

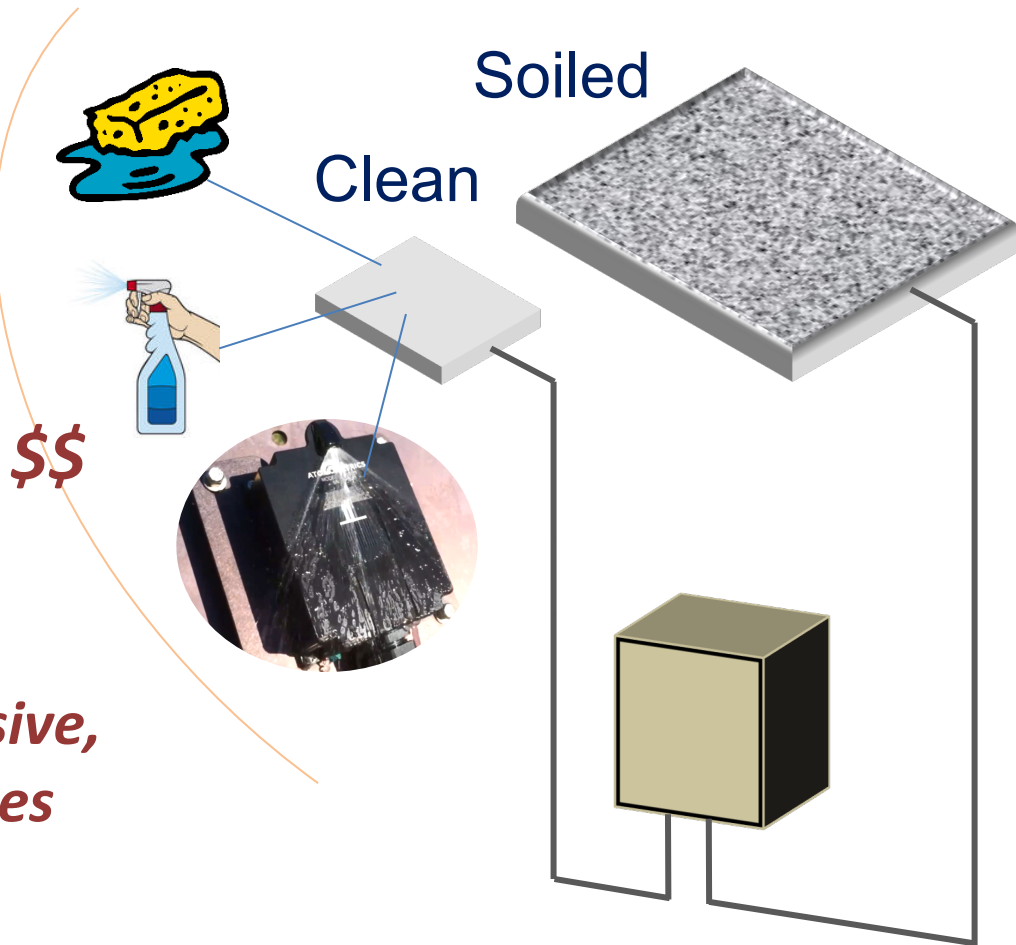
Evaluations of Mars™ Optical Soiling Sensor



Traditional Soiling Measurement

Compare dual PV devices: soiled/clean

Water, labor, or
mechanized
system



*Sometimes too expensive,
especially for small sites*

Ideal Soiling Measurement?

