

Making the Most of Module Matrix Measurements

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...Module Matrix Measurements



IEC 61853-1

Table 2 – I_{sc} , P_{max} , V_{oc} and V_{max} versus irradiance and temperature

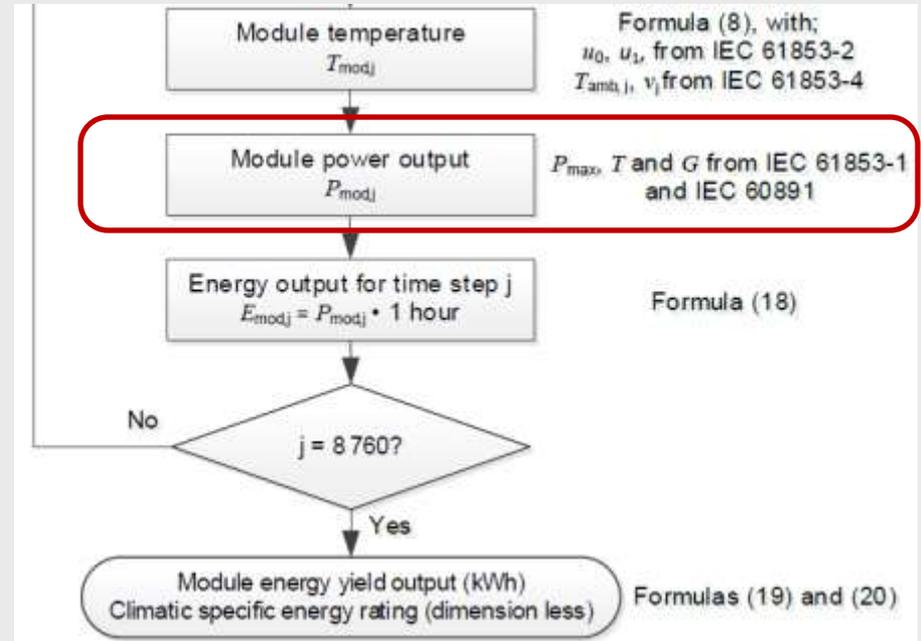
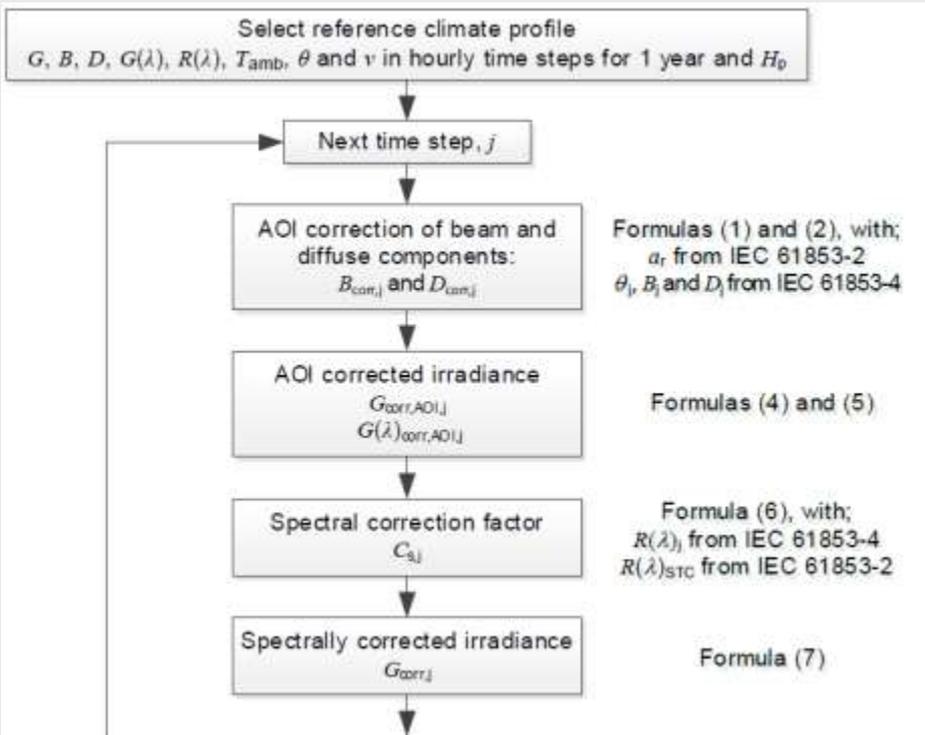
Irradiance $W \cdot m^{-2}$	Spectrum	Module temperature			
		15 °C	25 °C	50 °C	75 °C
1 100	AM1,5	NA			
1 000	AM1,5				
800	AM1,5				
600	AM1,5				
400	AM1,5				NA
200	AM1,5			NA	NA
100	AM1,5			NA	NA

Making the Most of...



- Module output varies with operating conditions
- Measurements on a range of conditions and combinations defines the real-world module behavior
- Knowledge of module behavior facilitates:
 - PV system simulation
 - PV module energy rating (IEC-61853-3)
 - model validation
 - system optimization
 - and in the hands of creative smart people like you—much, much more

Energy rating, IEC-61853-3



Matrix measurements in the value chain



1. Manufacturer designs a fantastic new module
2. Independent lab carries out IEC 61853 performance tests
3. Manufacturer prints detailed results on datasheet
4. Simulation software provider enters results in database
5. Project developer runs software and obtains more accurate predictions of real-world output
6. Investor sees lower risk
7. Everyone is happy

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Plan A



- Improve availability of Matrix data
- All else will follow

Existing software



SAM

- enhanced one-diode model, allowing parameters to vary over the temperature/irradiance space
- minimal validation and no data available to run it

PV*SOL

- published a “superposition” method in 2015
- no plans to implement it as of 2018

PVsyst

- third-party tweaking of one-diode model parameters

Existing software



PlantPredict

- calculates temperature coefficients from the matrix

Helioscope

- does not use matrix data

pvlib-python

- no functions available to process or use matrix data

pvlib-Matlab

- several functions available to fit models to matrix measurements

Plan A rev.



- Create open source software to read/write/process Matrix data
- Improve availability of Matrix data
- All else will follow

Survey



- Many modules are being tested according to 61853-1
 - but several manufacturer declined to provide reports
- Principal motive is production of PAN files (for PVsyst)
 - but PVsyst discourage PAN files optimized from matrix measurements
- Some concerns
 - measured samples vs. production runs vs. installed systems
 - published matrix vs. performance guarantees
 - validity of extrapolation to “similar” modules/other power classes
 - lab tests vs. real world performance

A good question



Are indoor module matrix measurements really indicative of outdoor system performance?

We can only answer this question if we obtain matrix measurements

Another good question



Single-diode and SAPM models can calculate module power at any matrix point and in between.
Aren't these models good enough?

We can more easily answer this question
if we obtain matrix measurements

Plan B



- Create open source software to read/write/process Matrix data
- Demonstrate what *could* be done with matrix data if it *were* available
- All else will follow

Data available so far



- Public mPERT data set distributed by NREL
 - many module types with reduced matrix measurements by CFV solar
- One Canadian Solar module
 - matrix with extra intermediate temperature measurements
- One Sunpower and one Yingli module measured by NREL
 - missing measurements at 100 W/m² level

All different file formats and matrix points. ☹️

Working format for data exchange



```
name: Canadian Solar CS5P-220M
manufacturer: Canadian Solar
model: CS5P-220M
datasheet:
  alpha_sc: 0.06
  alpha_sc_units: '%/C'
  beta_oc: -0.35
  beta_oc_units: '%/C'
  gamma_mp: -0.45
  noct: 45
  cells_in_series: 96
  source: Sandia National L
```

YAML

column,units

CSV

CSV

```
temperature,°C
irradiance,W
v_oc,V
i_sc,A
v_mp,V
i_mp,A
p_mp,W
```

```
index,temperature,irradiance,v_oc,i_sc,v_mp,i_mp,p_mp
```

```
0,75,1100.0,31.1,9.233,22.97,8.331,191.3
1,75,1000.0,30.98,8.472,23.07,7.661,176.7
2,75,800.0,30.6,6.831,23.21,6.198,143.8
3,75,600.0,30.1,5.176,23.24,4.704,109.3
4,50,1100.0,34.01,9.146,25.99,8.413,218.6
5,50,1000.0,33.88,8.392,26.08,7.729,201.6
6,50,800.0,33.51,6.769,26.21,6.244,163.7
7,50,600.0,33.01,5.134,26.24,4.731,124.1
8,50,400.0,32.32,3.476,26.08,3.196,83.33
9,25,1100.0,37.01,9.069,29.17,8.437,246.1
10,25,1000.0,36.88,8.324,29.26,7.746,226.6
```

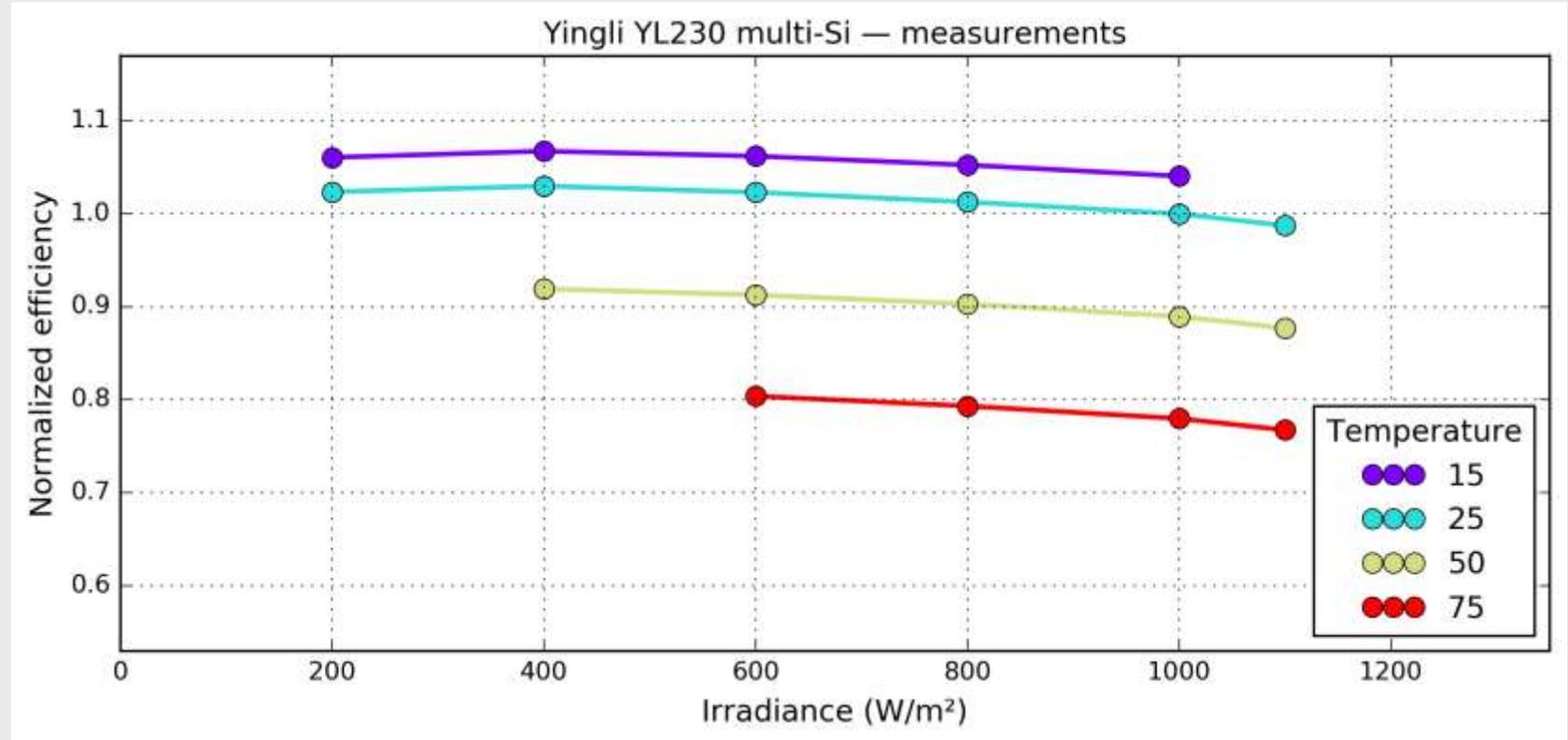
Three parts:

