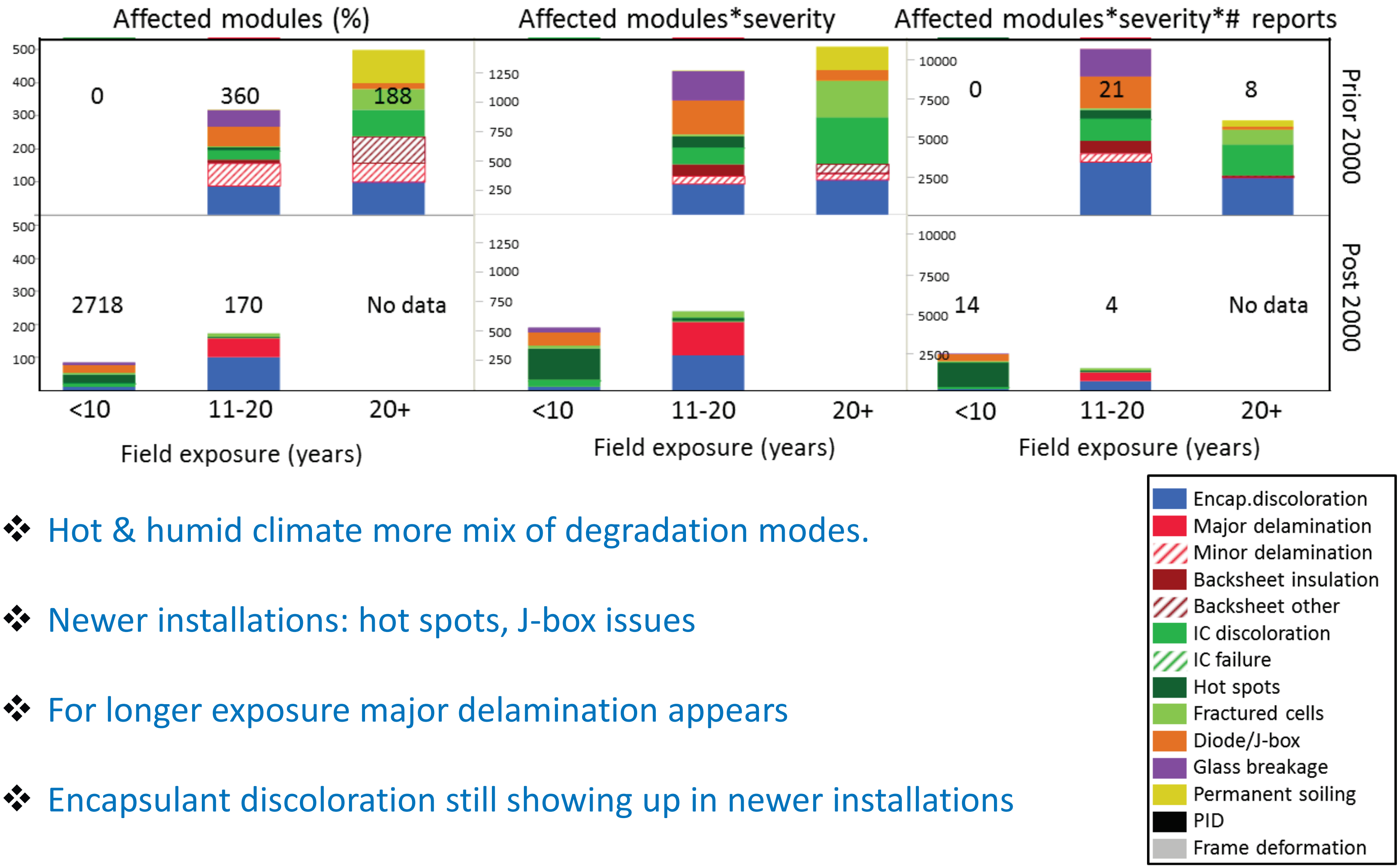
Moderate Climate



- Older installations, less than 10 field exposure dominated by pre-Block V modules
- Older installations: encapsulant discoloration dominant but absent in newer installations
- Percent of affected modules has gone down and changed.
- Hot spots & PID, and with more field exposure major delamination

