



Journées Nationales du PhotoVoltaire 2025

STRASBOURG

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Production of photovoltaic modules with irradiation enhanced by flat metal reflectors

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1 - GeePs, CNRS– CentraleSupélec – U-Paris-Saclay – Sorbonne Université,

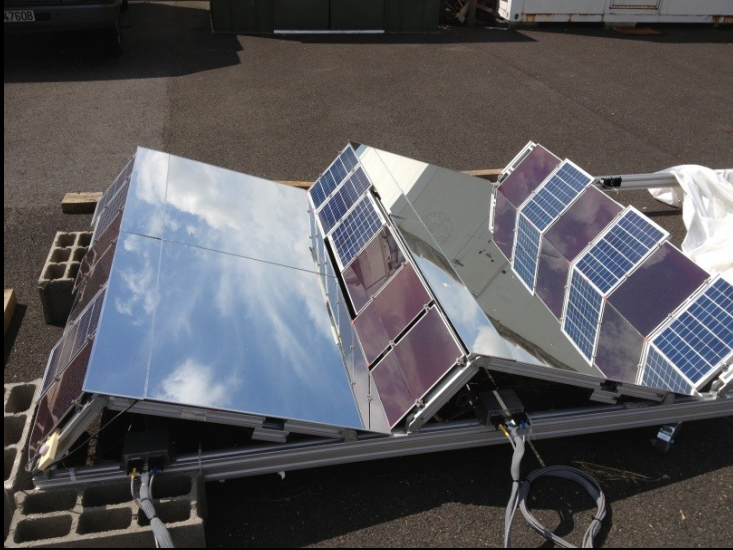
2 - LMD, CNRS, École Polytechnique

... not forgetting the support teams at SIRTA and the laboratories

This work has been supported by the Energy4Climate Interdisciplinary Center (E4C) of IP Paris, and received funding from the 3rd Programme d'Investissements d'Avenir [ANR-18-EUR-0006-02], and from the Foundation of Ecole polytechnique (Chaire "Défis Technologiques pour une Énergie Responsable" financed by TotalEnergies).

A team of researchers from several laboratories

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Polytechnique Novation Center rooftop 2019-2025



Aleph project 2012 - 2016

Scientific work based on measurement

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SIRTA: more than 300 instruments dedicated to meteorological science.
<https://sirta.ipsl.fr/>
An international reference in solar radiation measurement.

Part of **BSRN**
<https://bsrn.awi.de/>

Energy for climate, A multidisciplinary programme dedicated to the energy transition
<https://www.e4c.ip-paris.fr/#/fr/>

SIRTA instrumental site in Palaiseau

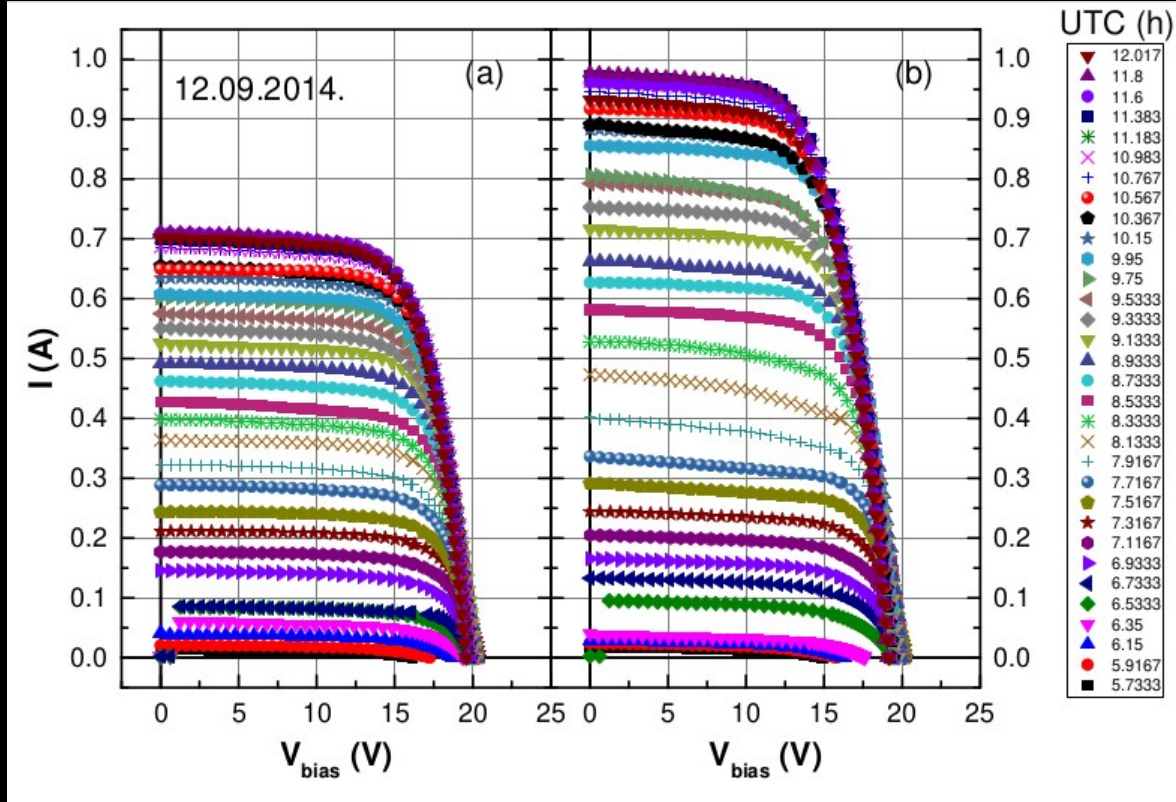
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Our first setup with aluminium glass flat reflectors



- For N flat reflectors the concentration factor is theoretically limited to $N+1$
- In our case less than 2
- Note that two kinds of silicon modules are installed : amorphous and crystalline
- There are no reflectors in front of the first row or behind the last row.