1. Meta data
2. Column definitions
3. Tabular data

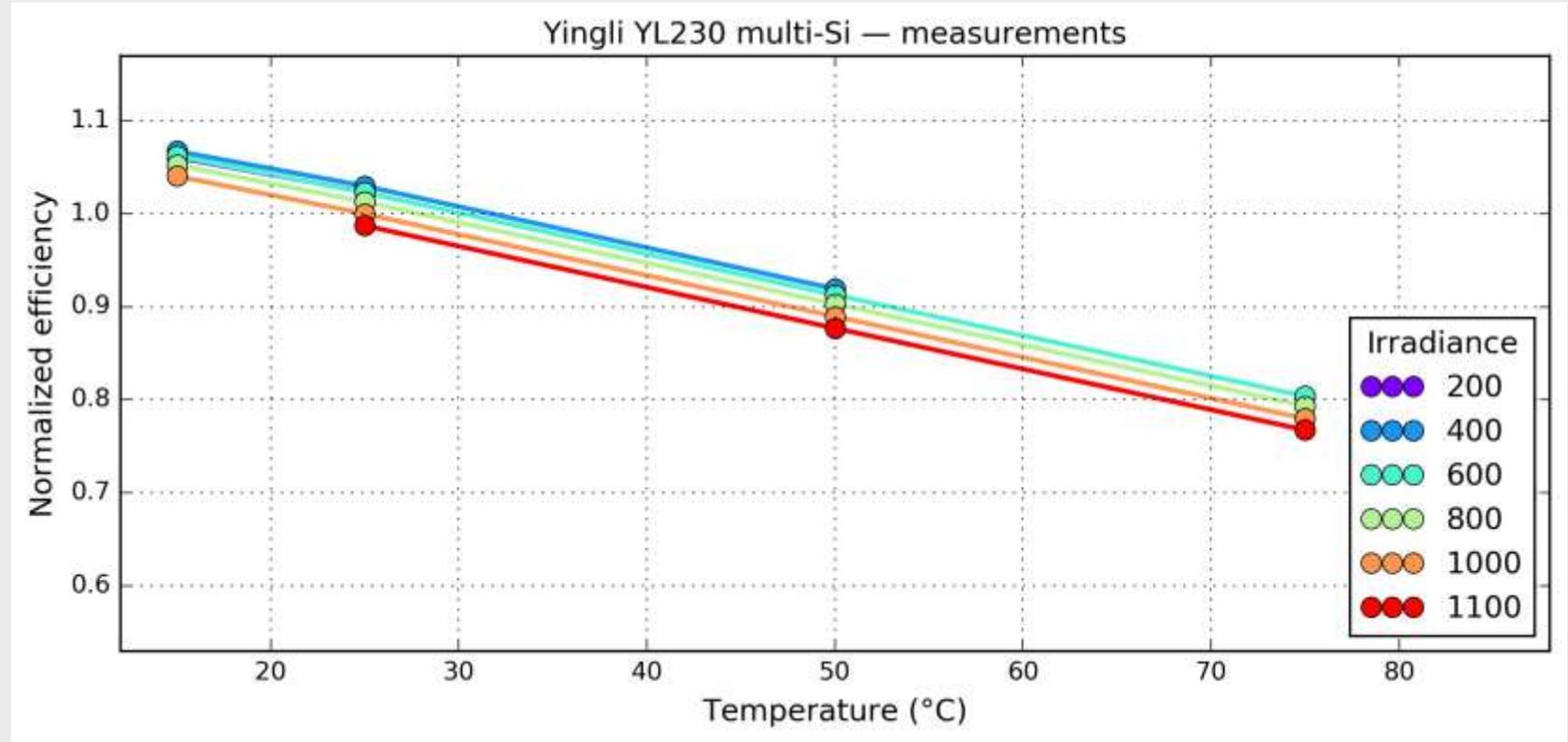
Yingli YL230 multi-Si (NREL 2018)



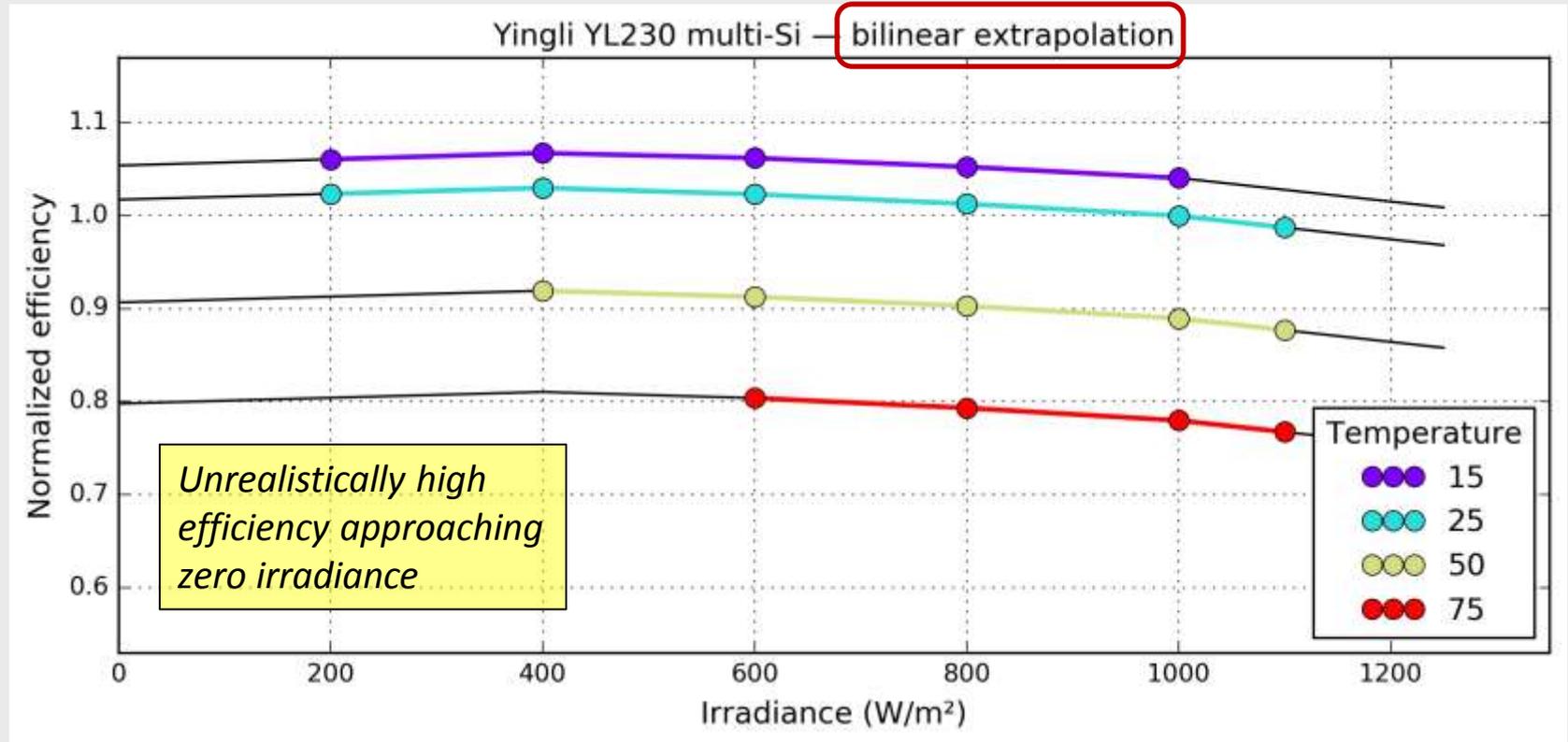
Yingli YL230 multi-Si (NREL 2018)