→ *Optical Soiling Sensor*



No water



No moving parts



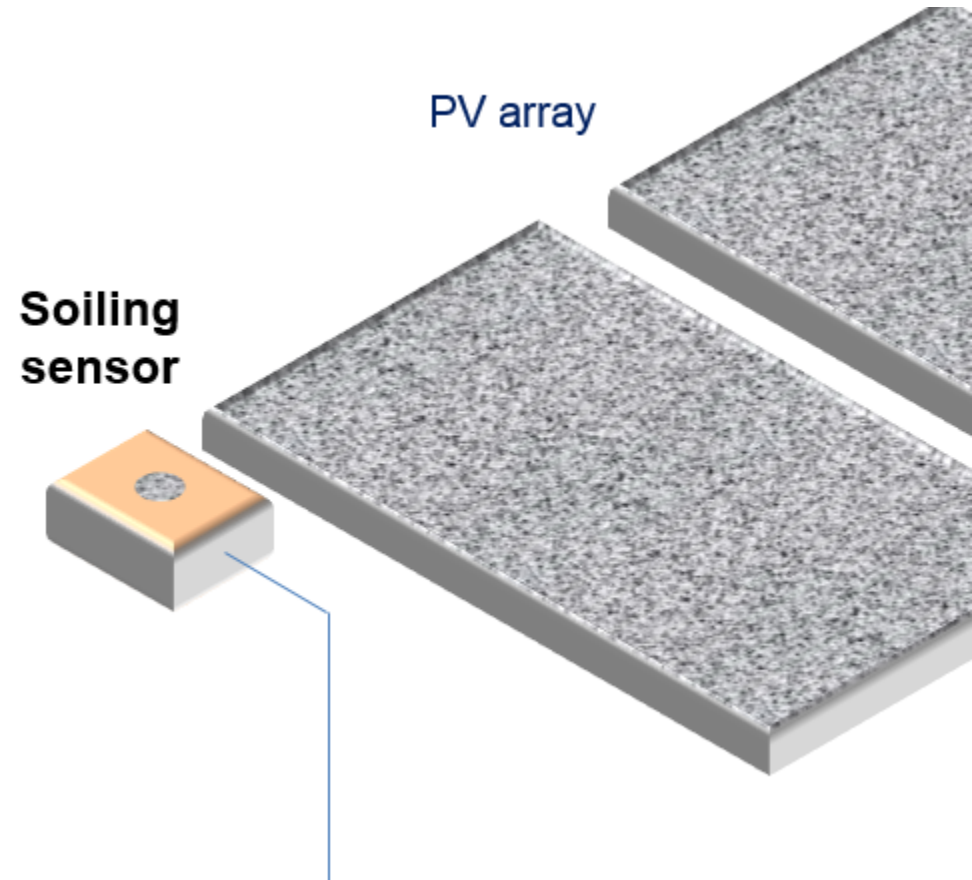
No maintenance



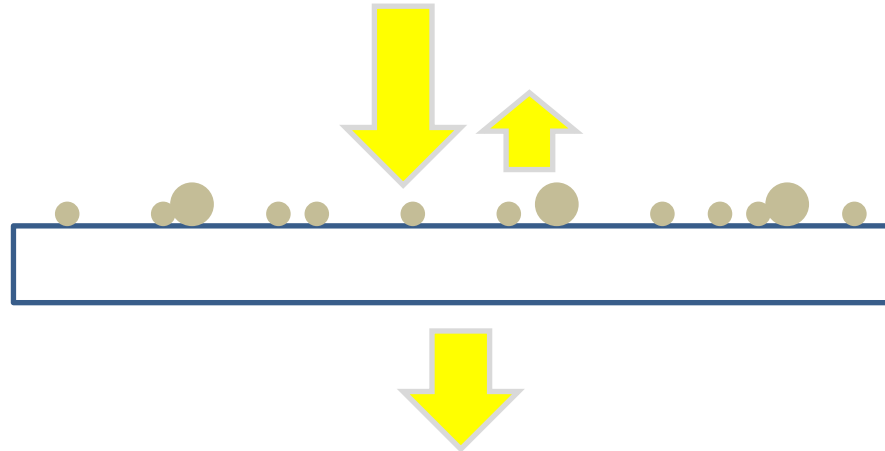
No on-site calibration



Compact, low-cost



Optical Measurement of Soiling



$$SL = 1 - T = R + A$$

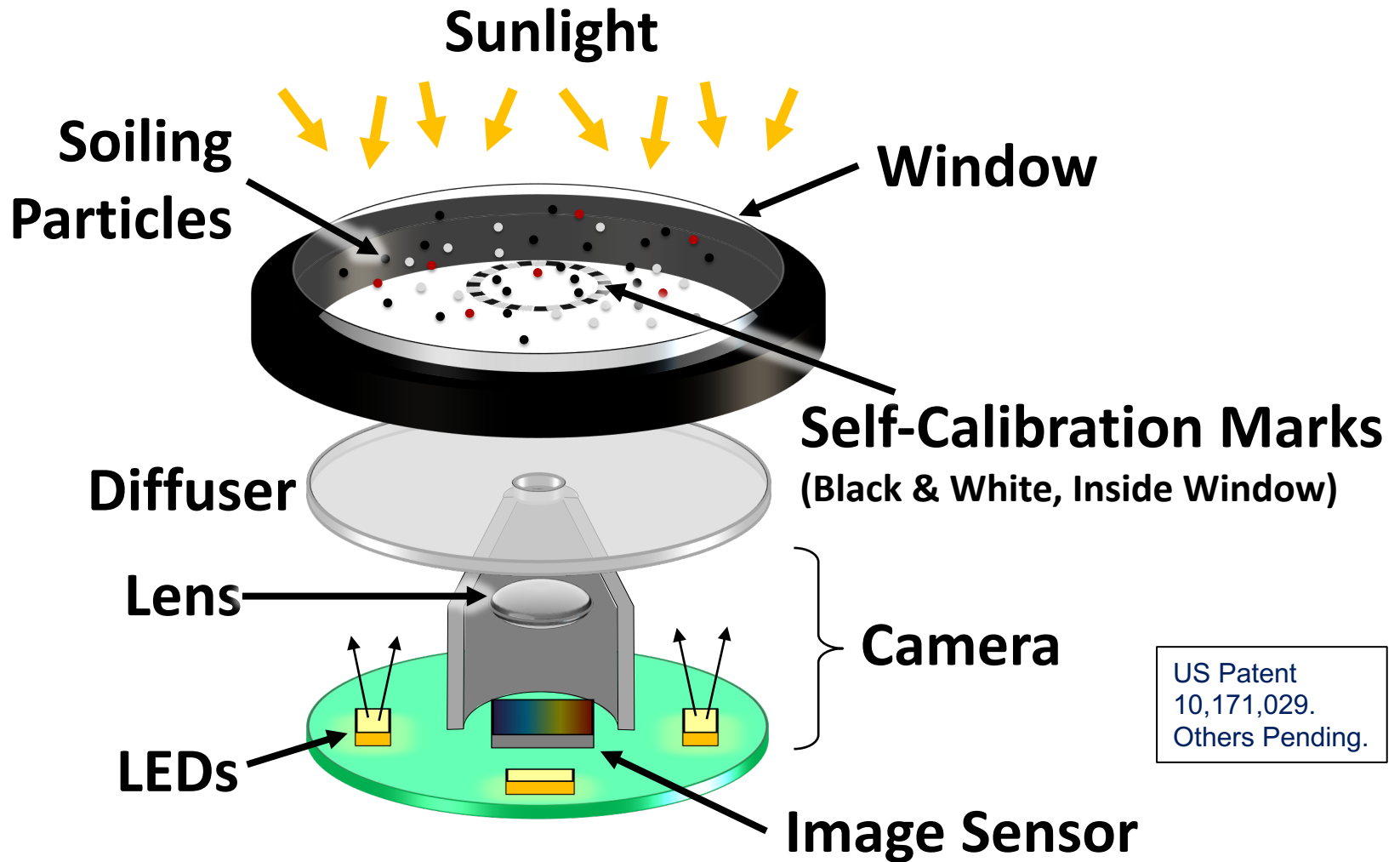
Soiling Loss

Absorption

Reflection

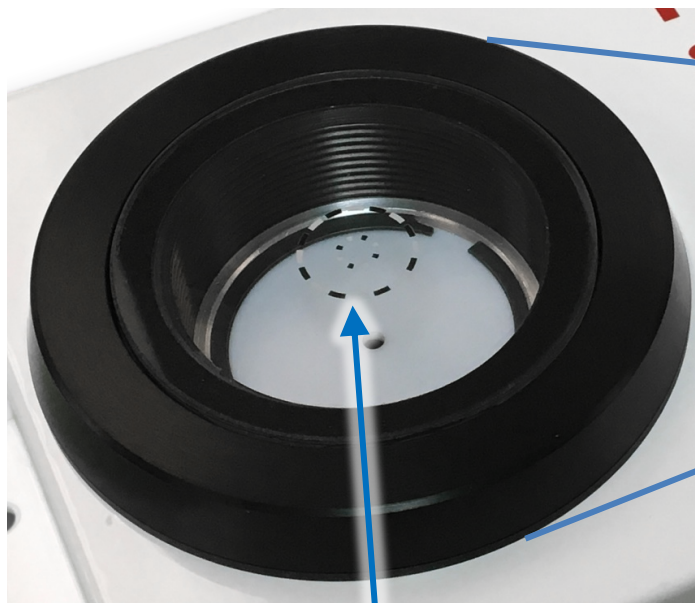
Transmission

Mars™ Technology



US Patent
10,171,029.
Others Pending.