Hot & humid see higher fraction of modules affected

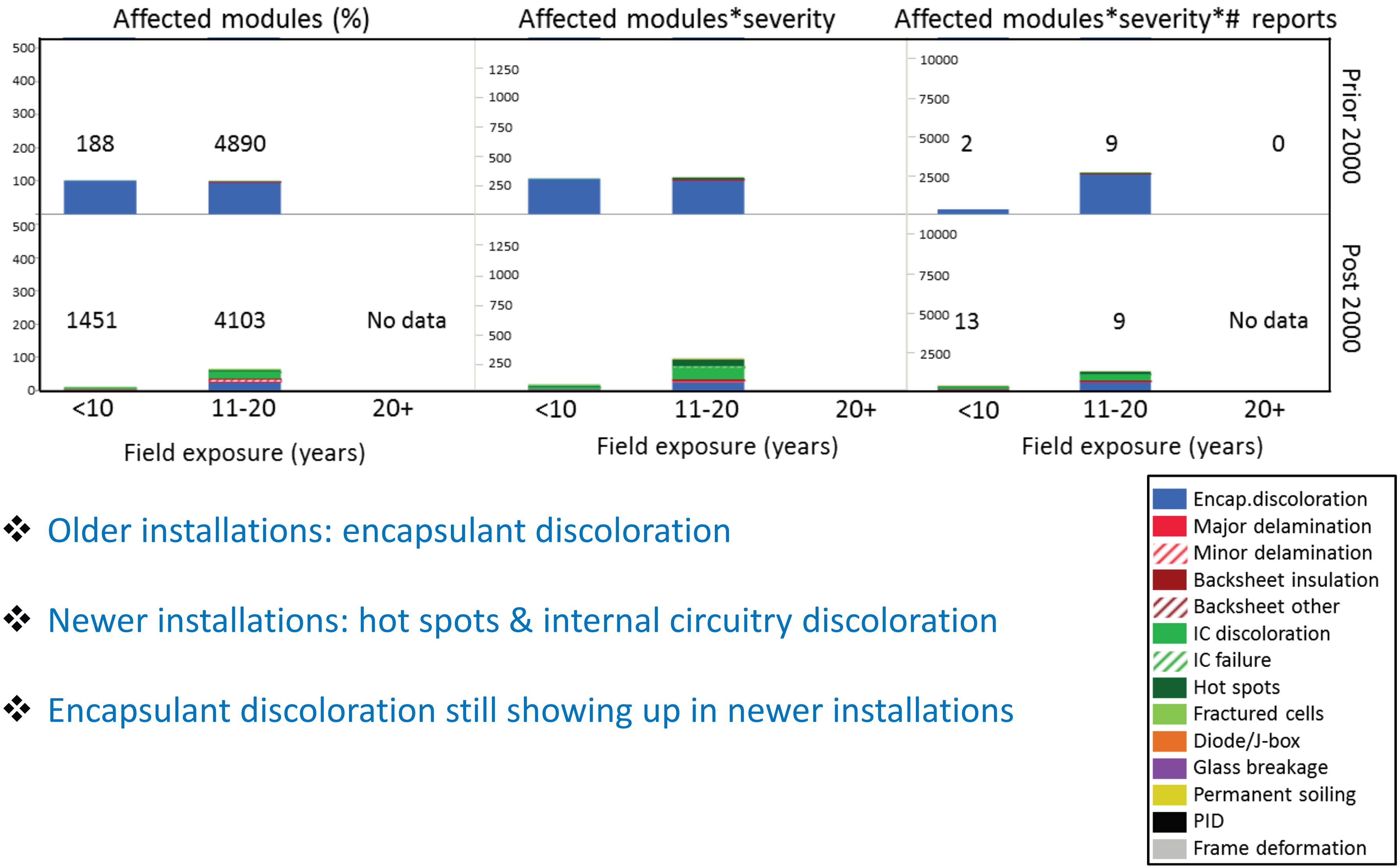
Hot & humid climate



- Hot & humid climate more mix of degradation modes.
- Newer installations: hot spots, J-box issues
- For longer exposure major delamination appears
- Encapsulant discoloration still showing up in newer installations