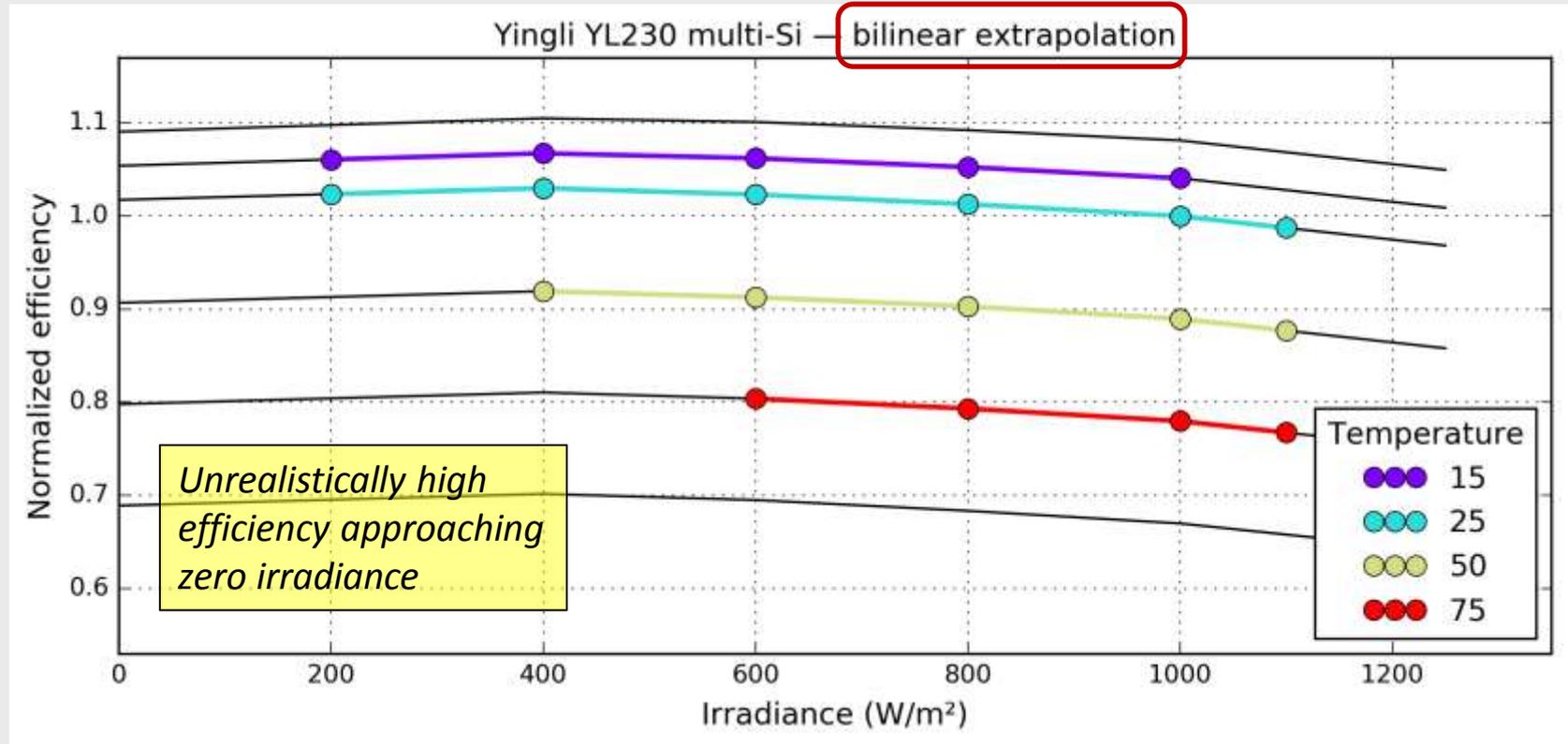
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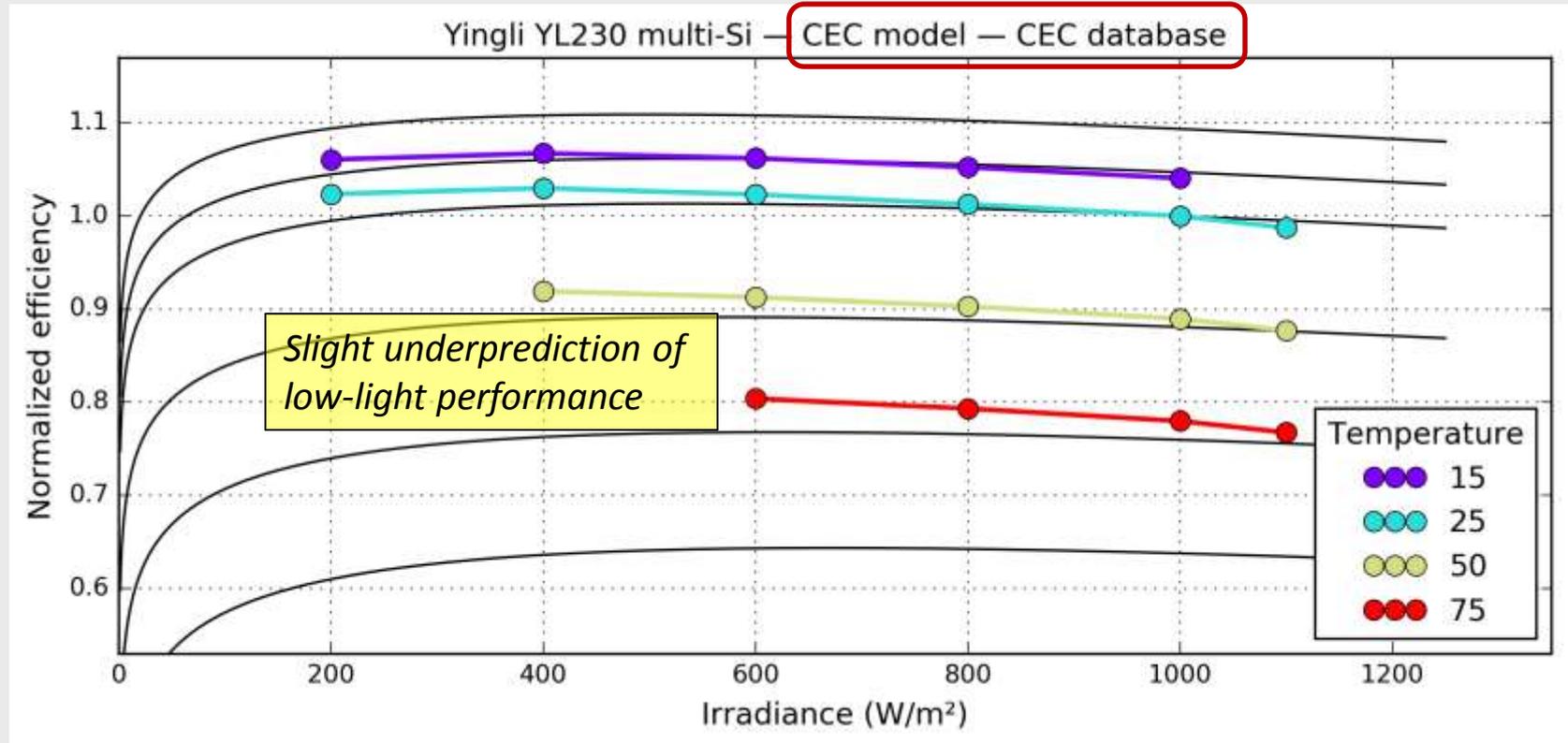
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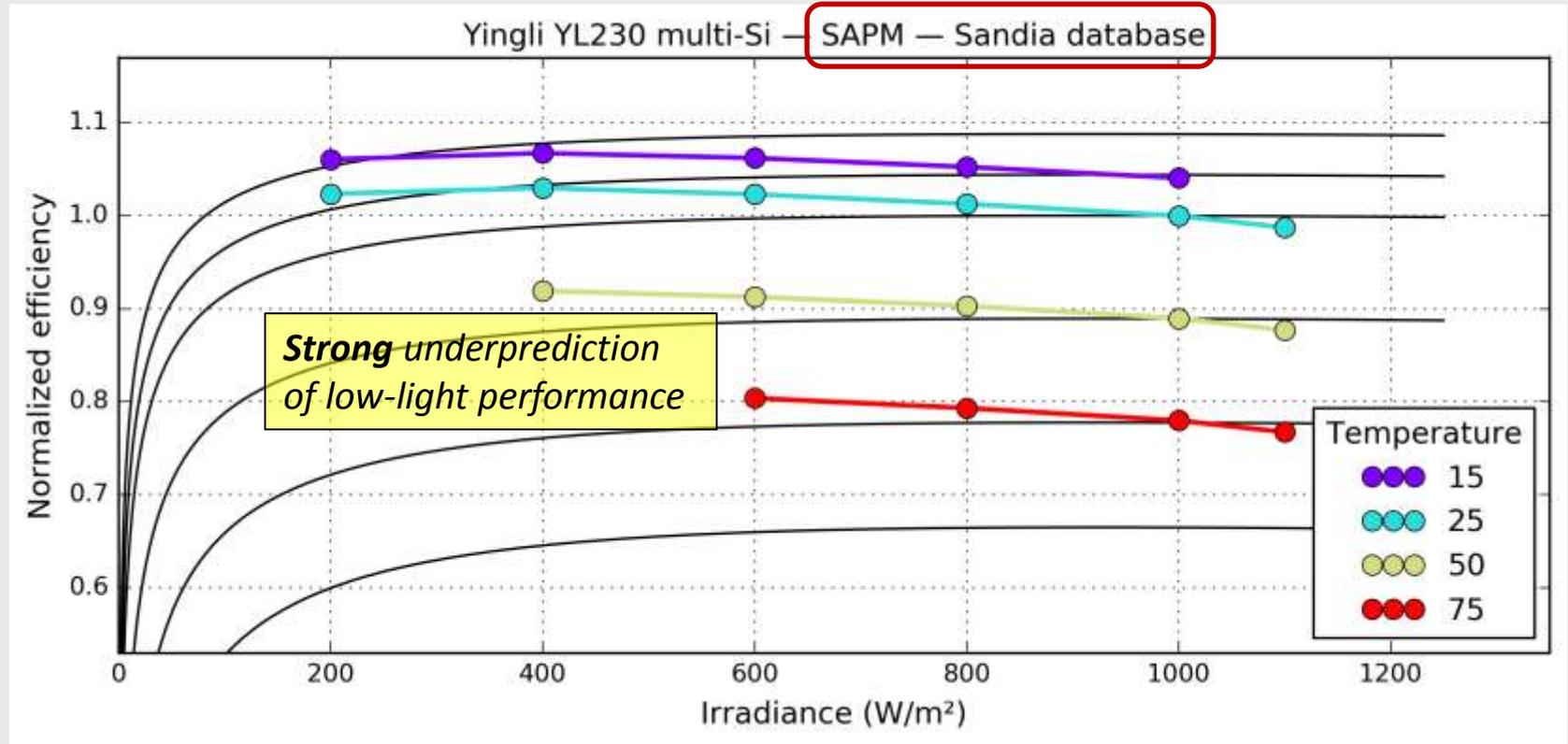
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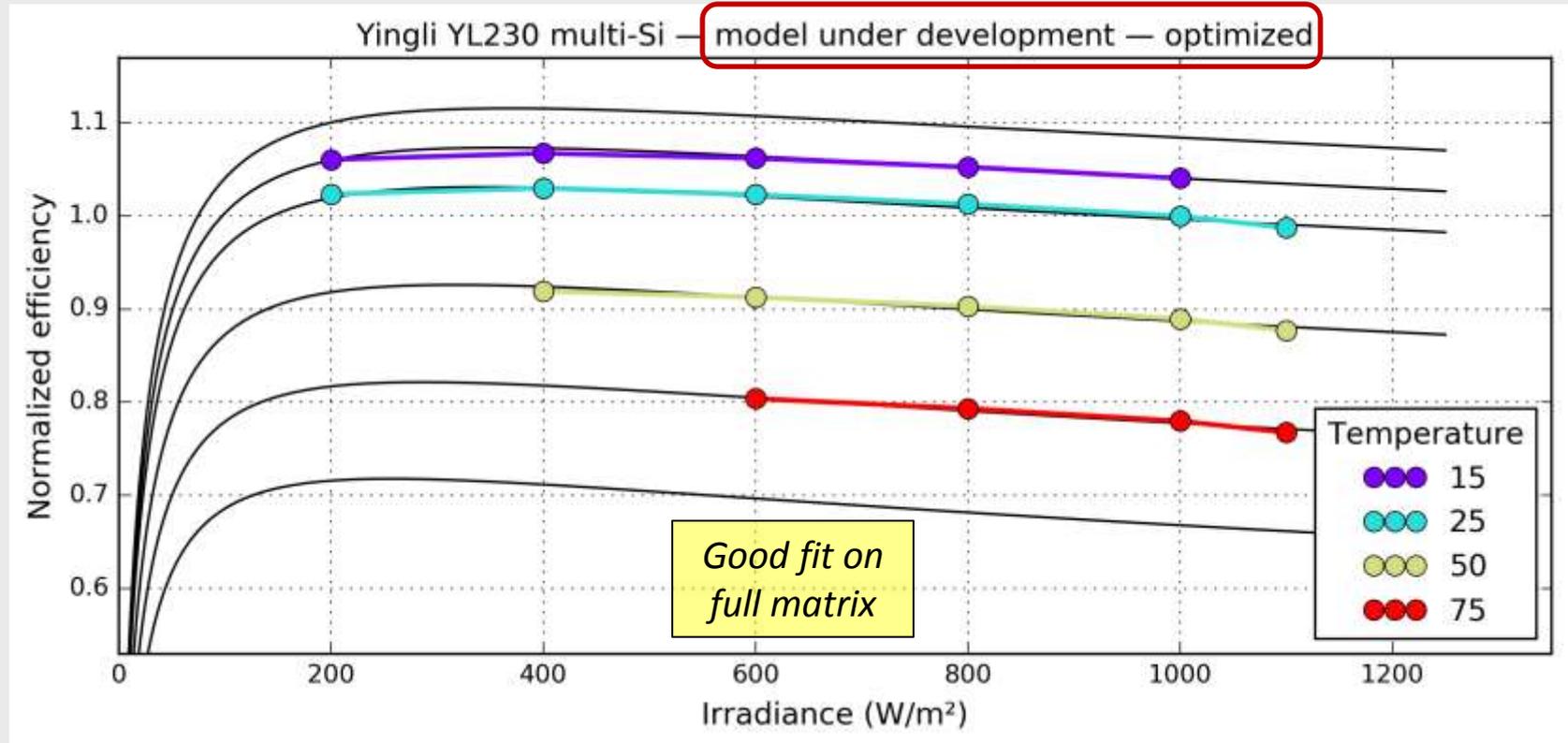
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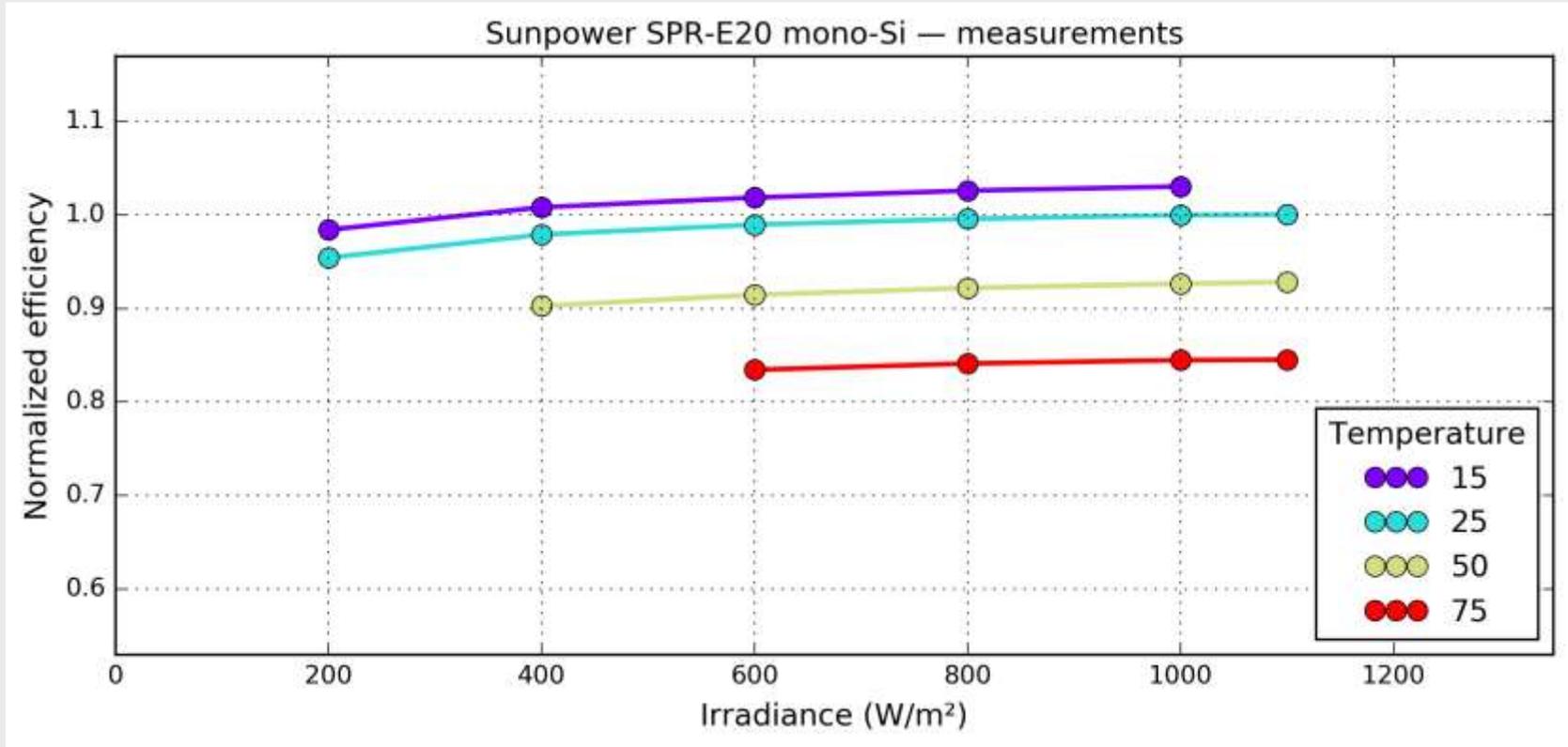