Mars™ Soiling Sensor



Calibration marks on window



Internal image processing software

~15 mm

Example image with dust

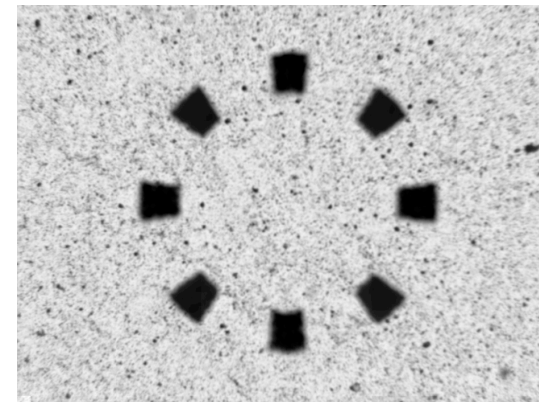
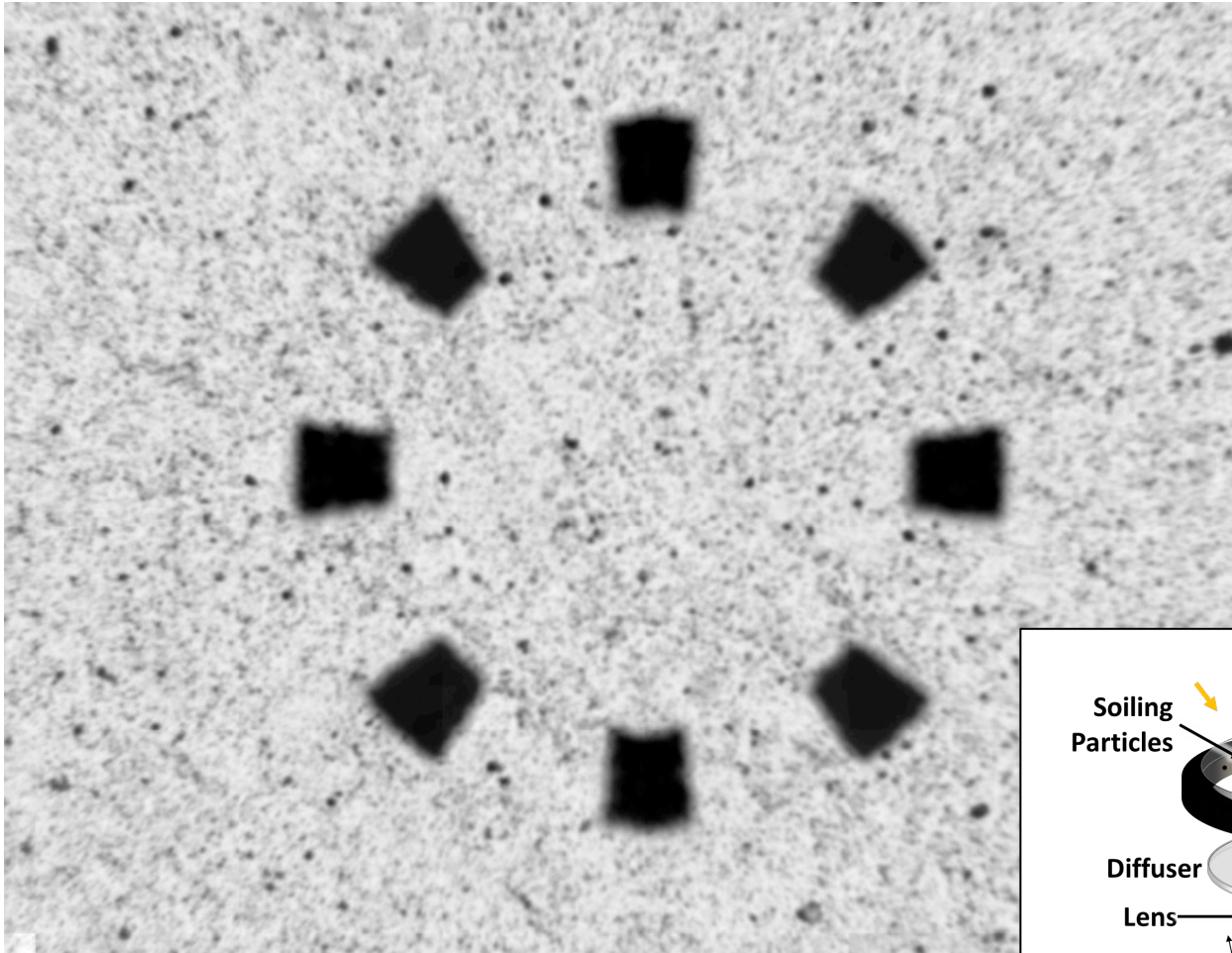
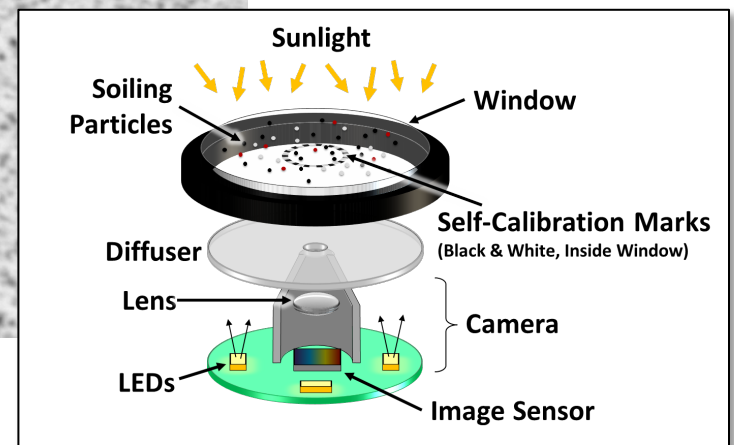