Desert, new installations: hot spots & internal circuitry discoloration

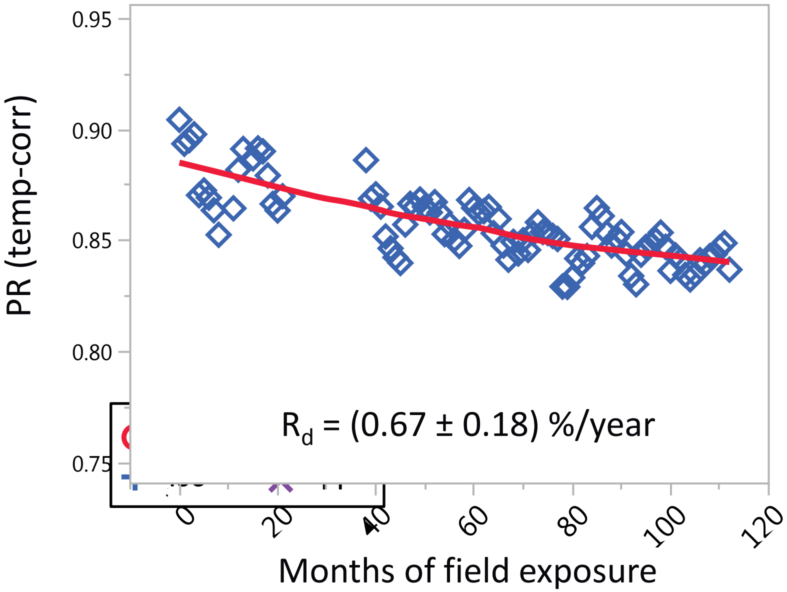
Desert climate

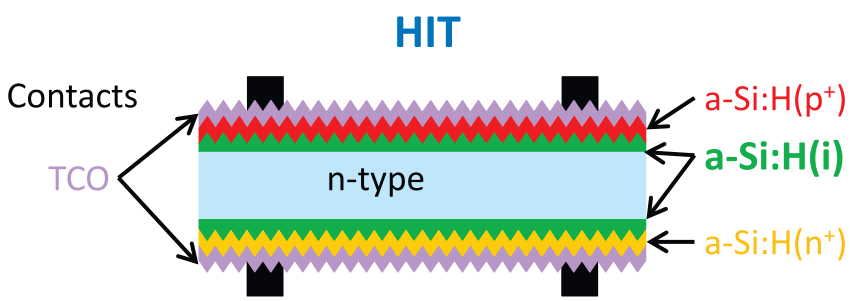


- Older installations: encapsulant discoloration
- Newer installations: hot spots & internal circuitry discoloration
- Encapsulant discoloration still showing up in newer installations

"New" Degradation Mode?

HIT (heterojunction with intrinsic thin layer)



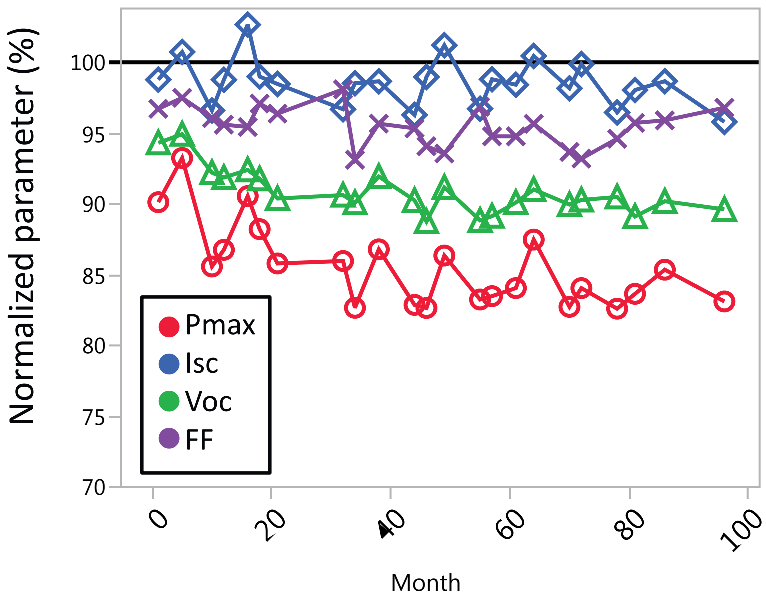


- System size: 1kW, 5 modules
- Installed Sep. 2007
- Kept control module indoors
- **Degradation is within warranty**