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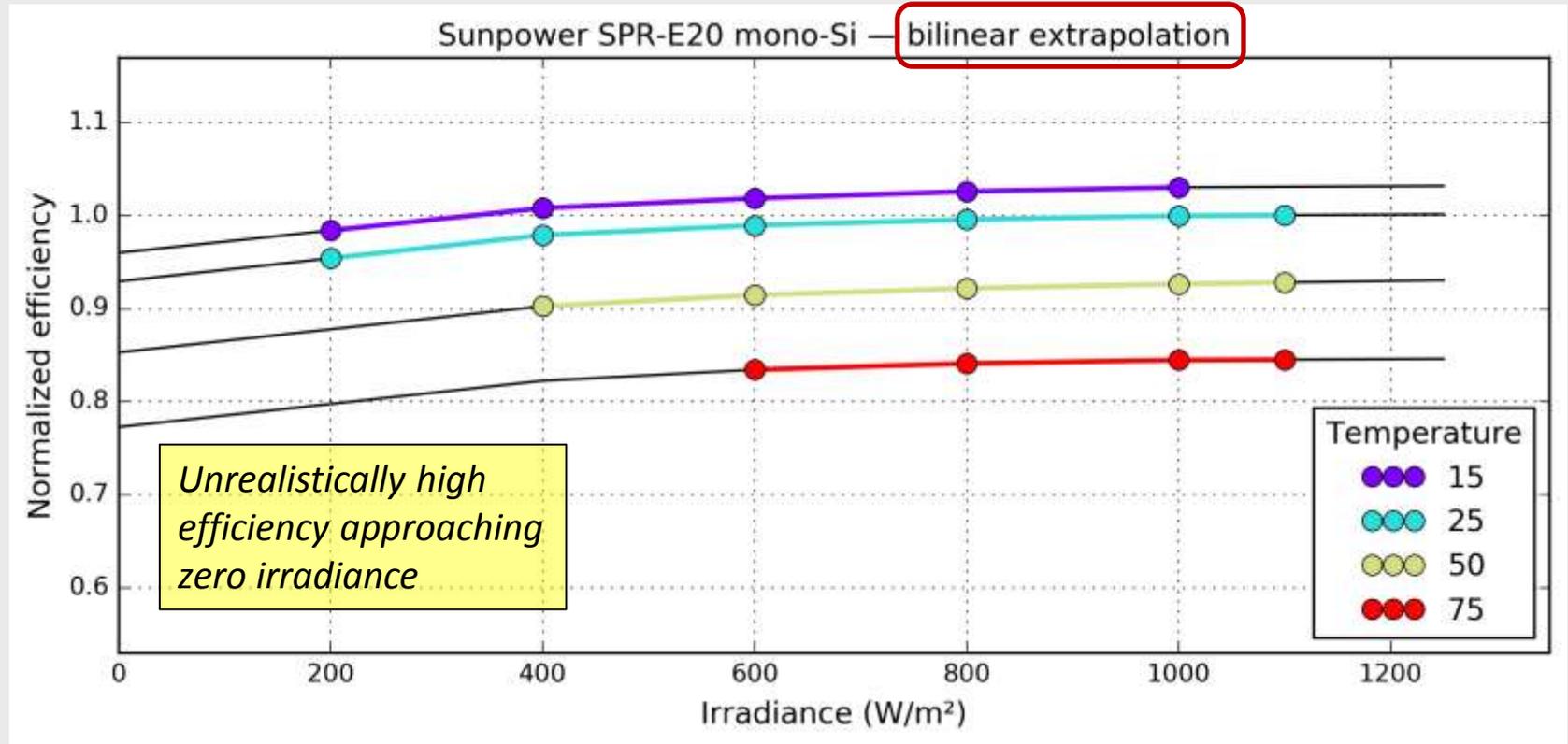


Sunpower SPR-E20 mono (NREL 2018) η

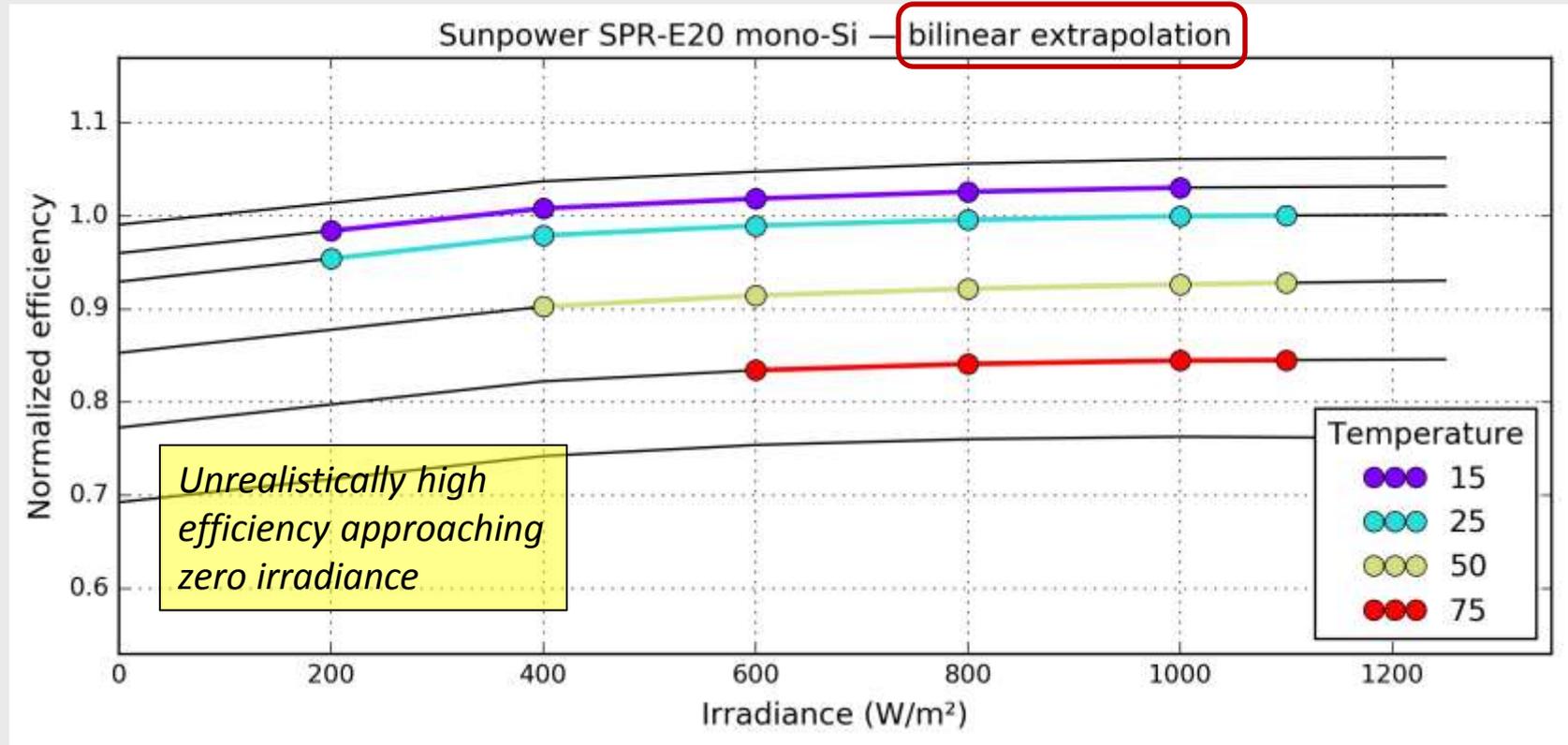
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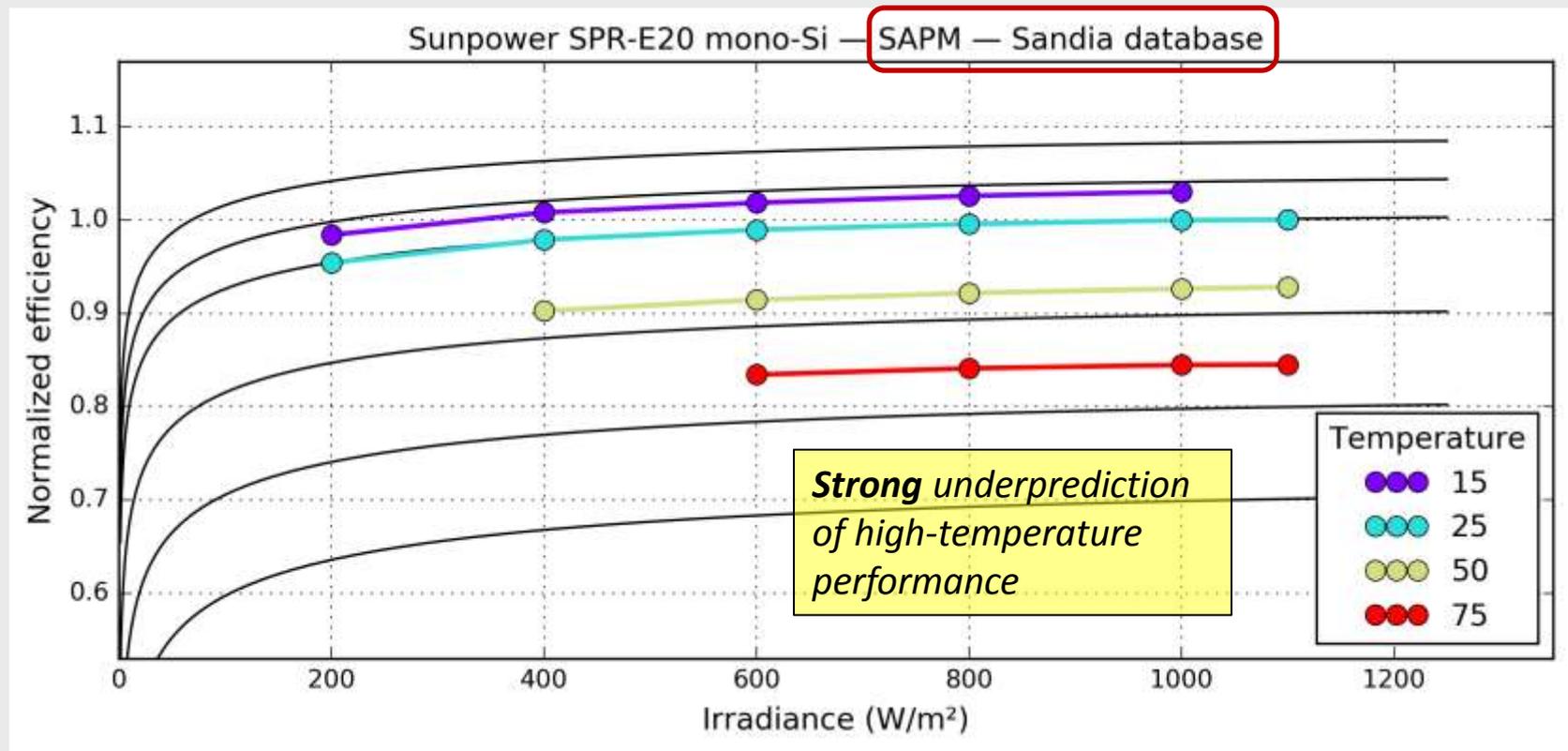
Sunpower SPR-E20 mono (NREL 2018) η