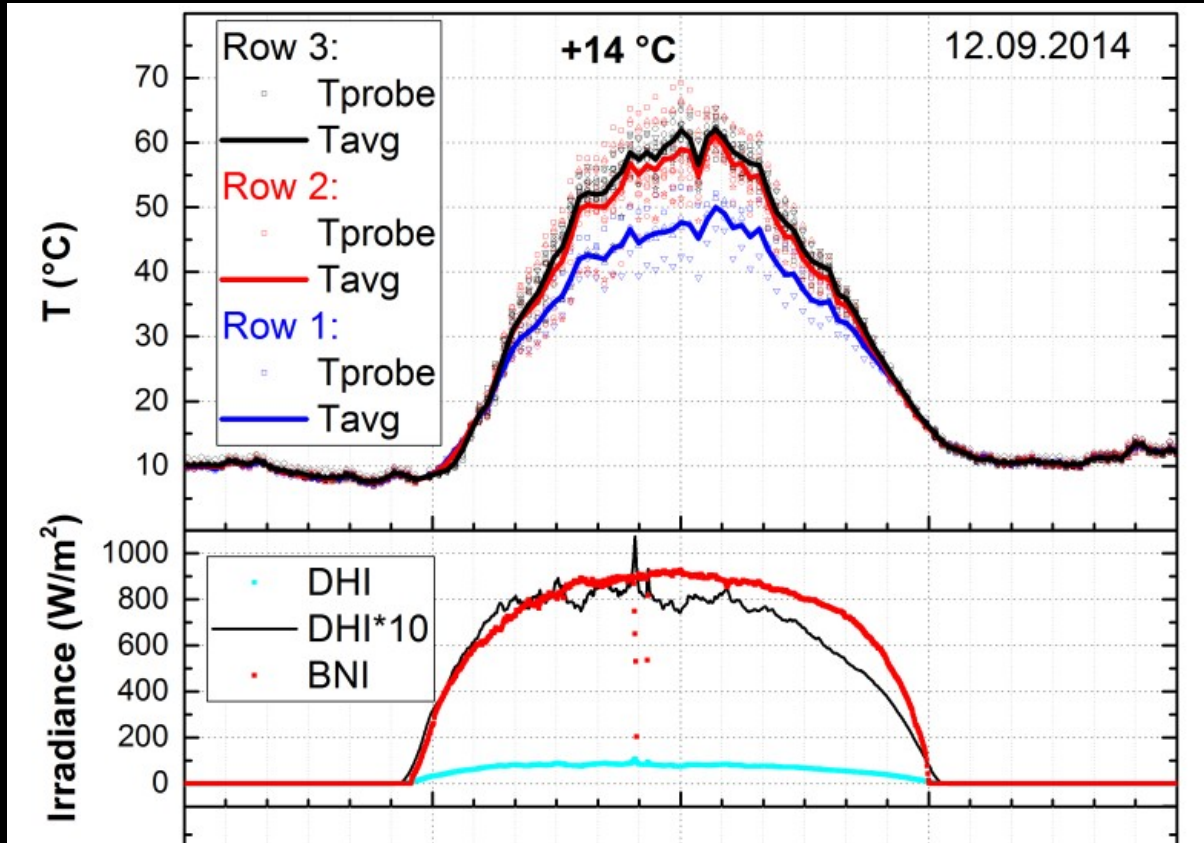
I-V curves without and with flat reflectors through a clear morning



- Left without reflector, right with reflector
- Current increases with irradiation in the morning
- The increase of photocurrent due to reflectors is about 40 %
- Note that the voltage decreases a little throughout the morning (more with the mirror).

From M. Pavlov Thesis (2016)

A higher radiation intensity means a higher temperature increase.

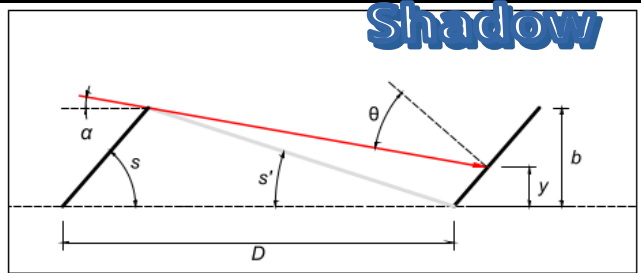


- Modules that receive more solar energy heat up more.
- Note that this is a very clear day
- Temperature fluctuations are due to wind fluctuations and variations in the transparency of the atmosphere for the intermediate infrared.

From M. Pavlov Thesis (2016)

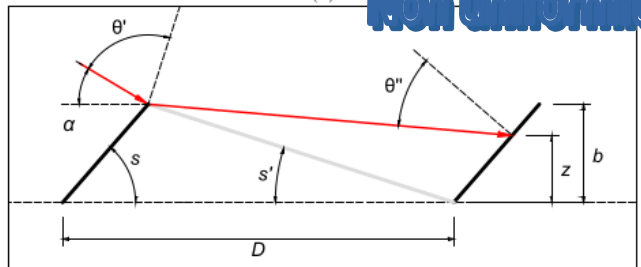
For certain solar heights, parts of the reflectors are 'useless'.

Shadow



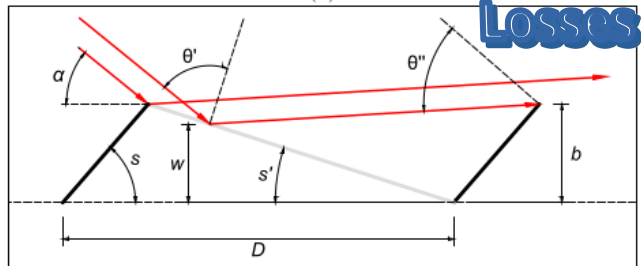
(a)

Non uniformity



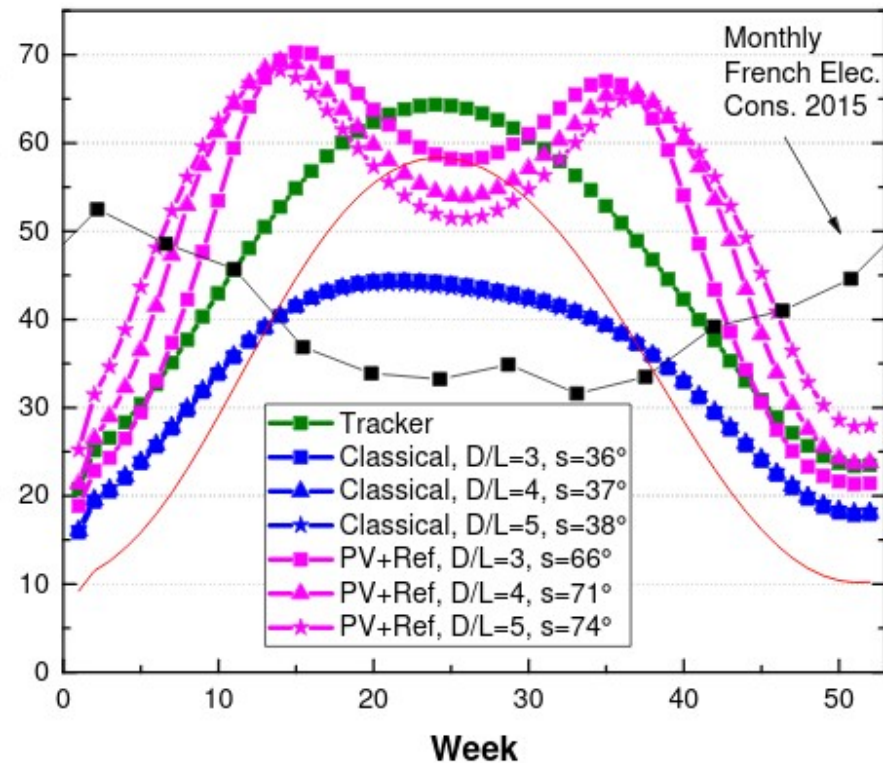
(b)

Losses



(c)