Jordan et al., *PVSC*, 2017

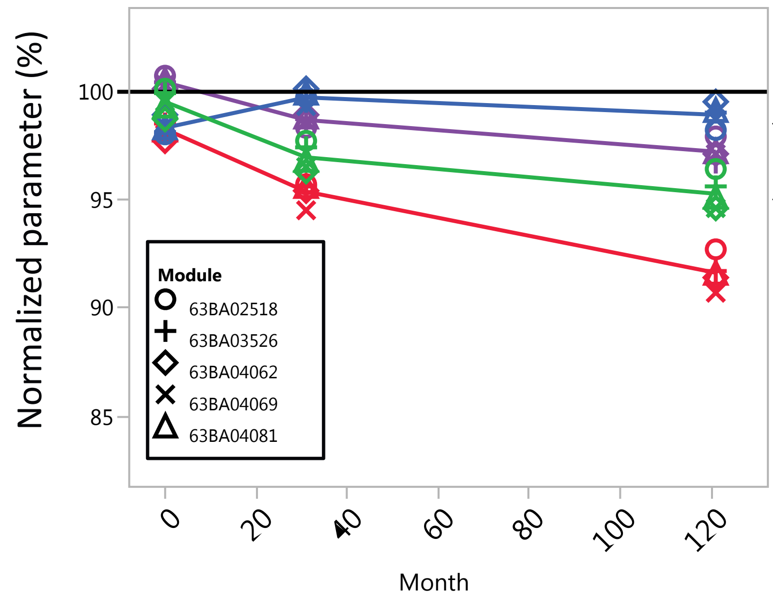
Nonlinear decline in ***Voc***

Outdoor IV



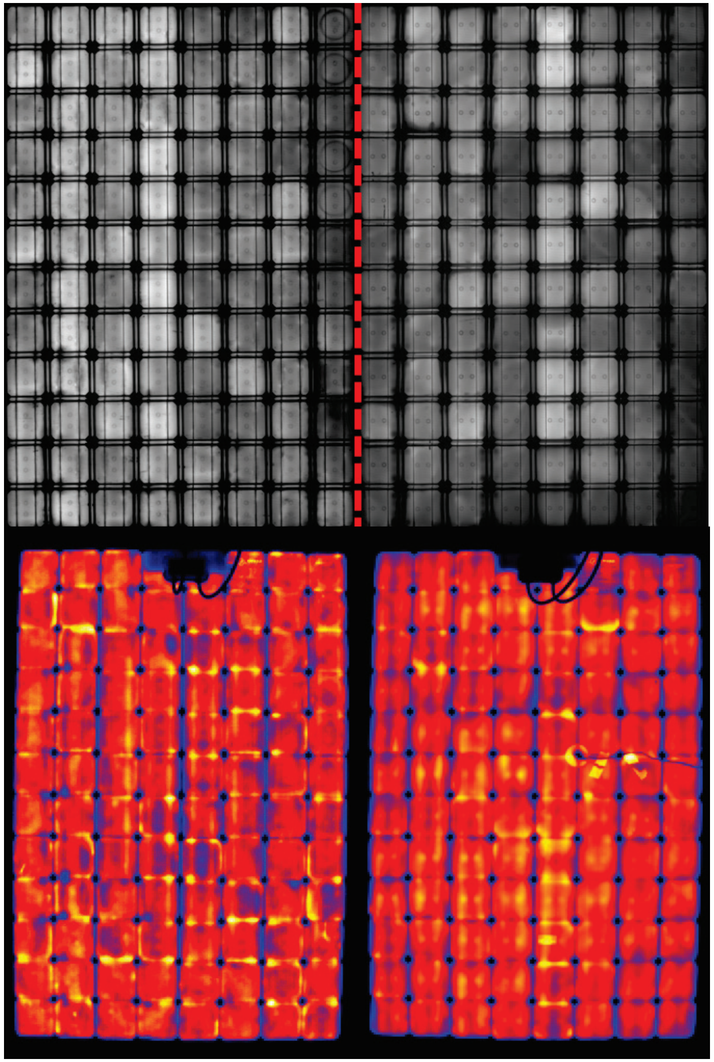