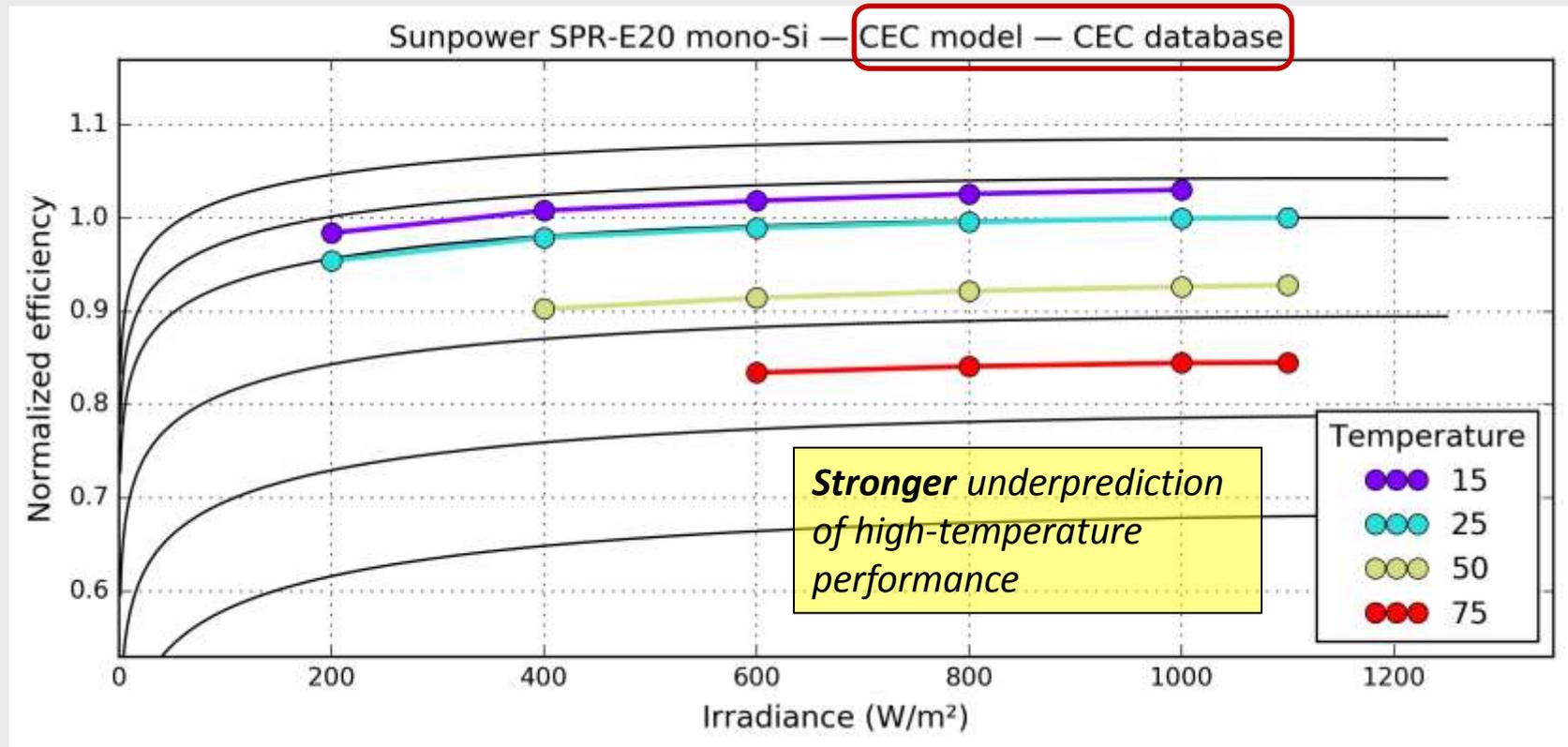
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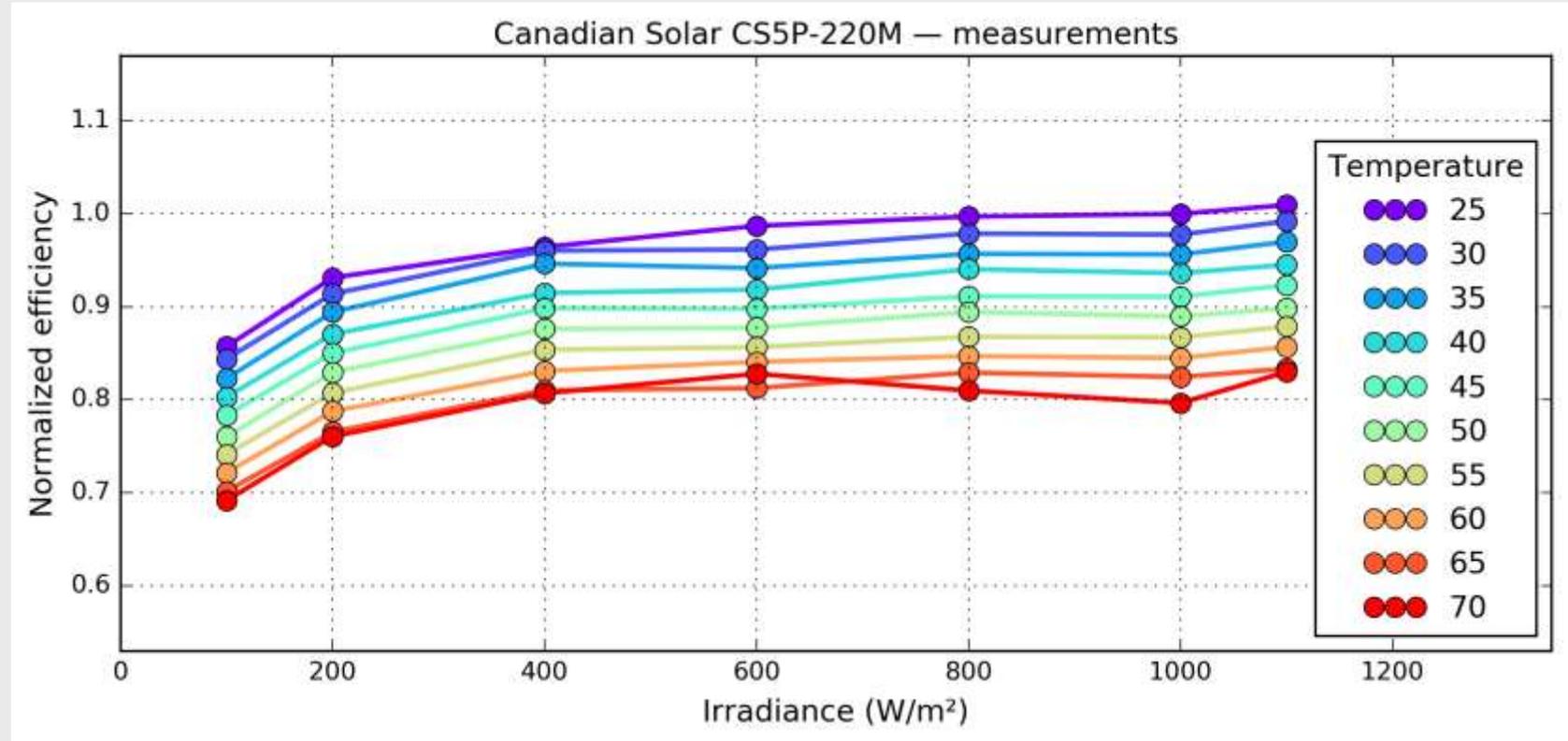
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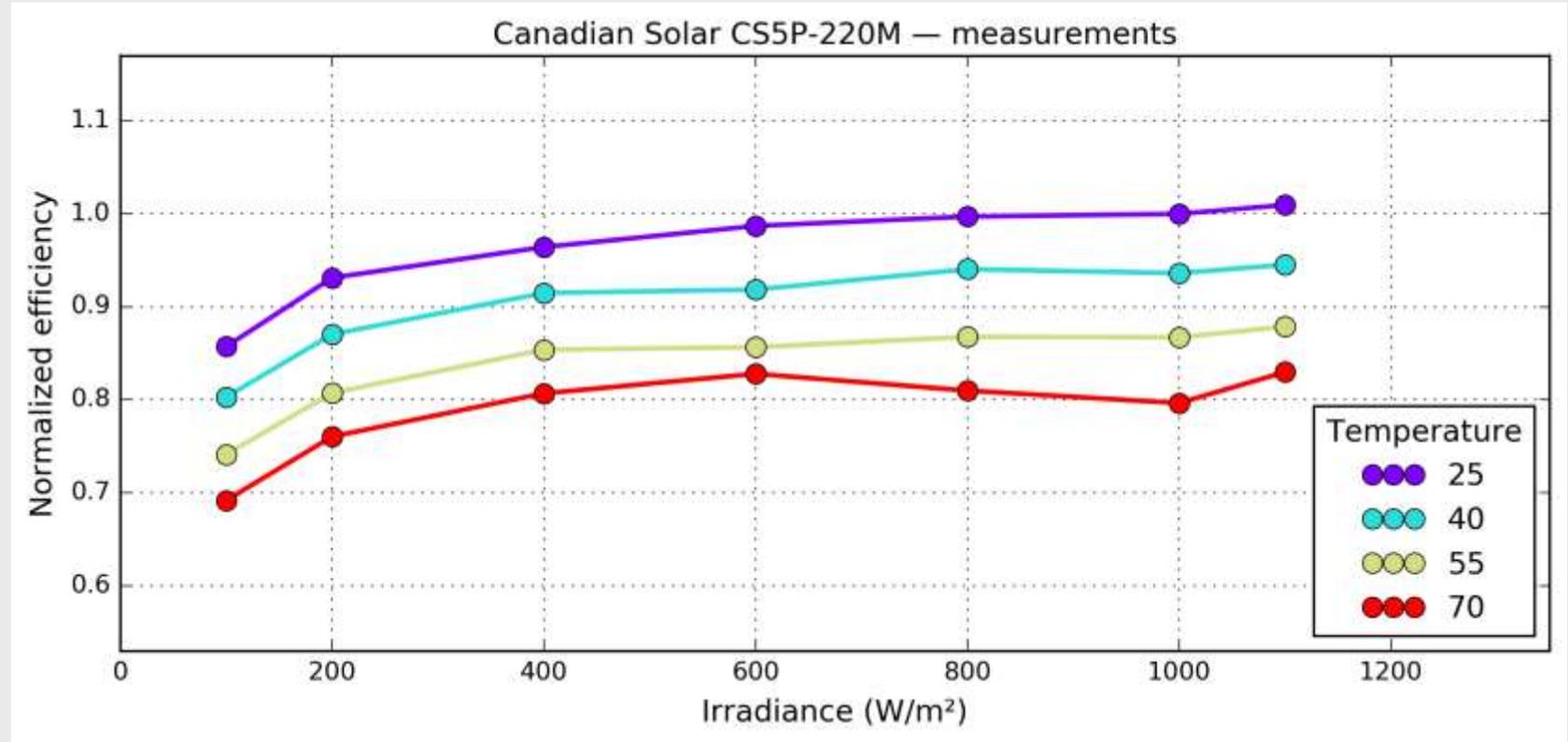
Canadian Solar CS5P-220M