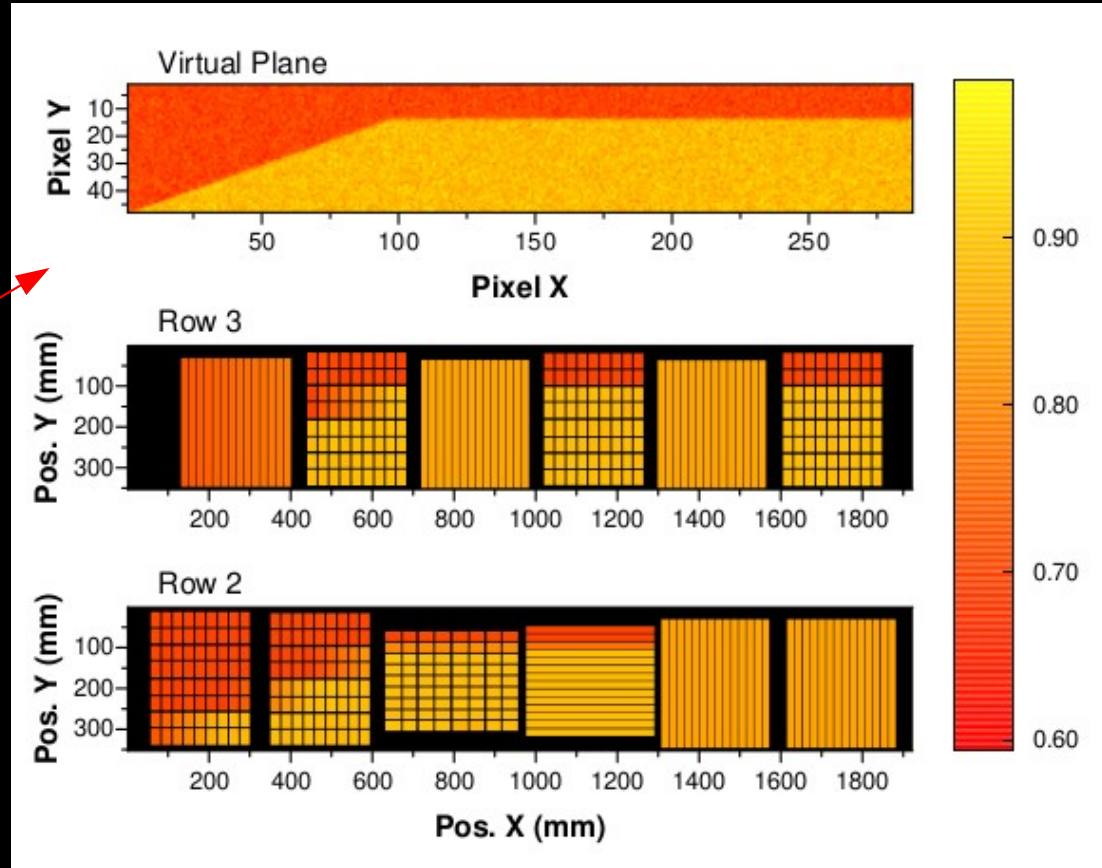
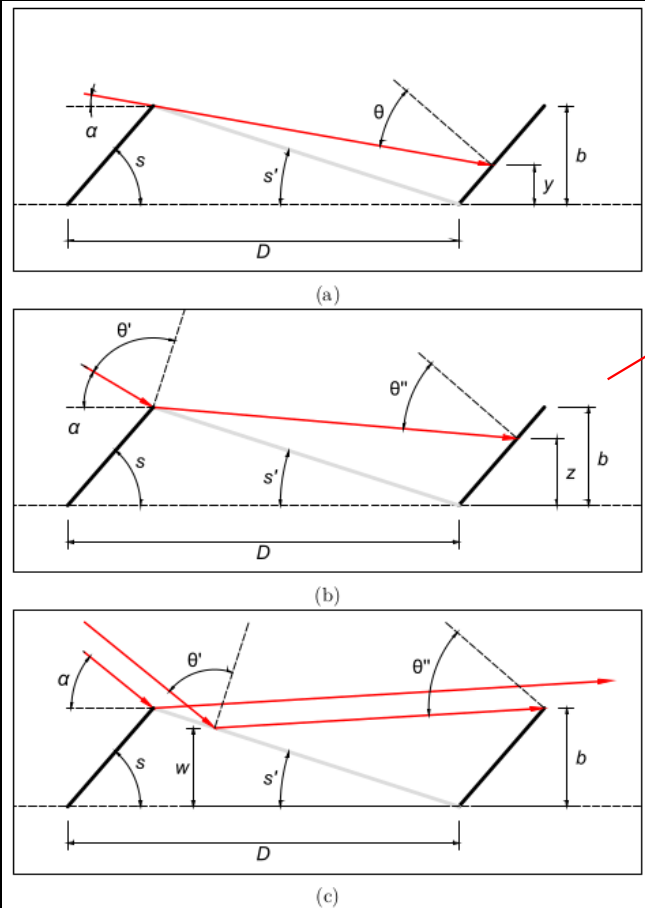
Weekly Transmitted Irradiation (kWh/m²)
Monthly French Elec. Cons. (TWh)



Weekly Global Horizontal Irradiation (kWh/m²)
(avg. McCleary data for Palaiseau)

From M. Pavlov Thesis (2016)

During periods of low solar elevation, uneven lighting occurs.



From M. Pavlov Thesis (2016)