Temperature corrected to 45°C

Indoor IV



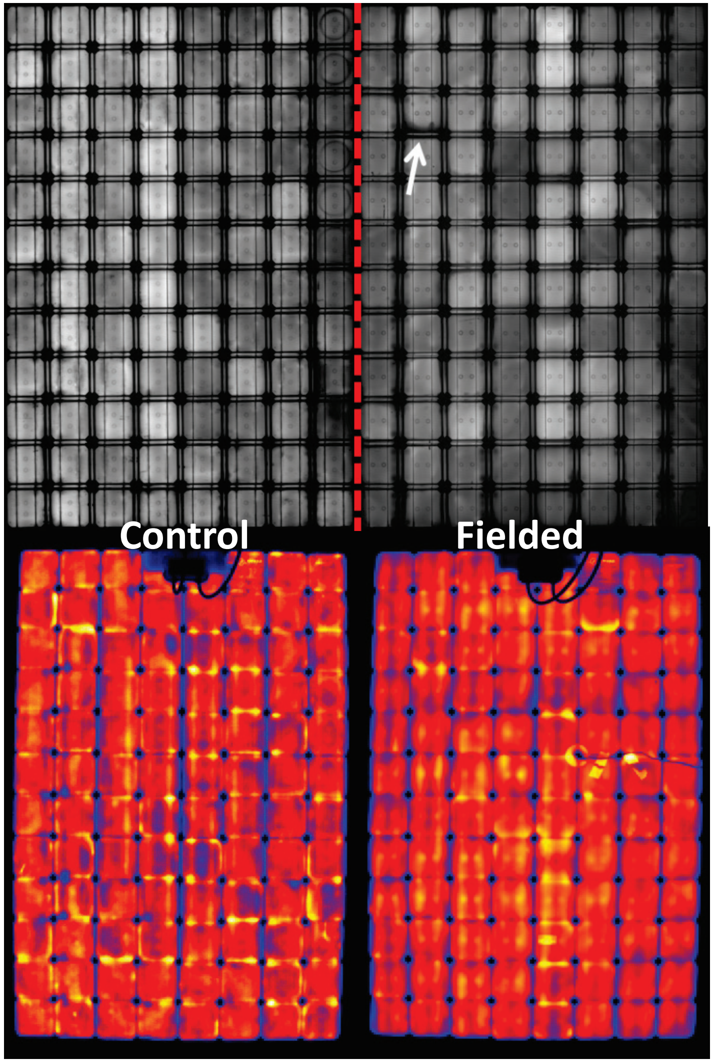
Isc: within measurement uncertainty
FF: small decrease
Voc: most of the decline in first 2 years