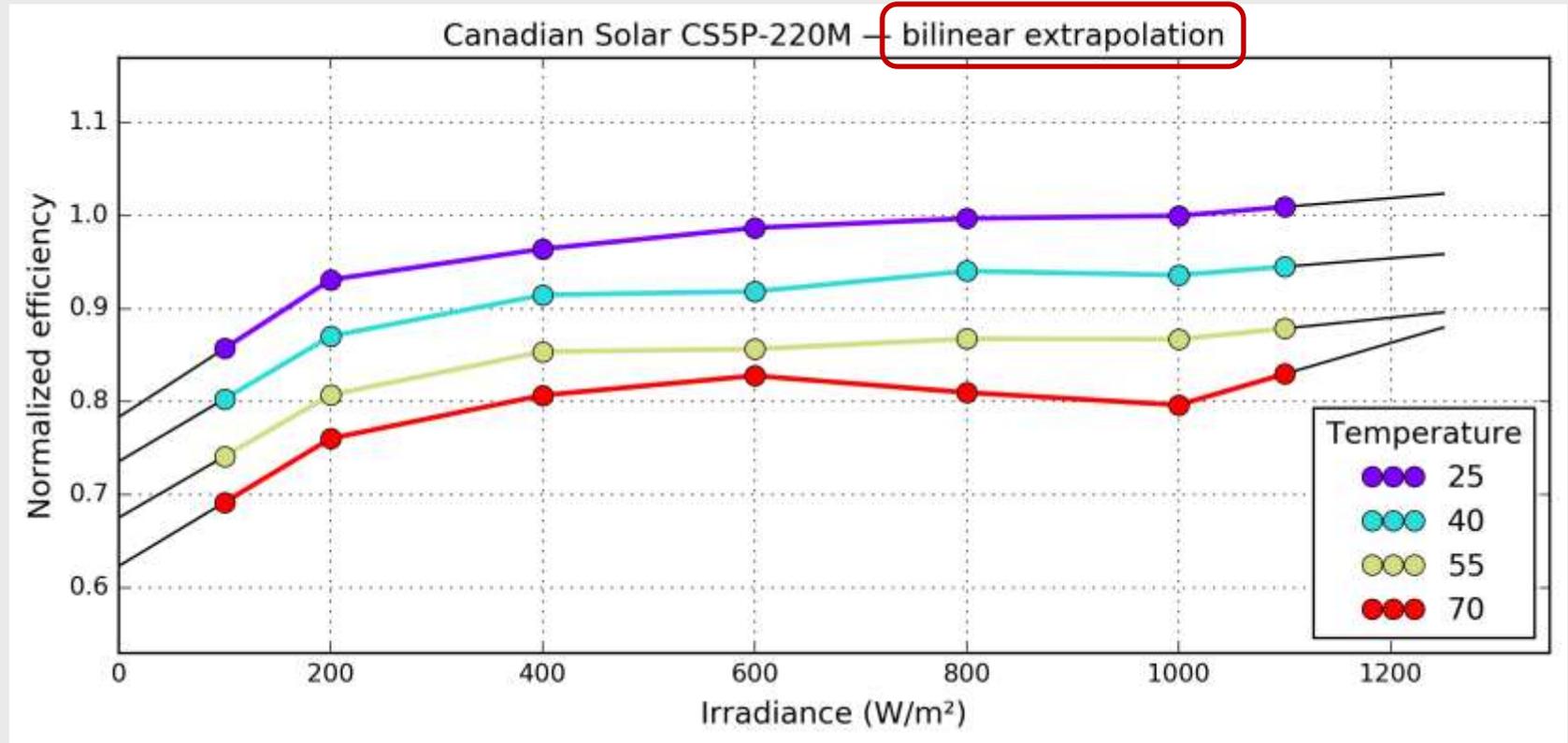
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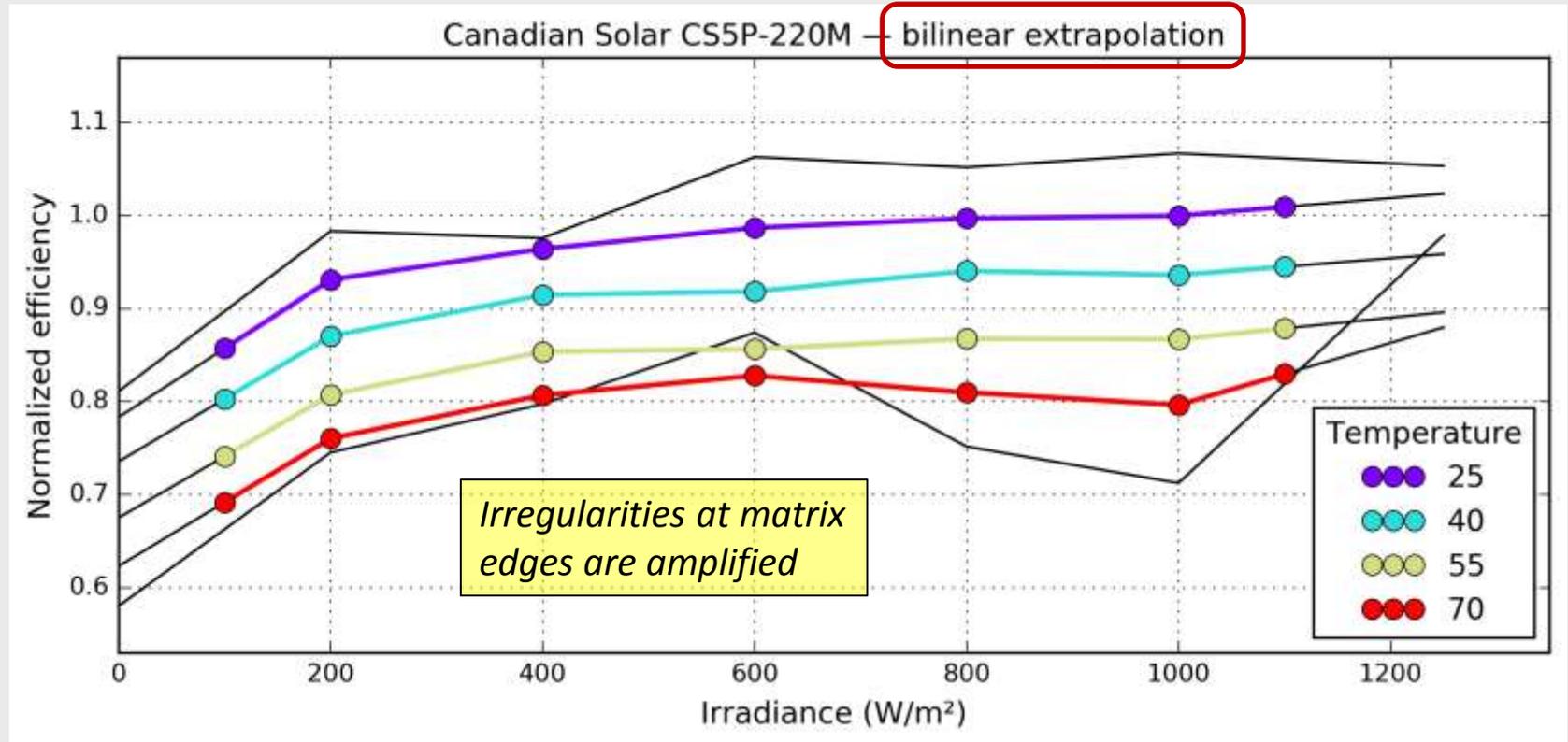
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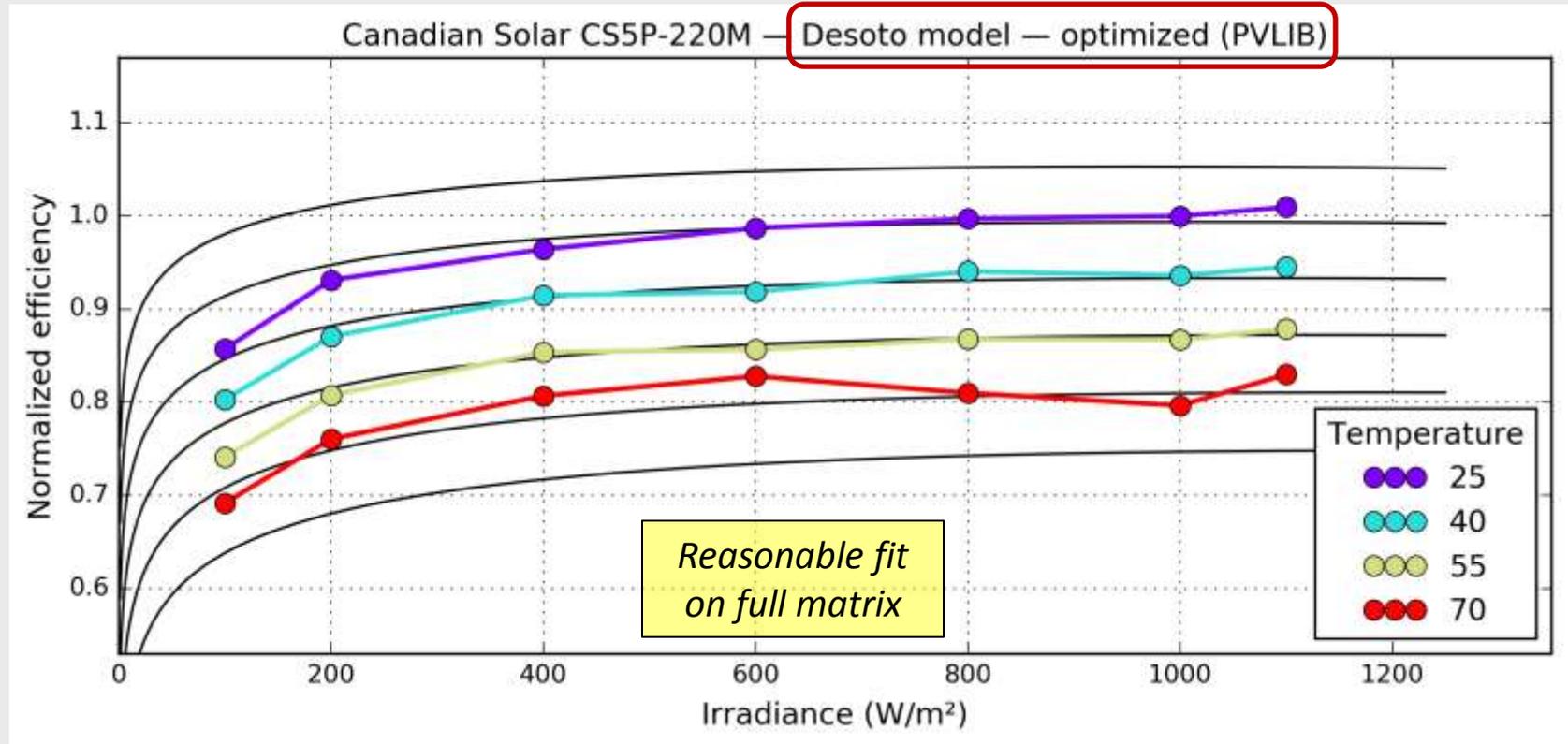
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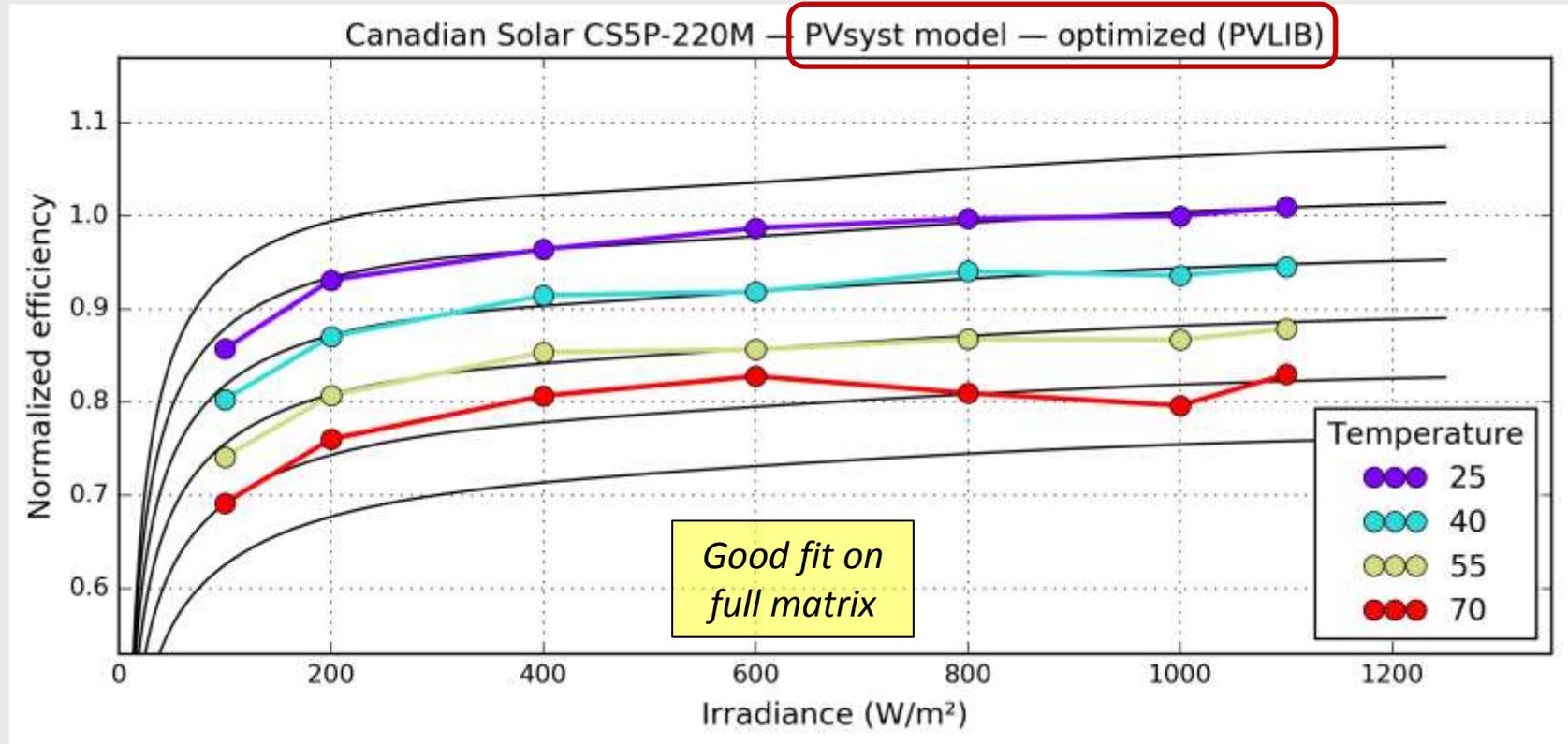
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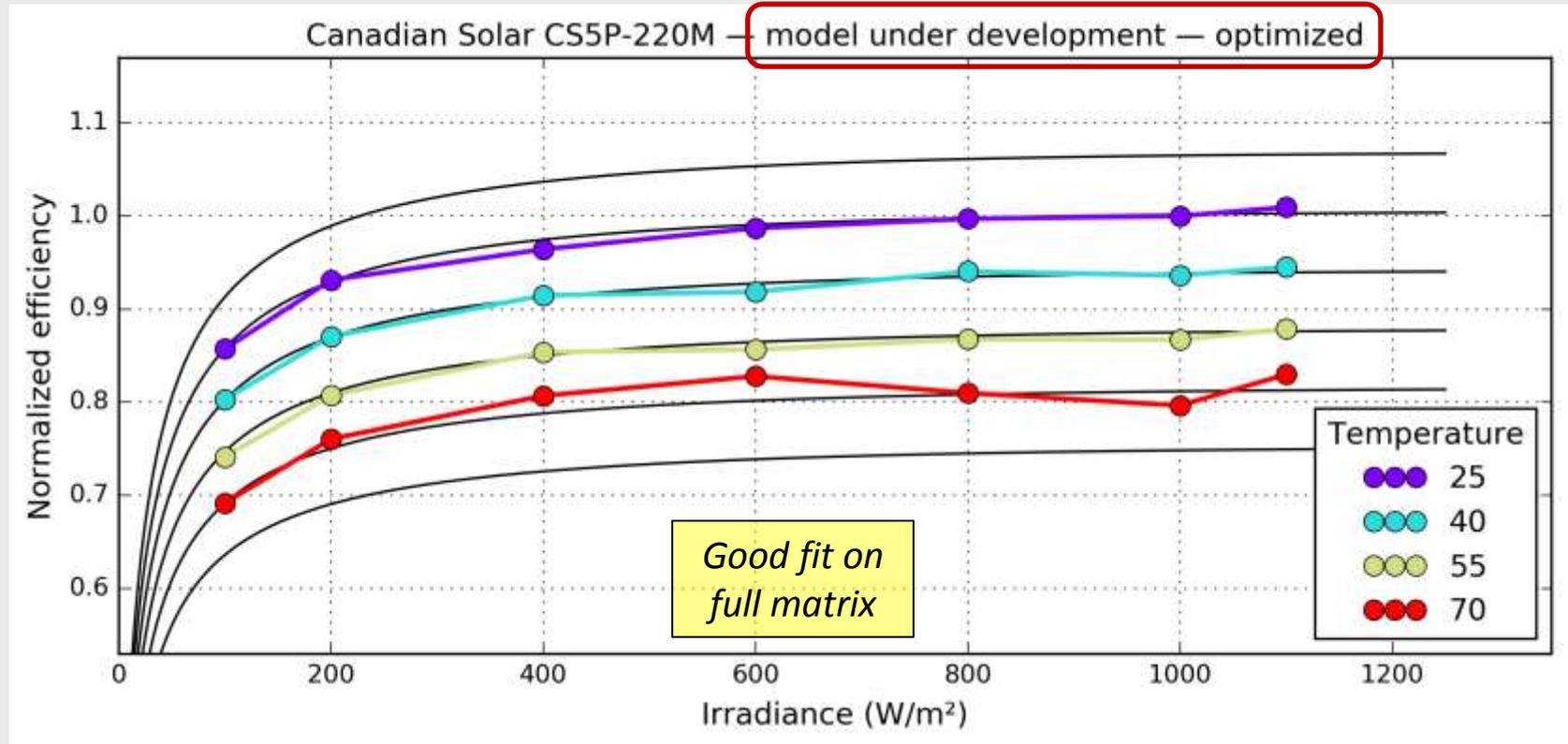
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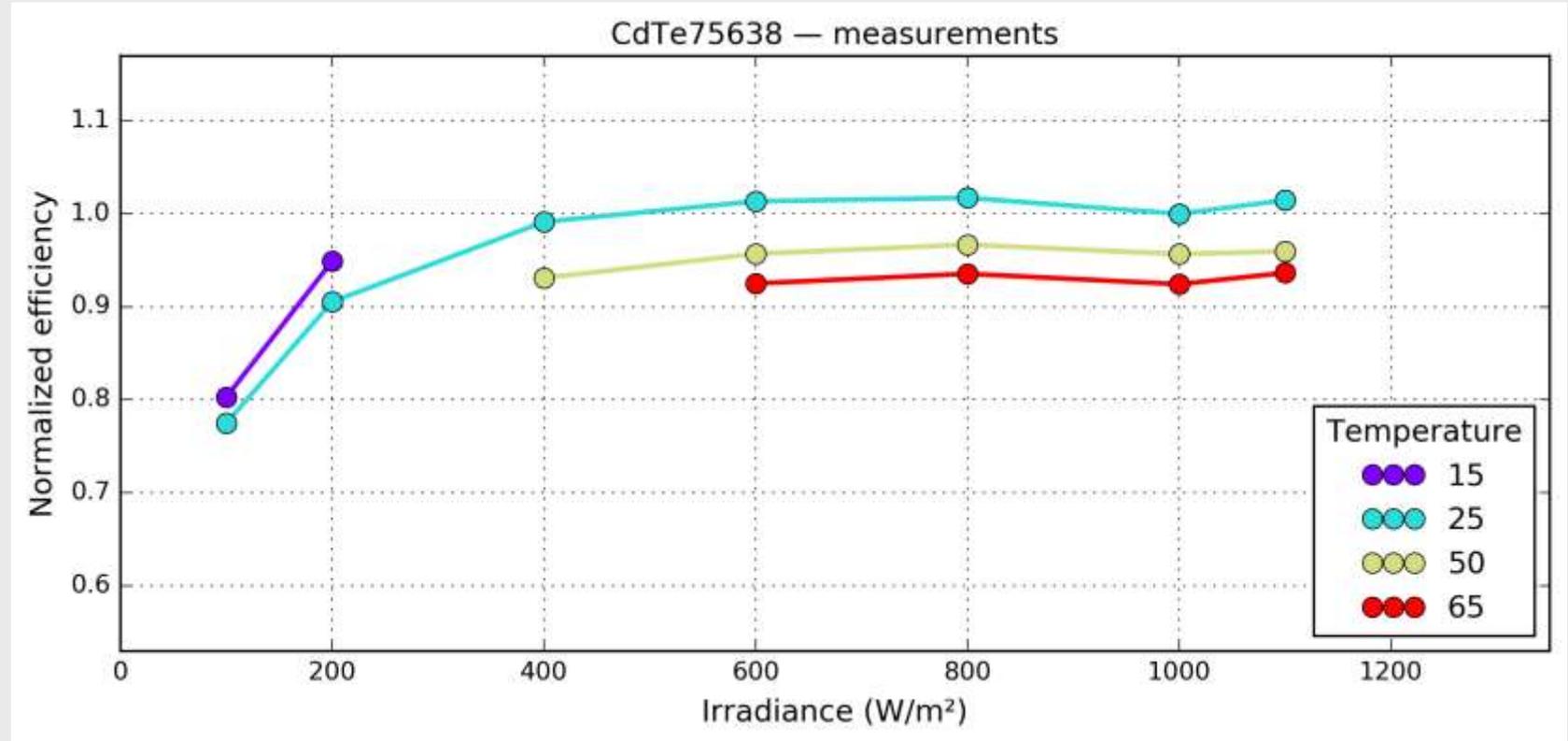
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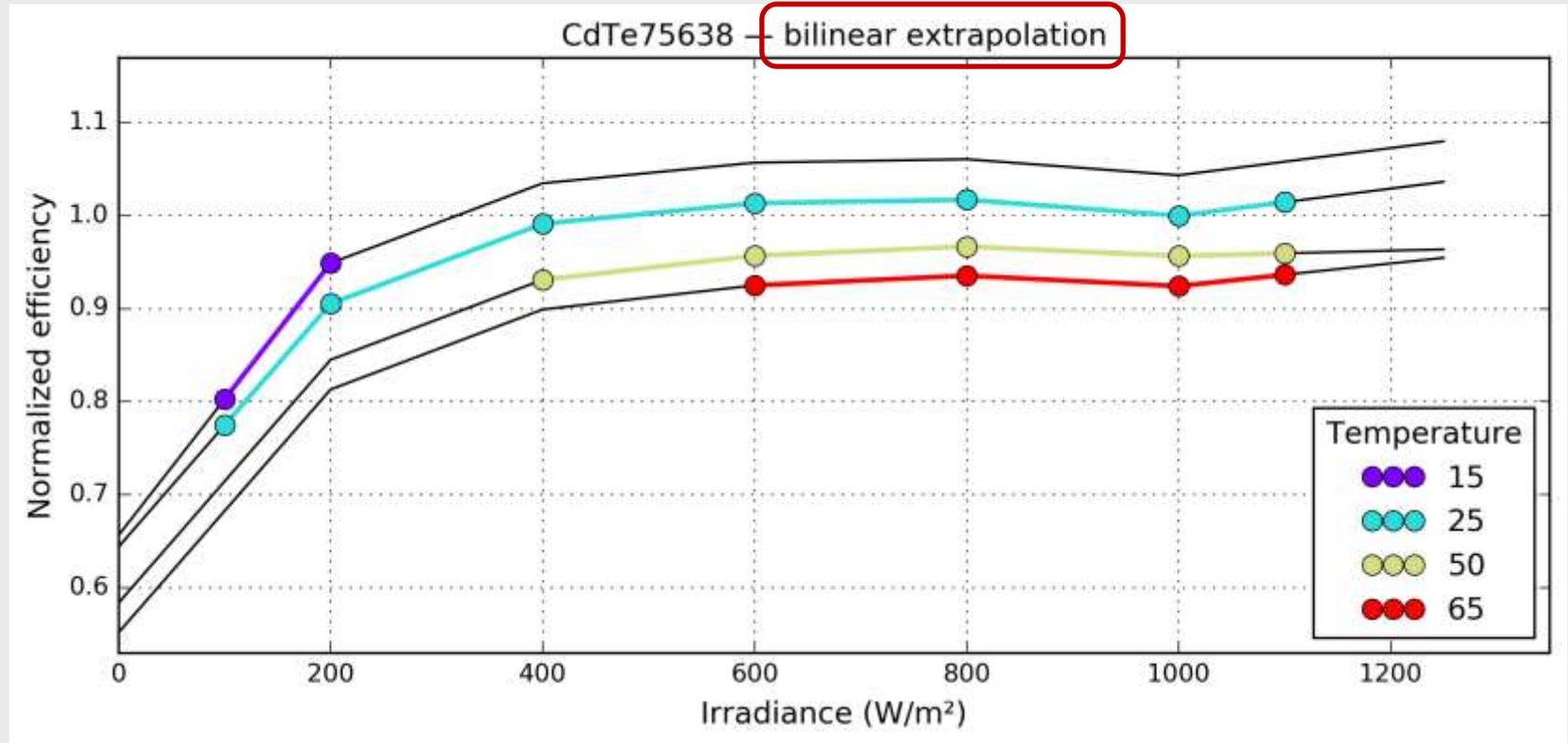
First Solar FS 267 (CFV 2014)