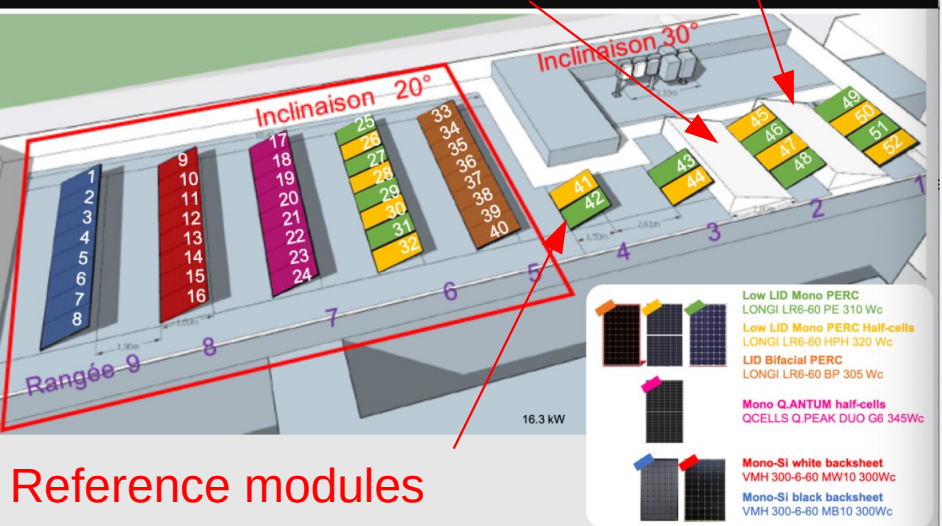
Polytechnique Novation center rooftop



Polytechnique Novation center rooftop

Raw rolled aluminium

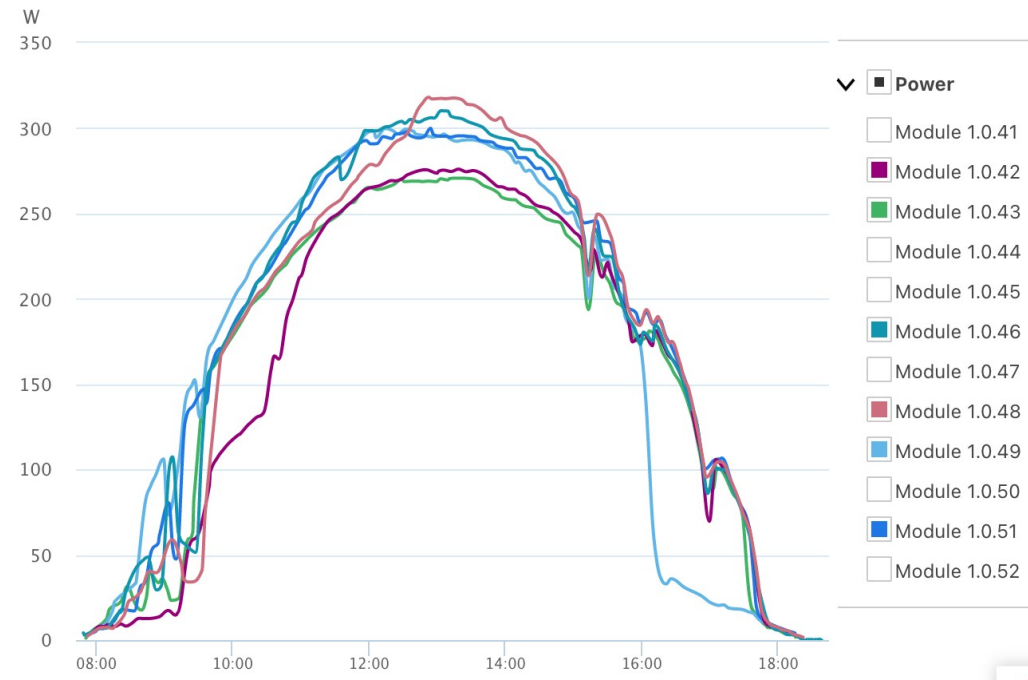
Stainless polished steel



>>

Last Day ▾ 27/02/2022 → 28/02/2022 📅

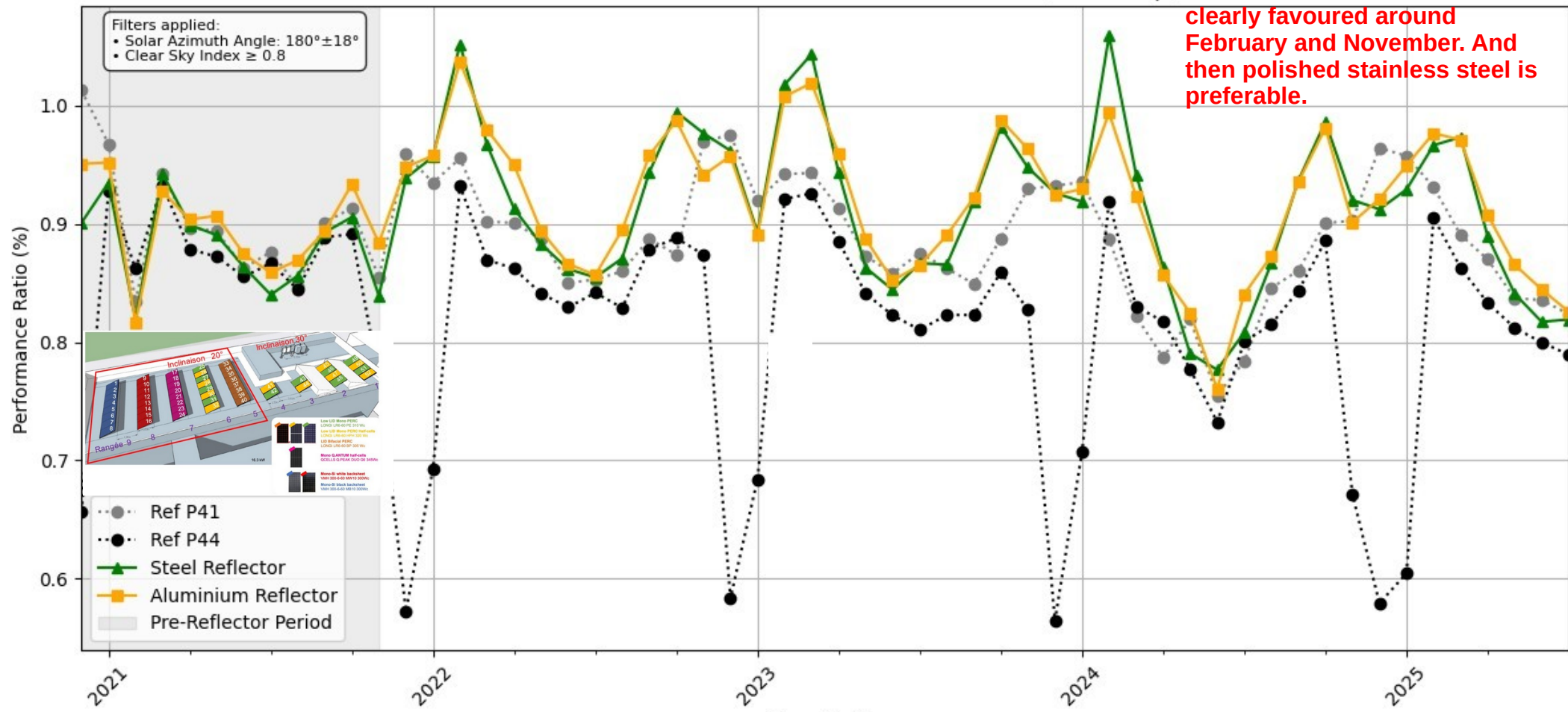
Chart 2



Performance ratio for PERC half-cells in clear days around solar noon

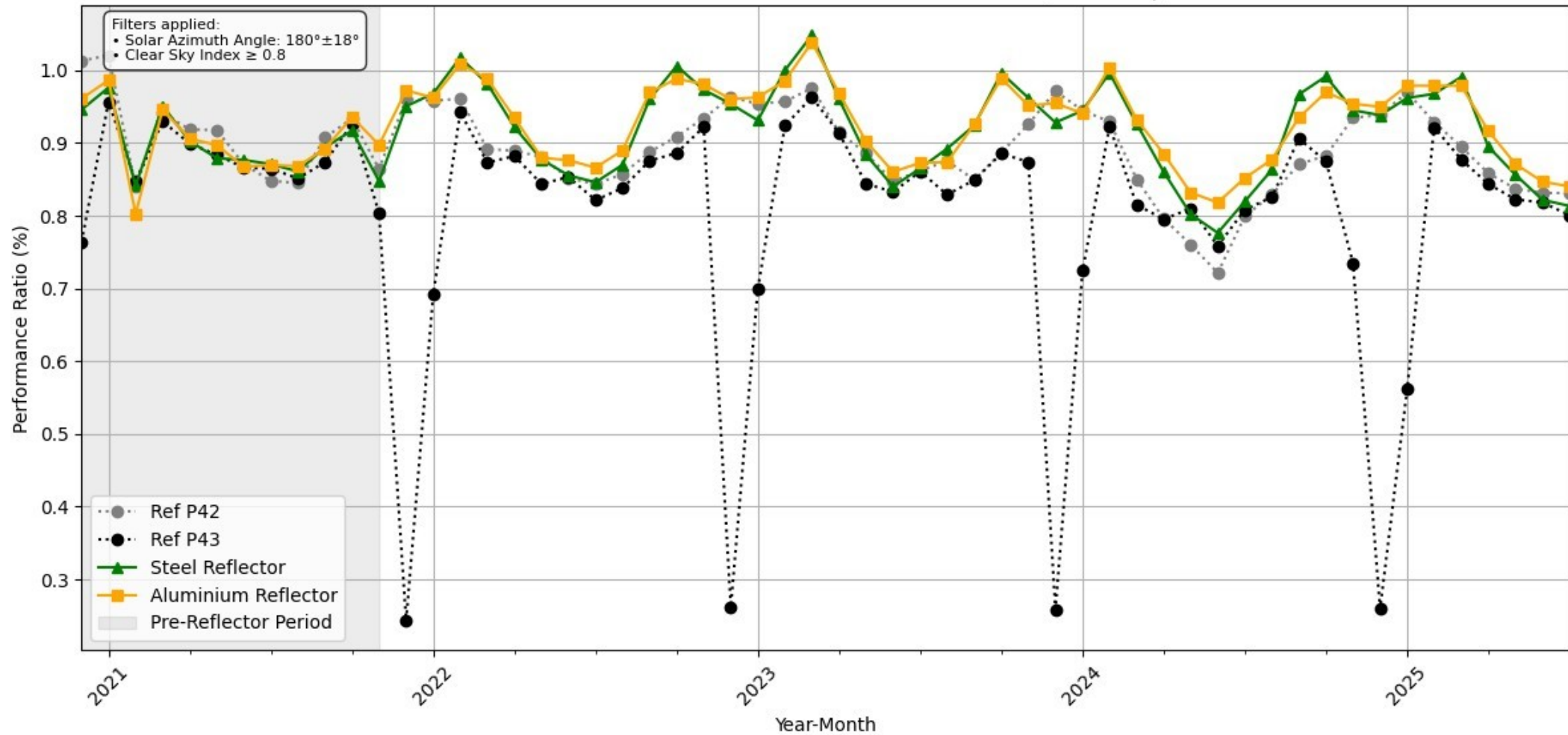
Reflector Performance for SAA: $180 \pm 18^\circ$: Perc Half (P41 Group)