Image Details

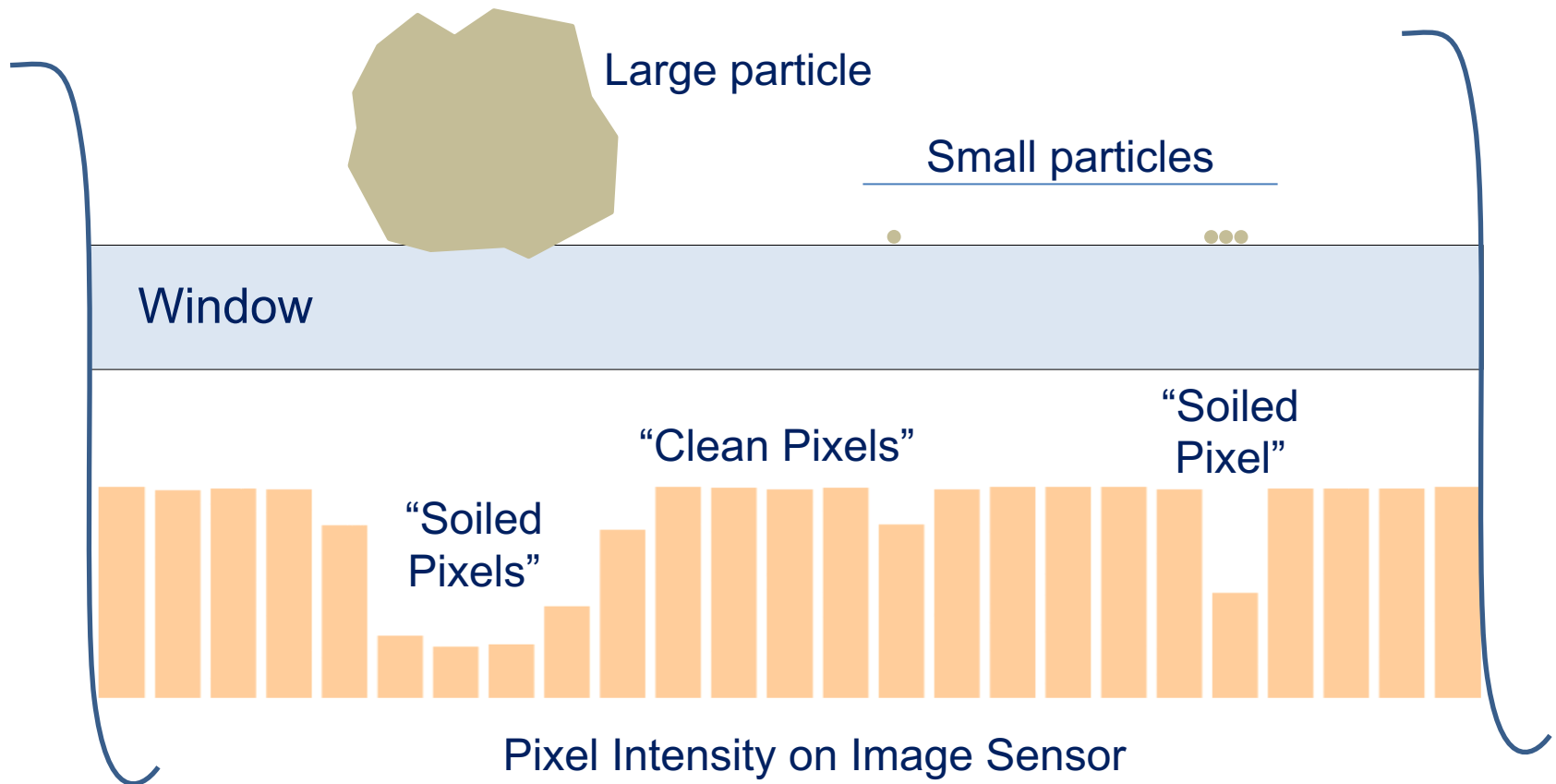


Shadows of dust particles

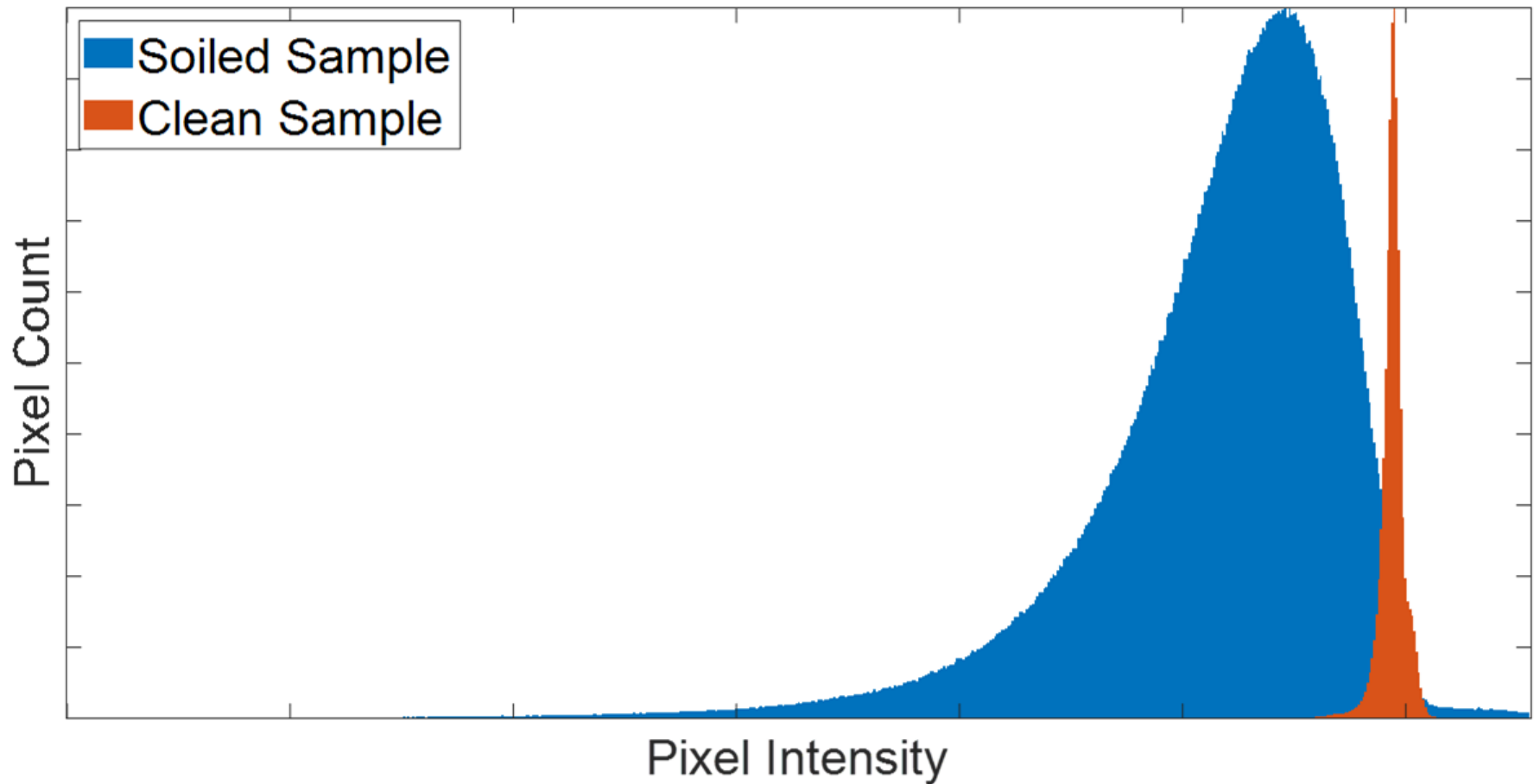


Analysis – Compare “Soiled” to “Clean” Pixels

Measures transmission loss due to particles



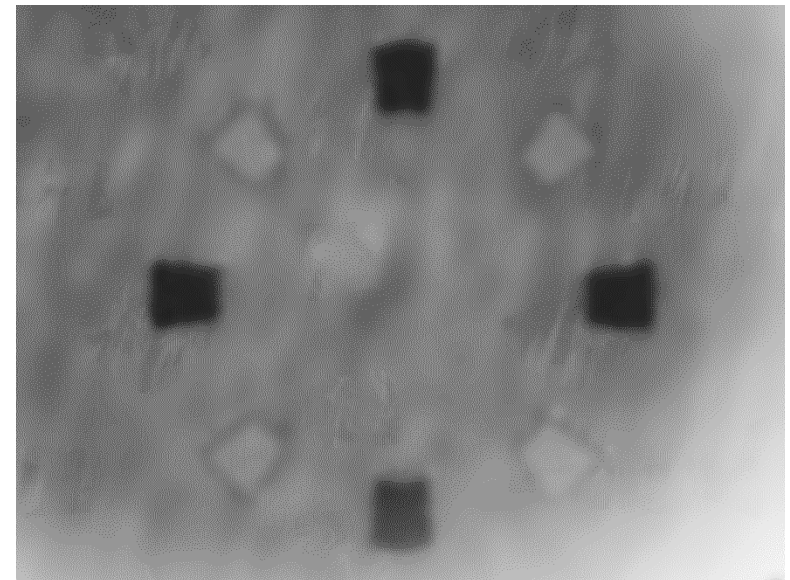
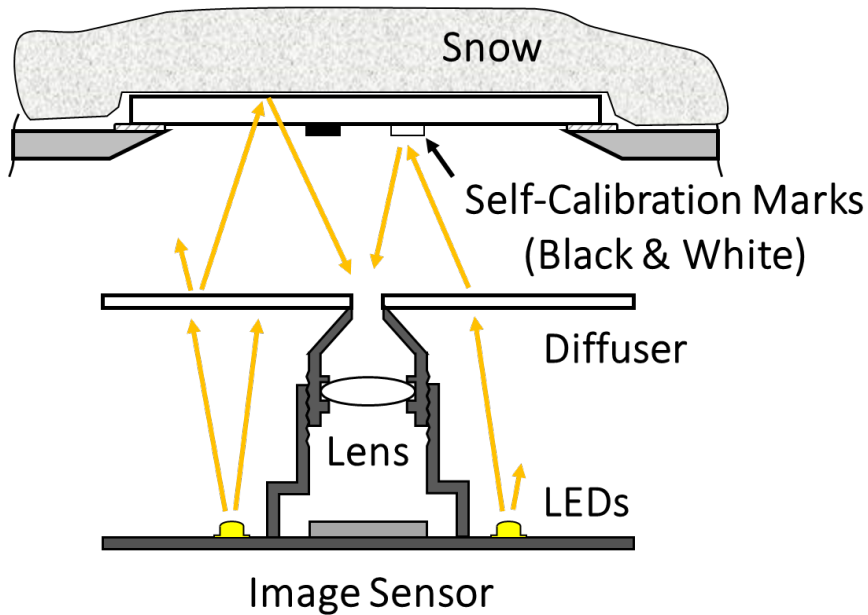
Histogram Analysis



Snow Detection

Use internal illumination to see reflective material covering sensor window

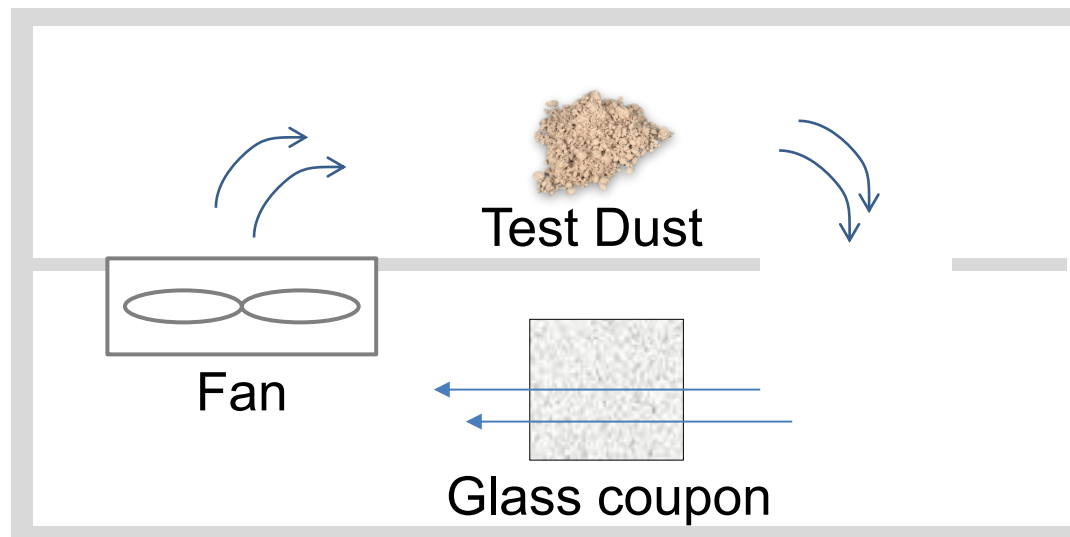
White reference marks calibrate reflectivity



Simulated snow cover (styrofoam sheet)

Preparing Test Coupons

- 50 mm x 50 mm glass coupons
- Chill to promote condensation
- Insert in dust box with circulating air and test dust



Dust box, top view

Test Dusts



Arizona Road Dust

ISO 12103-1, A2 FINE

~1-100 um dia.



Carbon Black

<~30 um dia.

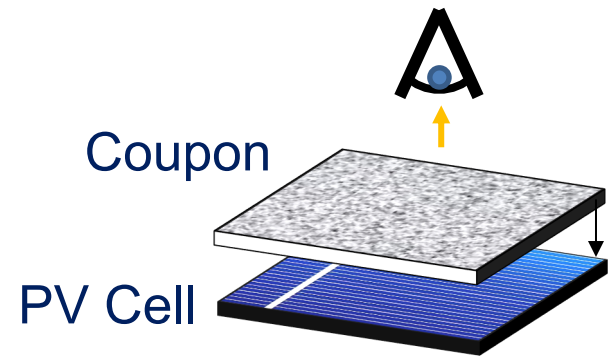


Red Iron Oxide

<~30 um dia.