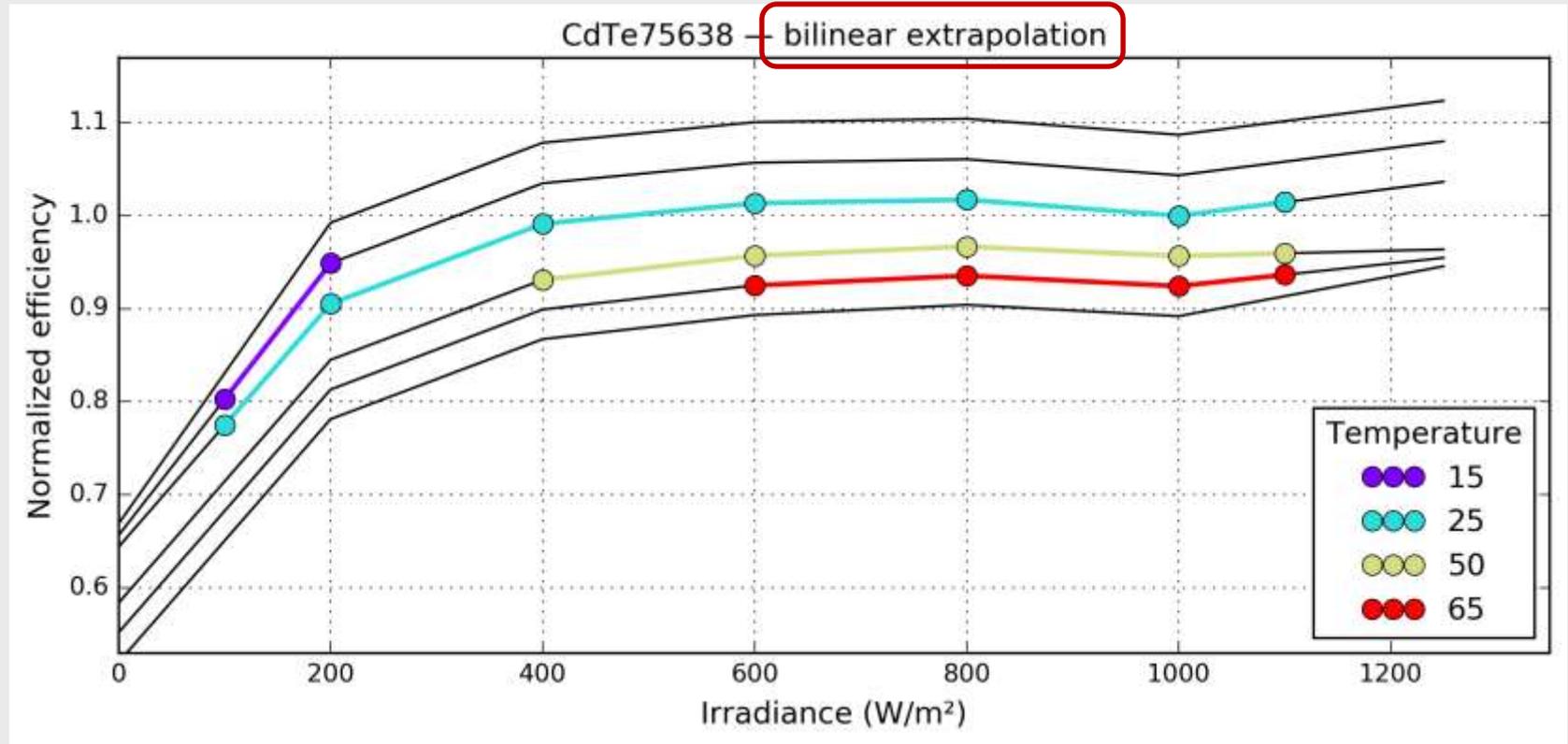
First Solar FS 267 (CFV 2014)