Modules with reflectors are clearly favoured around February and November. And then polished stainless steel is preferable.

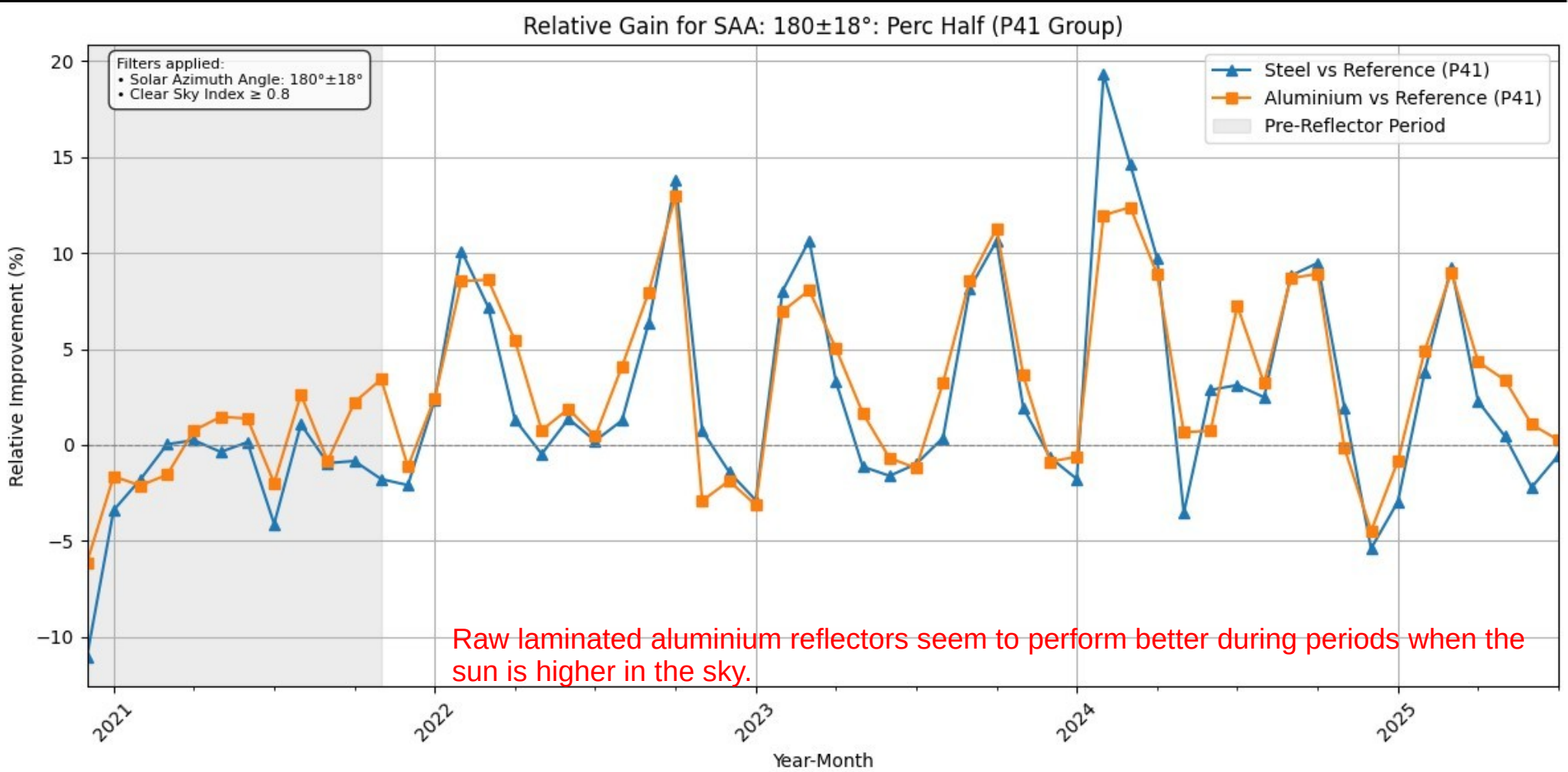


Performance ratio for PERC full-cells in clear days around solar noon