Electroluminescence



Dark Lock-in Thermography

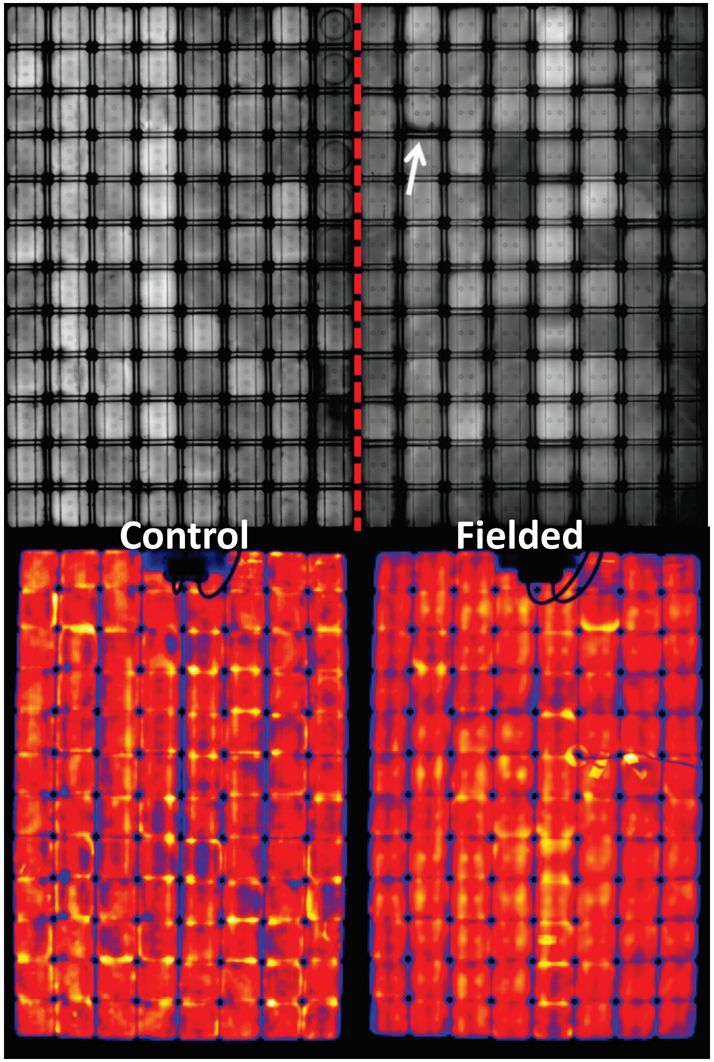
Electroluminescence



Dark Lock-in Thermography

Uniform across module, R_s increase

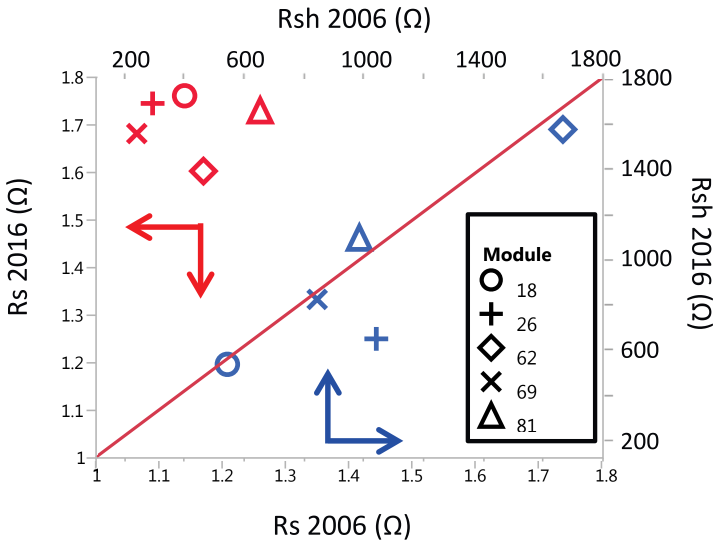
Electroluminescence



Dark Lock-in Thermography

Some cells show slight edge-shunting, but..
it is also present in the control module!