Representative of airborne particulates

Soiling Appearance



Arizona Road Dust

~12% loss



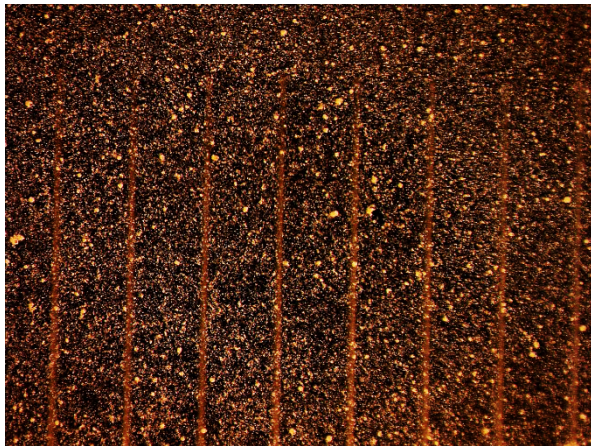
Carbon Black

~12% loss

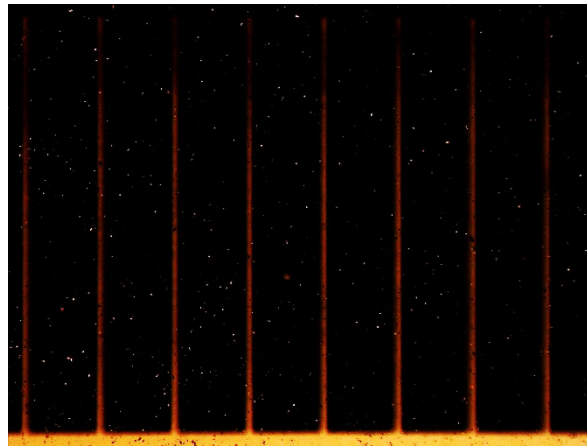


Red Iron Oxide

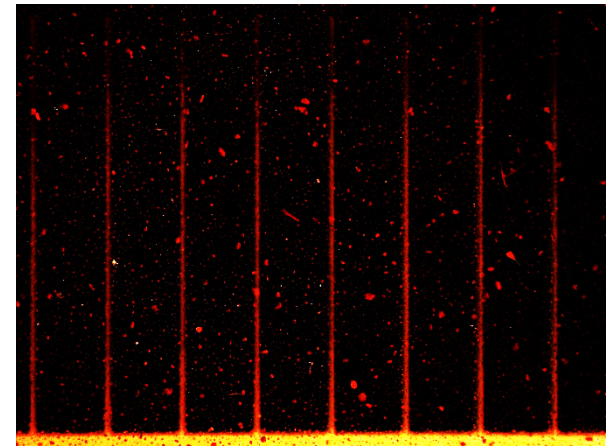
~12% loss



10 mm

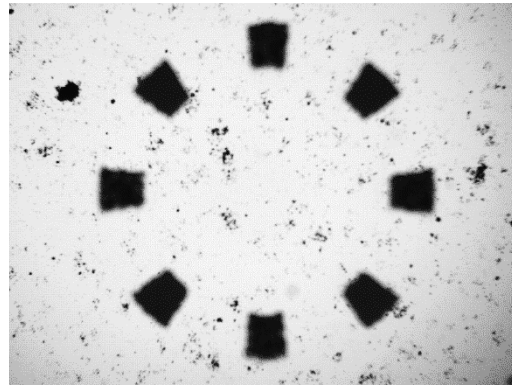
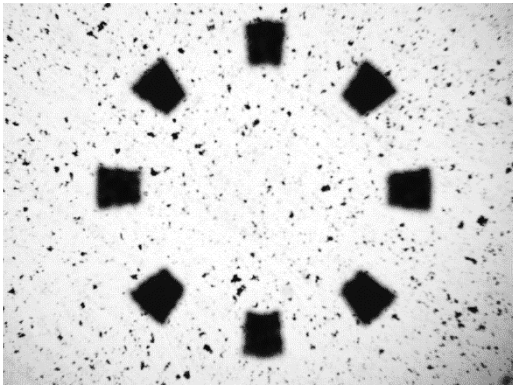
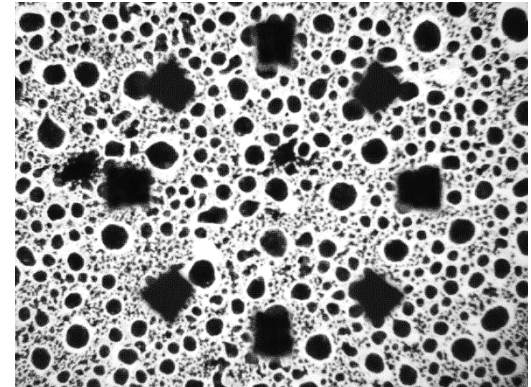
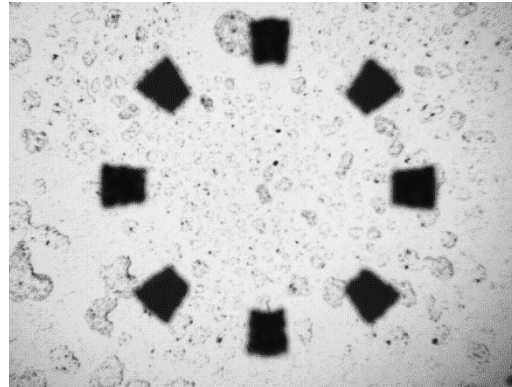
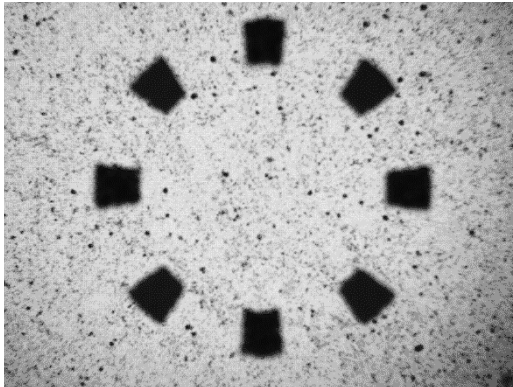