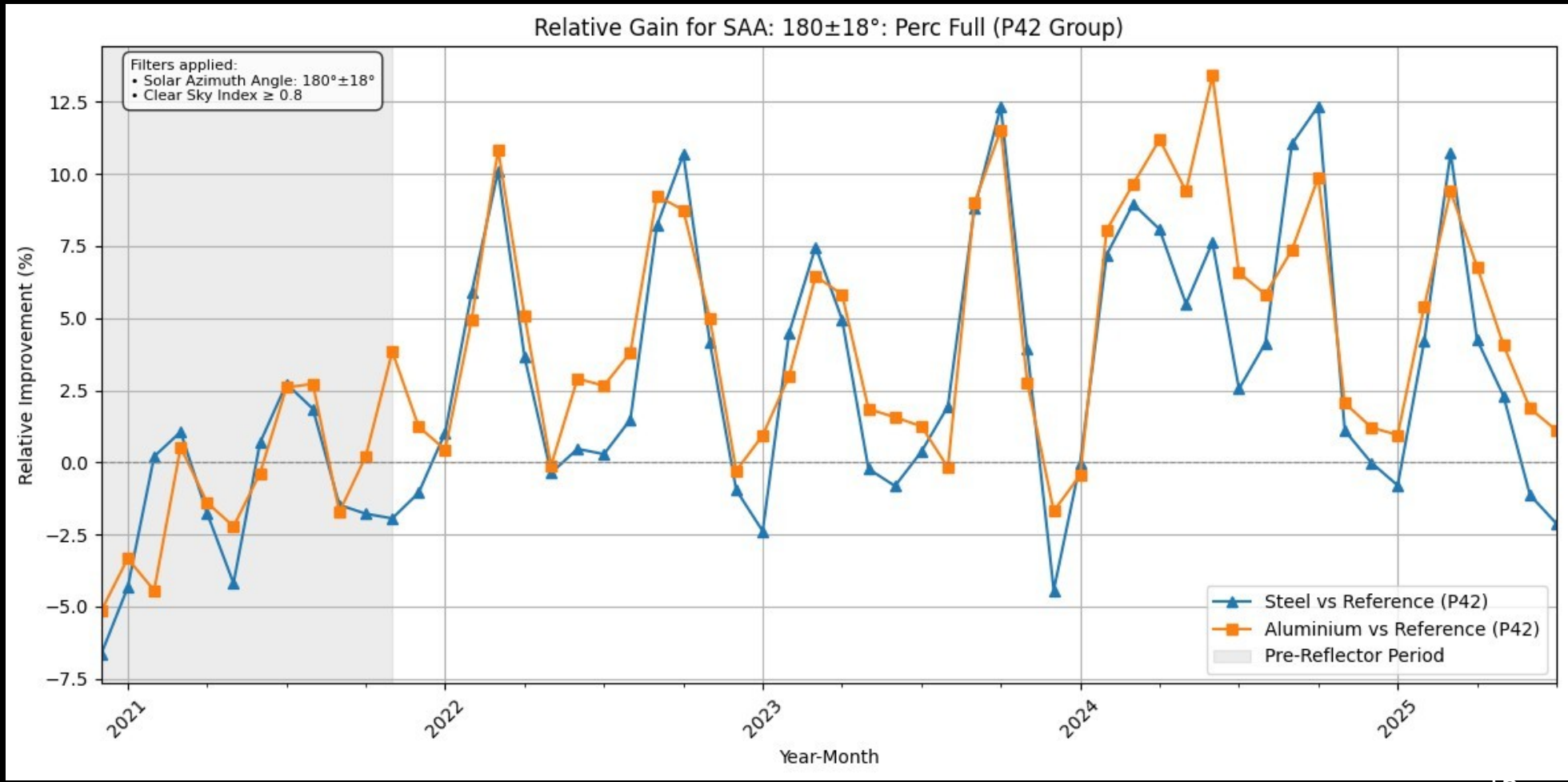
Reflector Performance for SAA: $180 \pm 18^\circ$: Perc Full (P42 Group)



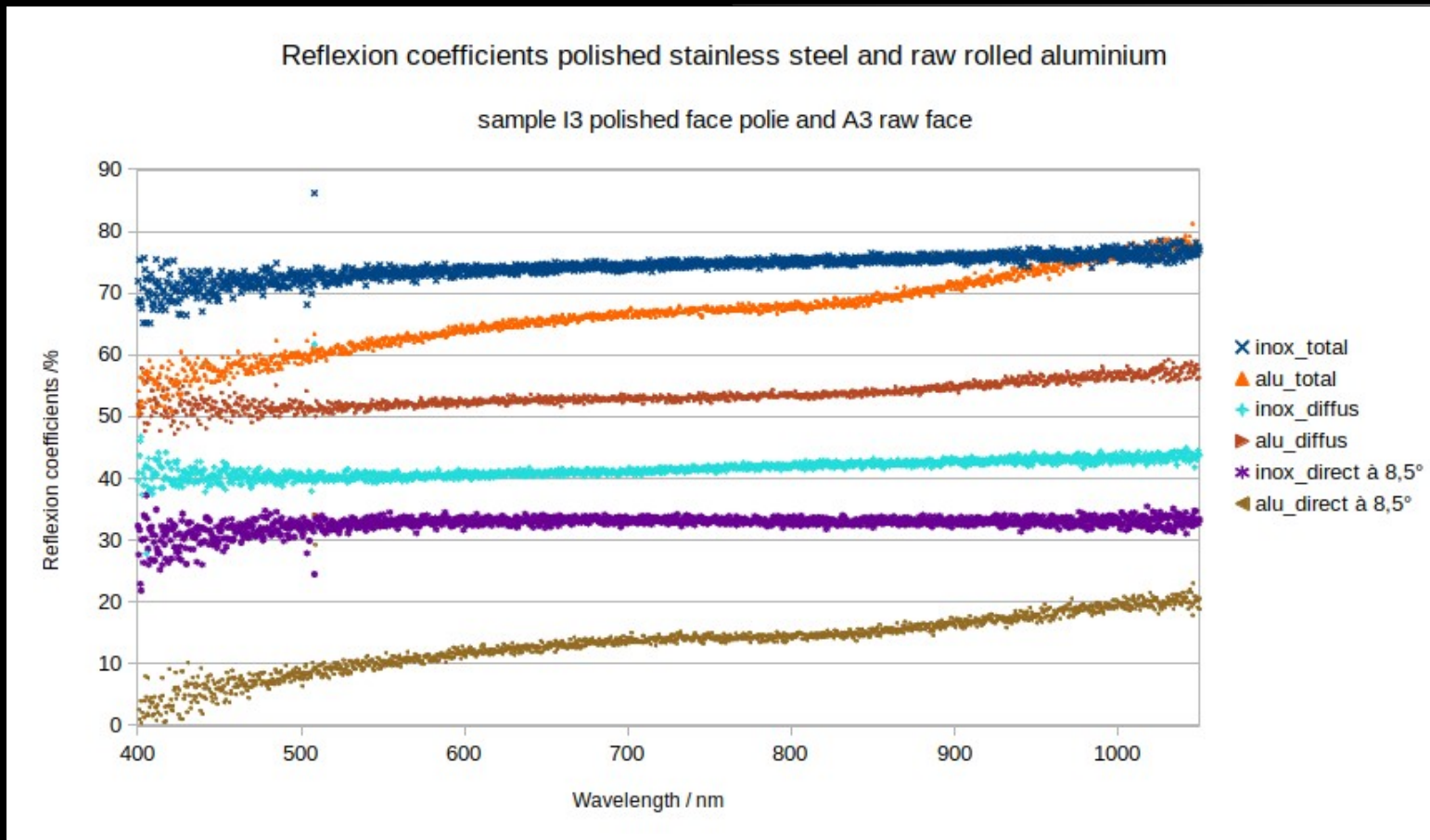
Relative gains due to reflectors around solar noon on clear days for half-cells