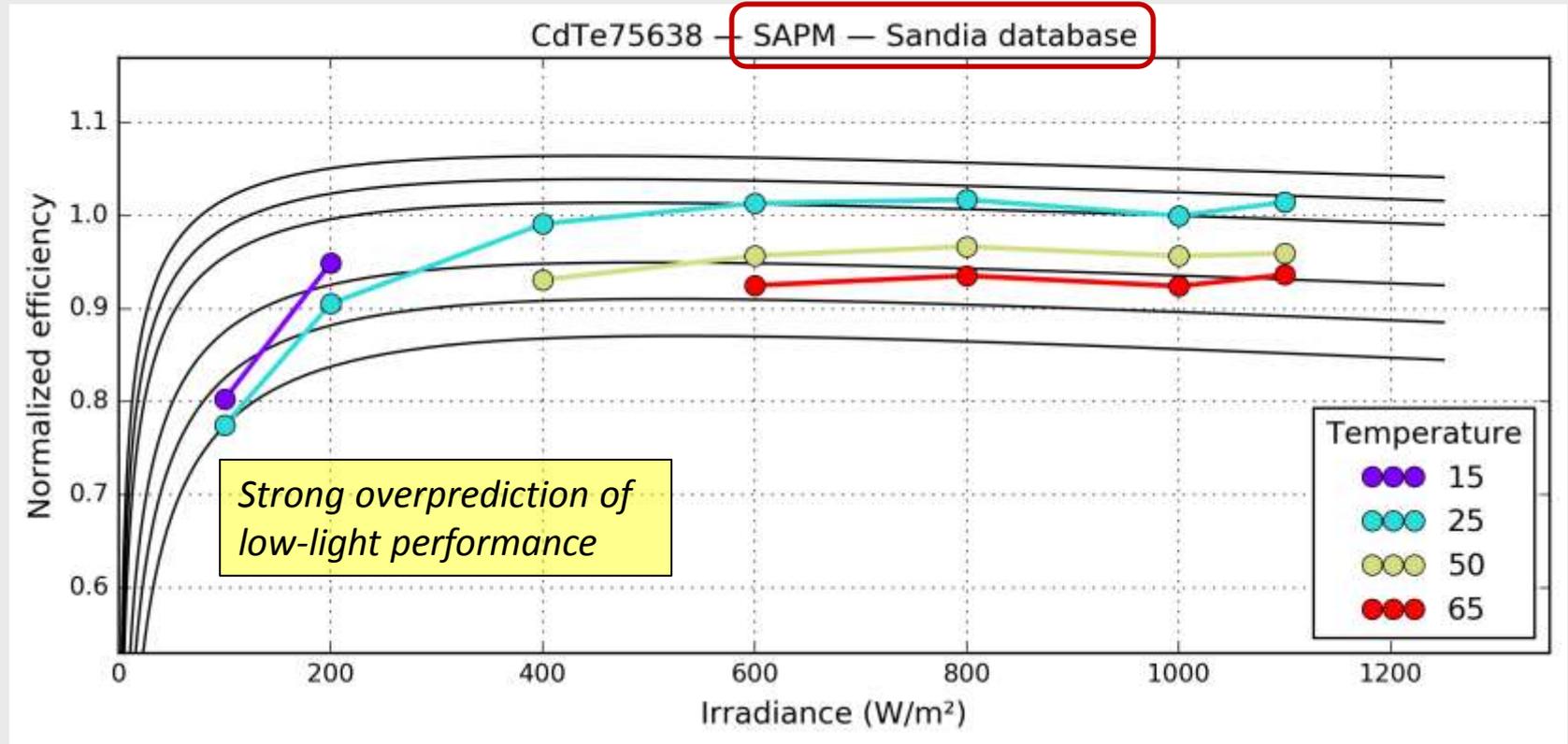
First Solar FS 267 (CFV 2014)



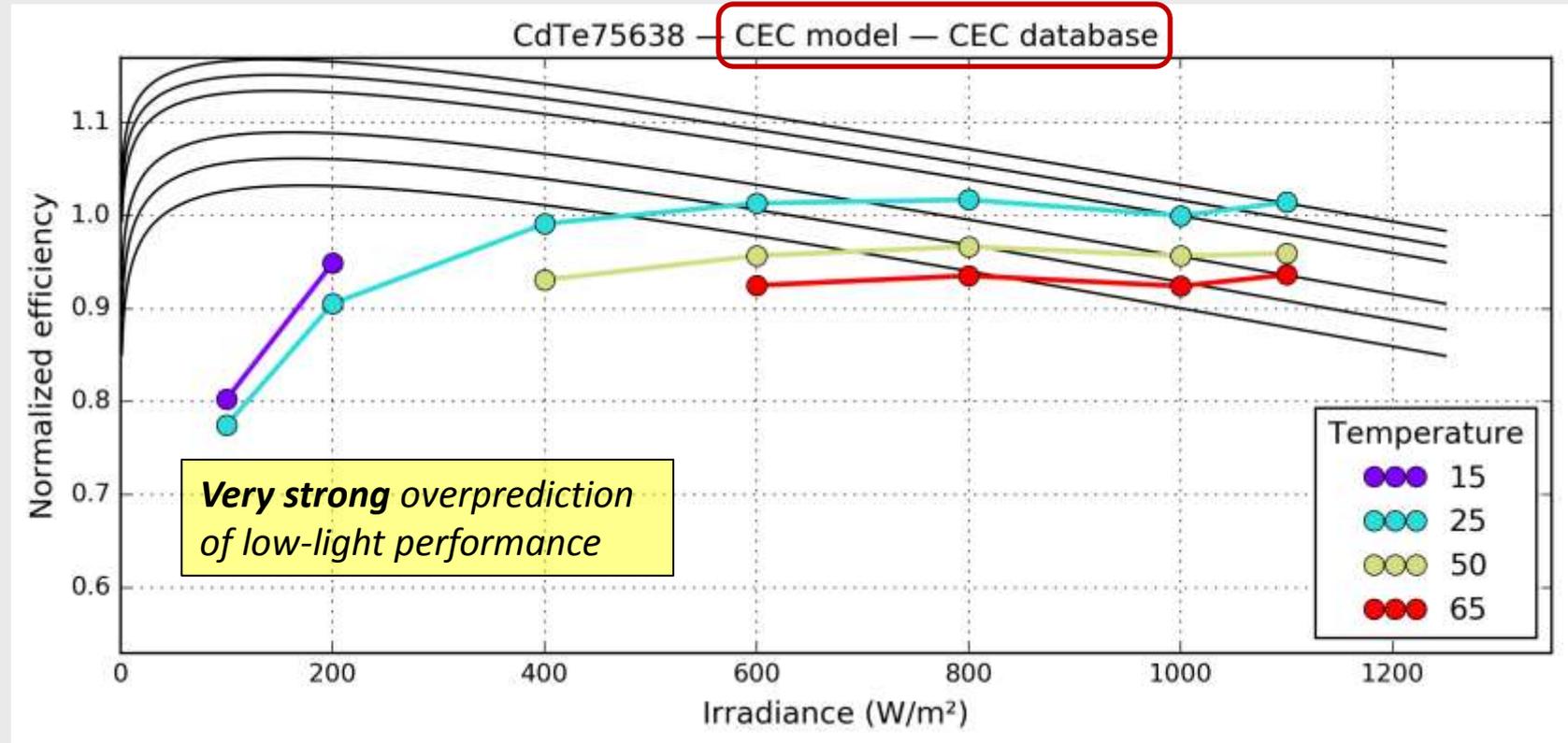
First Solar FS 267 (CFV 2014)



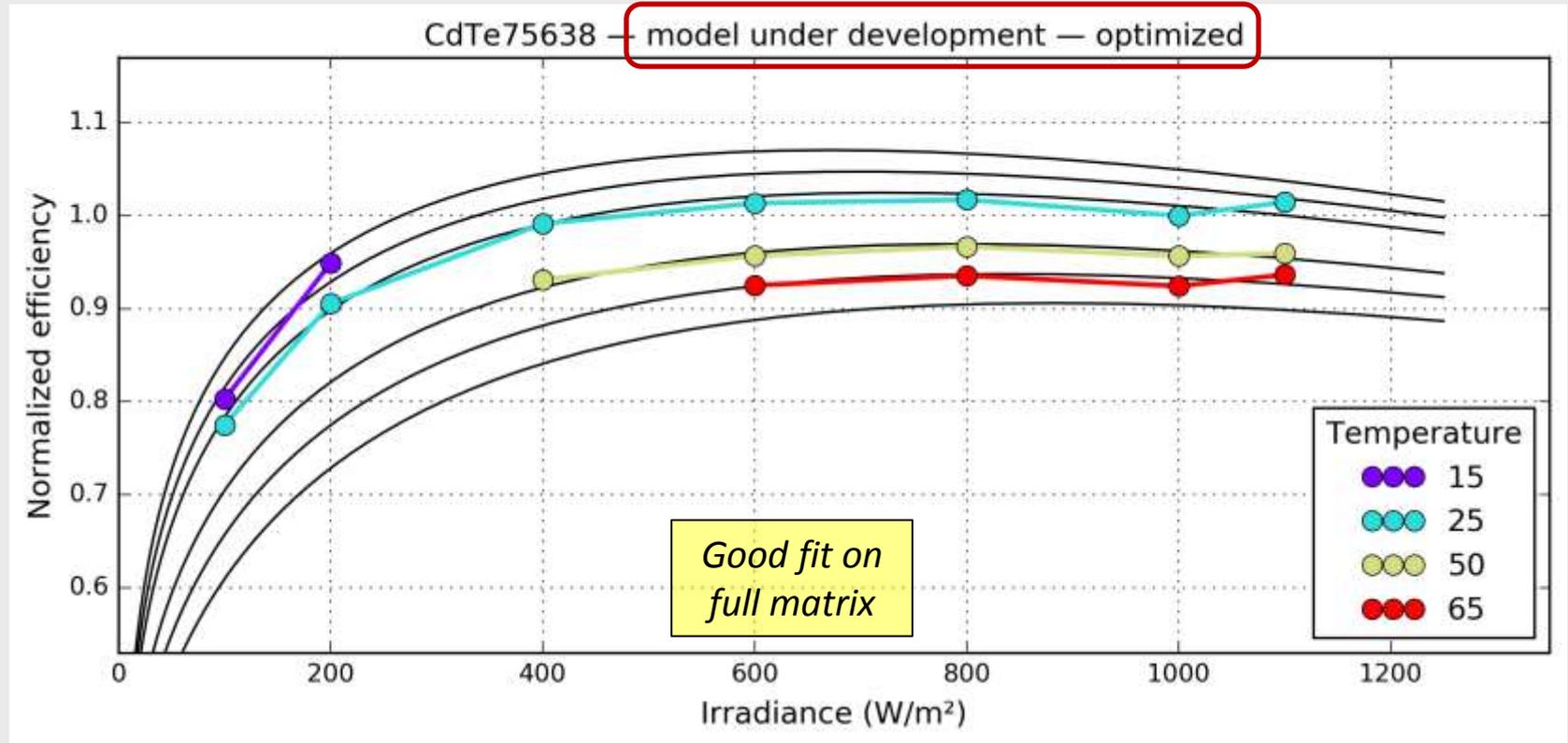
First Solar FS 267 (CFV 2014)



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First Solar FS 267 (CFV 2014)



Observations



- Bilinear extrapolation amplifies measurement errors or irregularities at the matrix edges
- Model fits can help to identify outliers in the measurements and prevent them from affecting simulations
- There are sometimes considerable discrepancies between measurements and models using database parameters
- Existing models probably do not have enough degrees of freedom to fit the performance matrices of all existing module types

Next steps



- Collect more matrix measurements from people inspired by this presentation
- Distribute public data in a uniform format
- Publish useful functions for data exchange and processing in pvlib-python
- Develop additional functions to perform the energy rating according to IEC 61853-3
- Engage further with stakeholders to identify and address concerns and promote distribution of matrix measurements



For more information on this project
or
to discuss your modeling/measurement needs:

anton.driesse@pvperformancelabs.com