10 mm

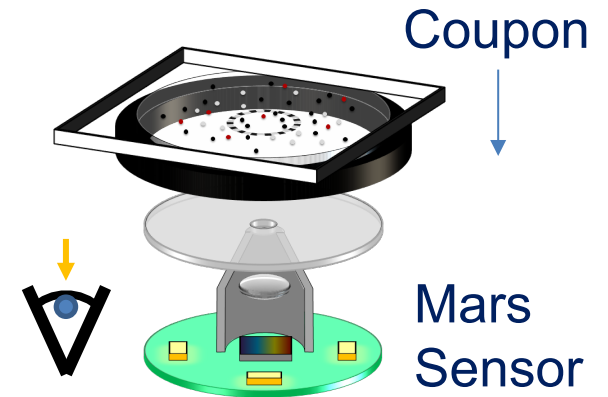


10 mm

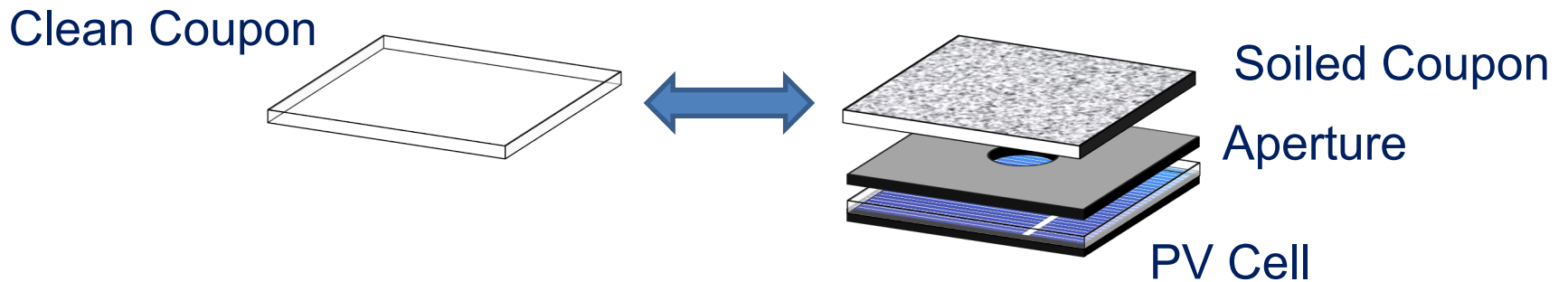
Many Different Samples...