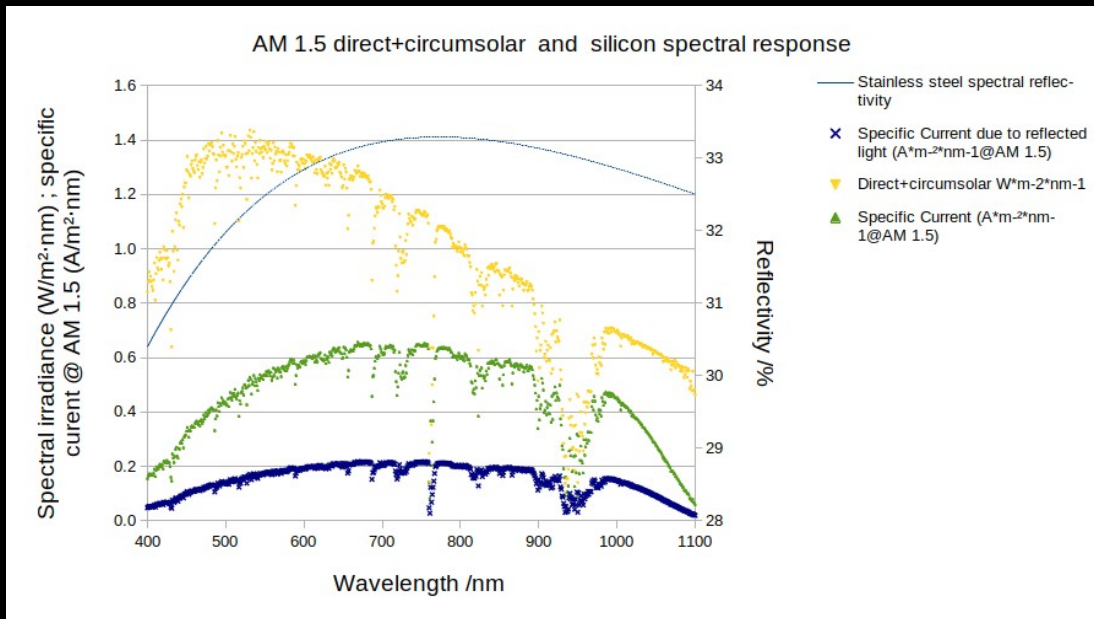
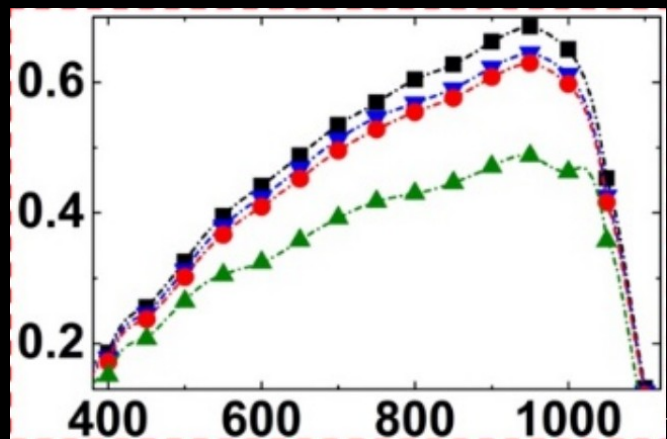
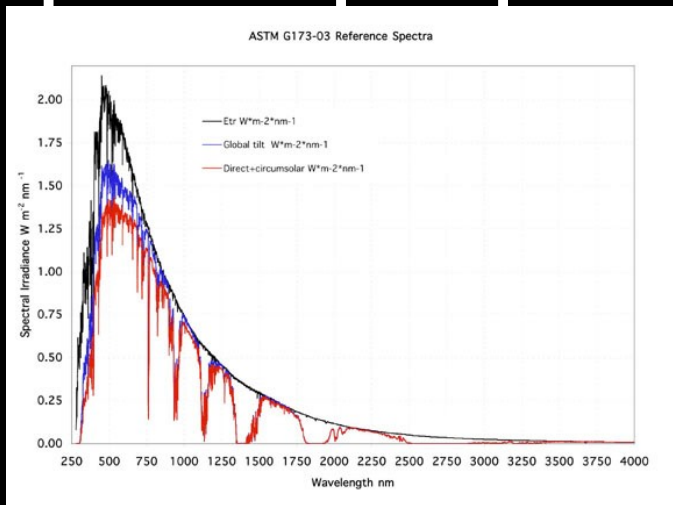
Relative gains due to reflectors around solar noon on clear days



Optical properties: reflectors and silicon



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Intégrales (358 – 1150 nm) :

BNI (direct+circumsolaire) W/m^2	after specular reflexion		
	silicon	polished steel	rolled aluminium
A/m^2	320.6	105.3	43.7
W/m^2 @ $U = 0.55 V$	176.3	57.9	24.1
Efficiency for DNI	25.94%	8.52%	3.54%



PV-reflector rooftop installation may contribute to building insulation and to combating urban heat islands

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Conclusions

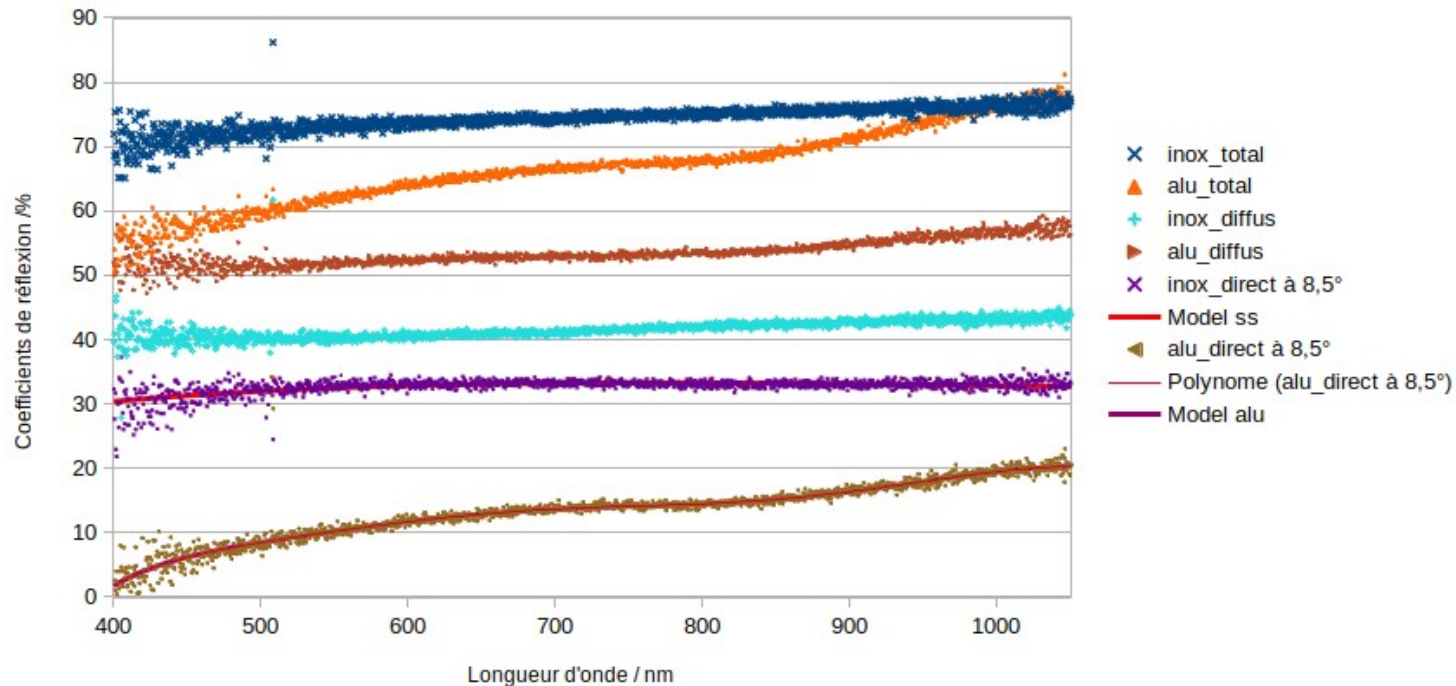
- adding a single reflective fixed plan can increase electricity production by 5 to 20%.
- the gain shows 2 maxima during the year at periods that depend on the geometry of the system wich permit a range of adaptation to the demand.
- In our setup, aluminium reflectors are more effective than polished stainless steel ones for different possible reason : higher diffuse reflectivity, lower over heating due to higher thermal exchange coefficients on the back of the row.
- A durable and inexpensive surface treatment would enable the system to be considerably improved from an electrical and thermal point of view.
- Possible applications to building insulation and urban heat island reduction.

Thank you for your attention !