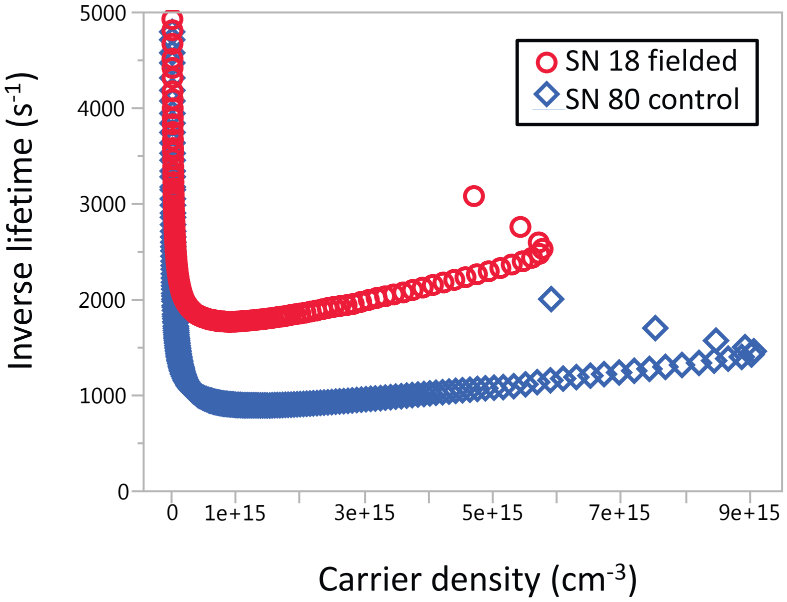
Dark IV taken in 2006 & 2016



Some series resistance increase
No shunt resistance decrease

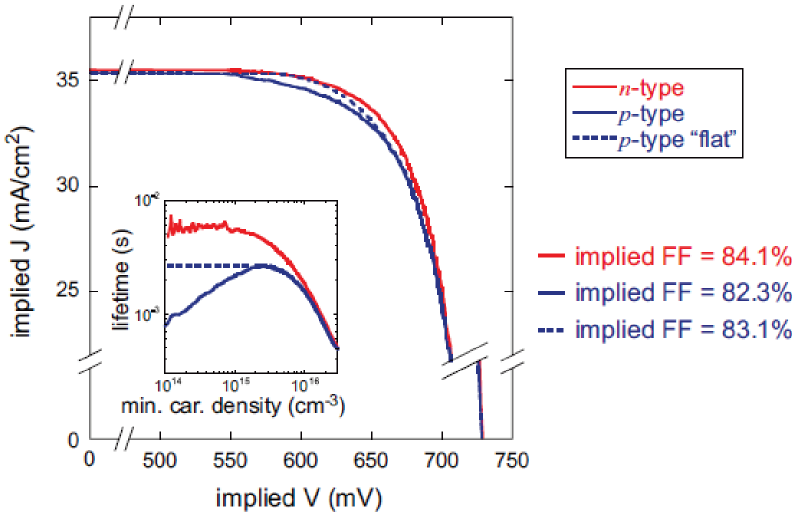
New cell designs may lead to "new" degradation modes

From Suns-Voc measurements



Sinton et al., EU PVSEC, 2000.

Same HIT structure on n- & p-type



Descoeudres, De Wolf et al., JPV, 2013.

p-type lower FF → lower quality passivation layer
Appears as a slightly "higher series resistance"
Passivation layer is degrading

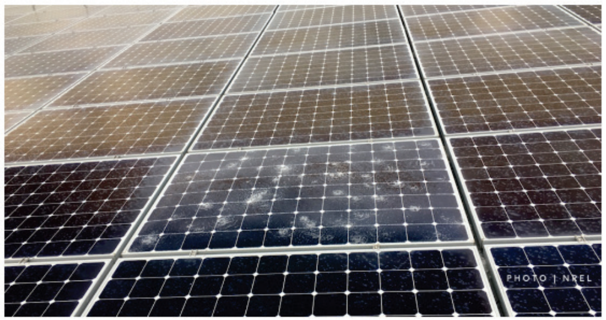
Cell structure has changed with field exposure

1. **Prices go down → new bill of materials leads to question on dependability**
2. **Efficiencies go up → new cell designs may lead to "new" degradation modes**

Modules fairly robust even in severe storms

10 modules out of 3790, 8 year field exposure
→ failure rate λ = 0.03 %/year

Hail No! National Lab's Solar Panels Survive Severe Storm



Just one PV panel out of more than 3,000 was damaged at NREL following the hailstorm. Photo | NREL

Summary

- Failure rates are not often reported but mostly relatively low ca. 5 out of 10,000 annually
- Fewer degradation modes in newer installations
- Most dominant degradation modes in the last 10 years is hot-spots
- Change of bill of materials may lead to occurrence of new of old degradation modes
- Evolution of cell designs may lead to “new” degradation modes

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