Supplement: adjustment curves for the specular reflection coefficient

Coefficients de réflexion inox et aluminium

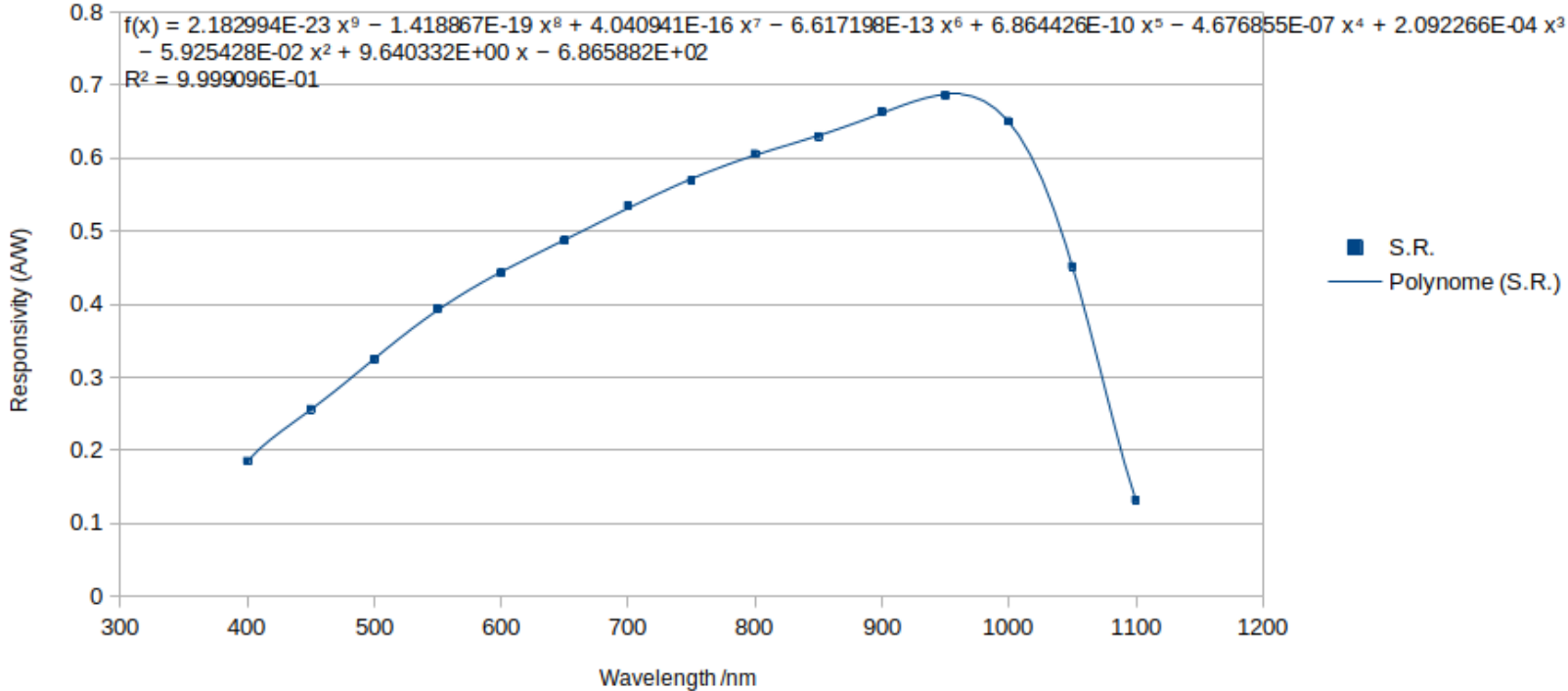
échantillon I3 face polie et A3 face brute



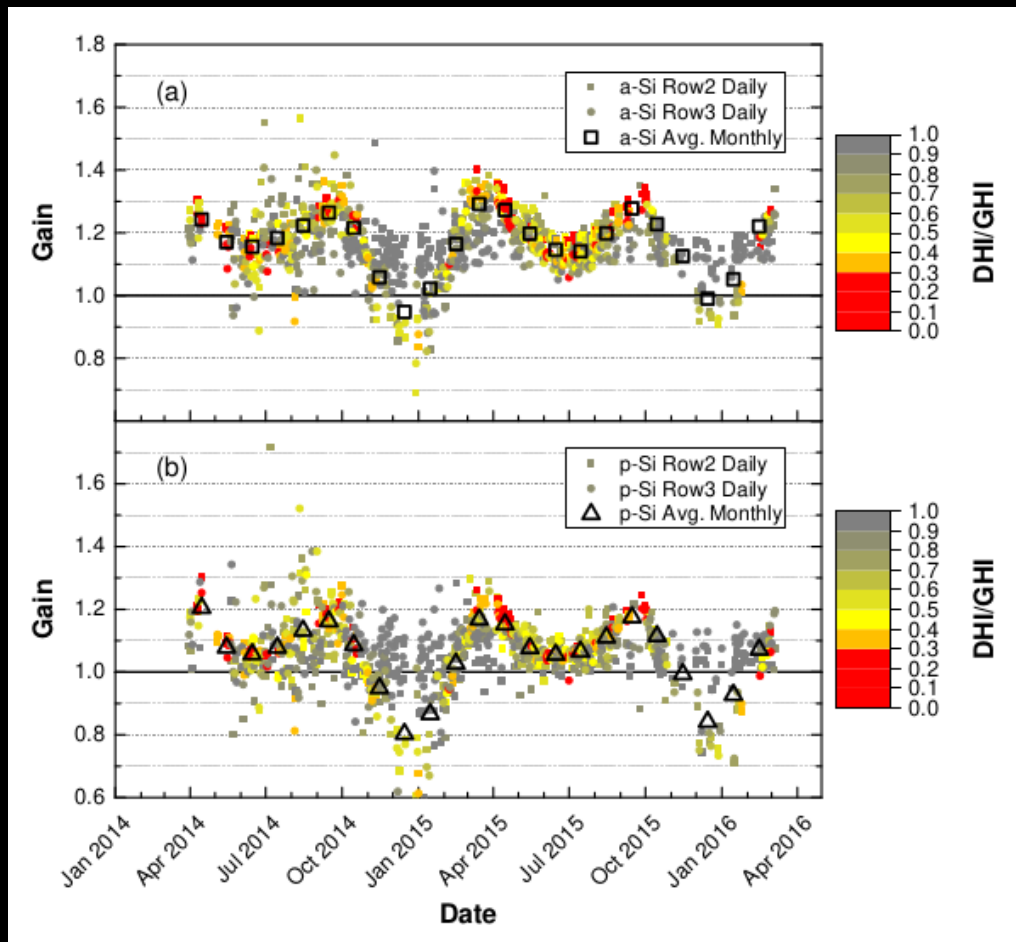
Supplement: adjustment curve for the spectral response of silicon

Silicon Spectral Response

Hengyang Xiang, Lei Zhou, Hung-Ju Lin, Zhelu Hu, Ni Zhao, et al. Nanotechnology, 2020, 31 (49), pp.495201. 10.1088/1361-6528/abb2c4. hal-02989880



What we know about photovoltaic systems boosted with flat reflectors



The gain is higher for amorphous modules, which are less sensitive to current imbalances due to the geometry of their cells.

As the diffusion ratio increases, there are fewer situations where performance deteriorates.

The orientation (landscape or portrait) of the modules can penalise electricity production to a greater or lesser extent by affecting more or fewer cells.

From M. Pavlov Thesis (2016)