Many different dust morphologies depending on deposition conditions

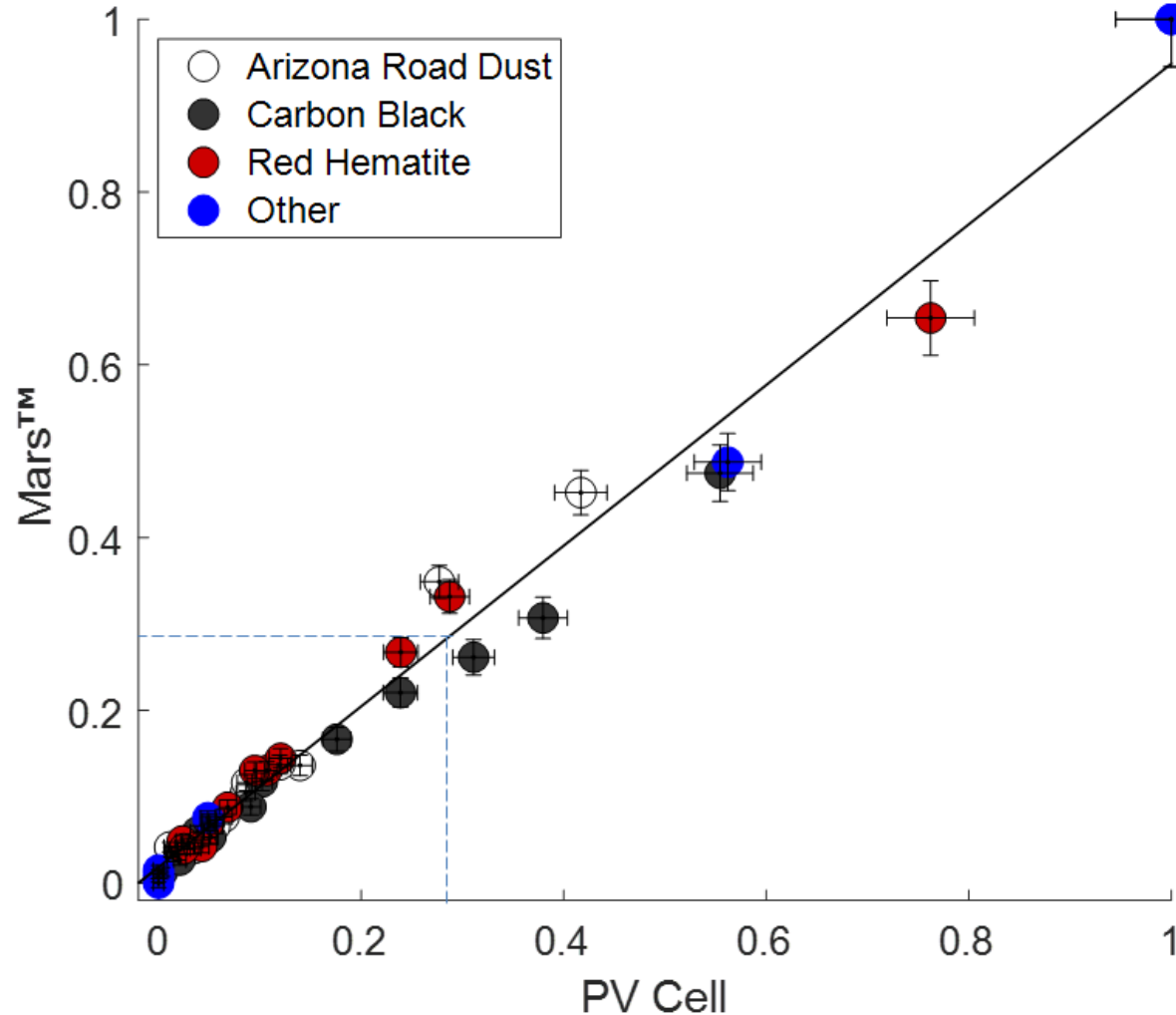


Control Measurement with PV Cell

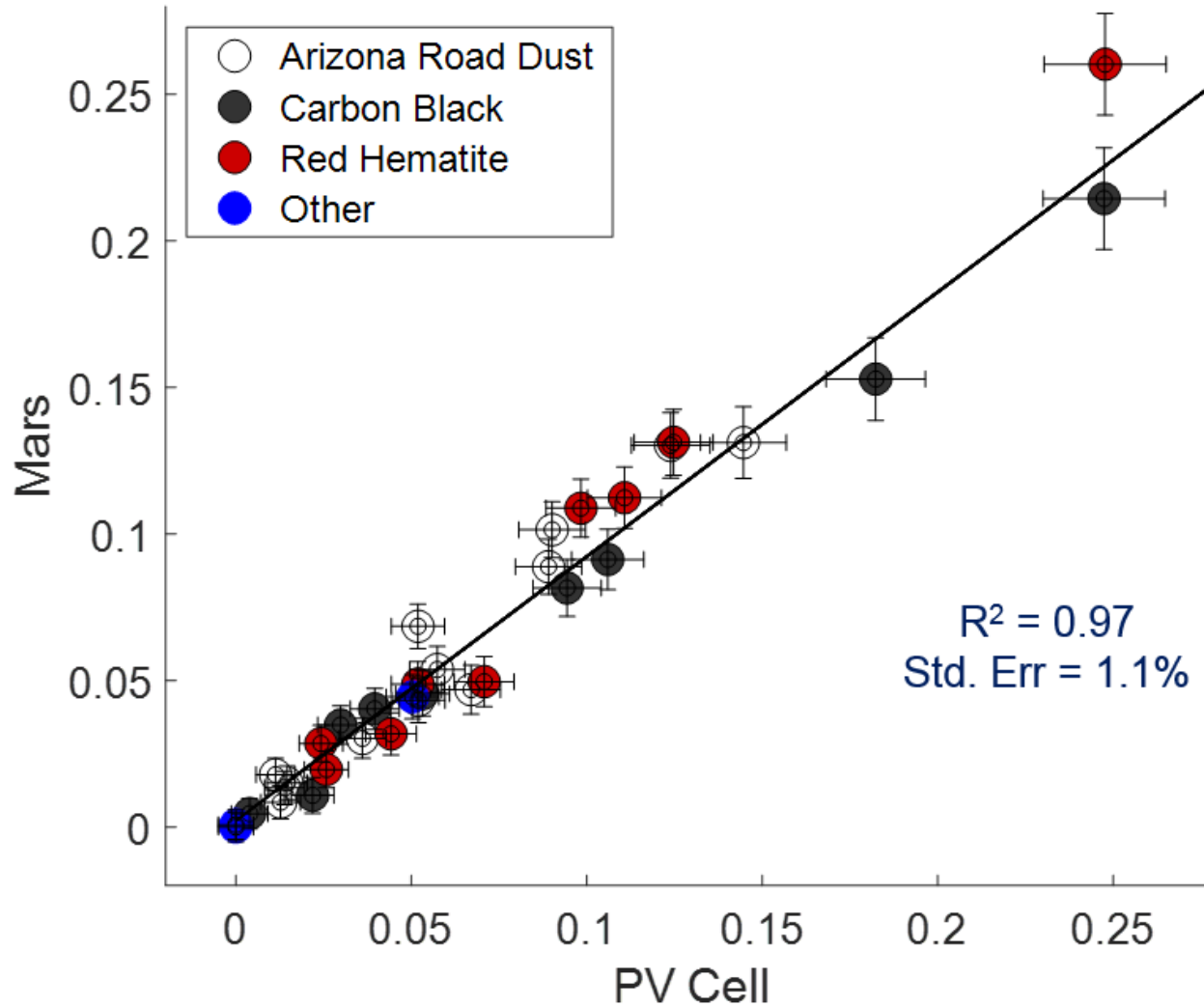


Compare PV Cell Isc:
Soiled Coupon vs. Clean Coupon

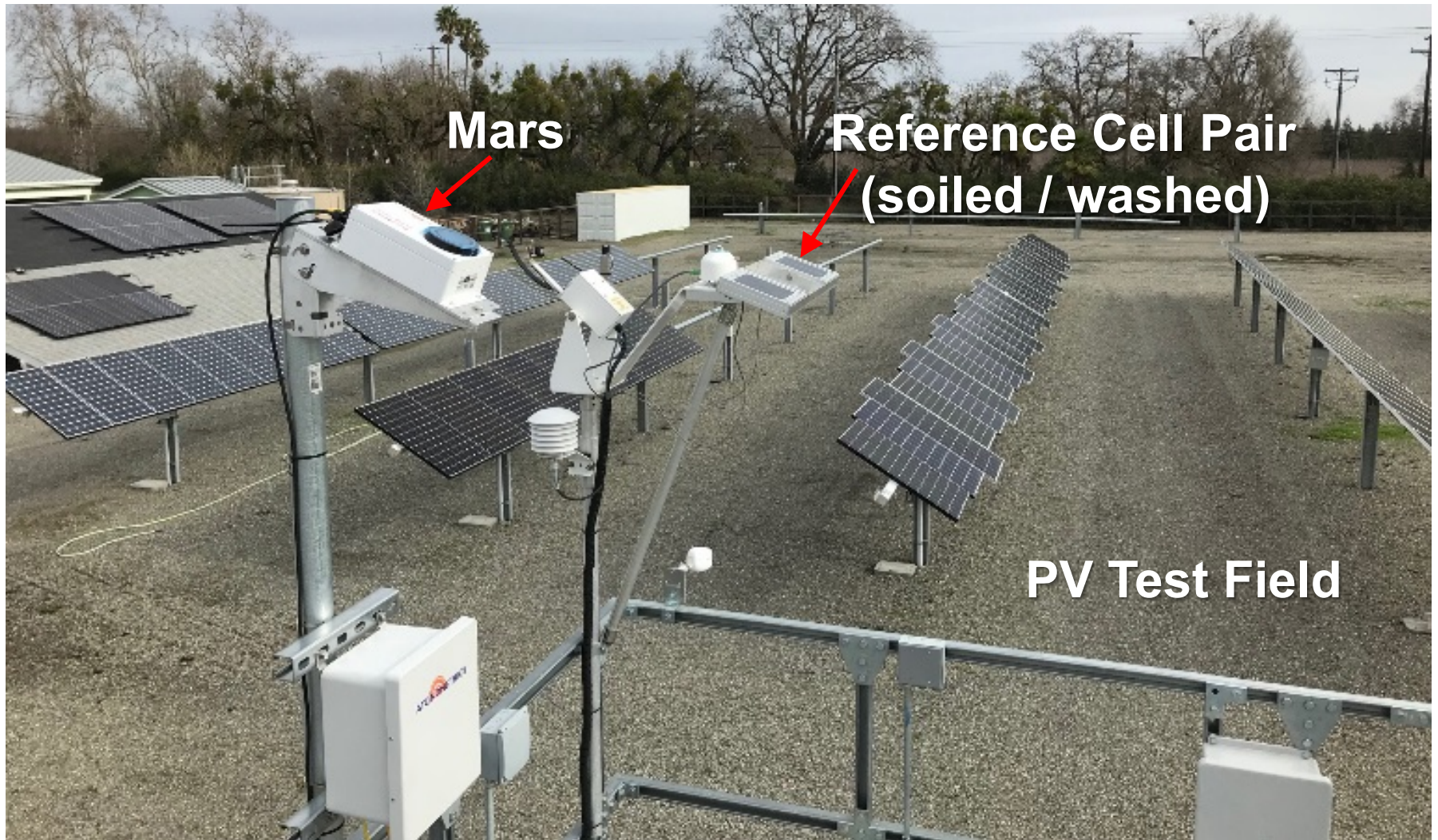
Lab Test Results



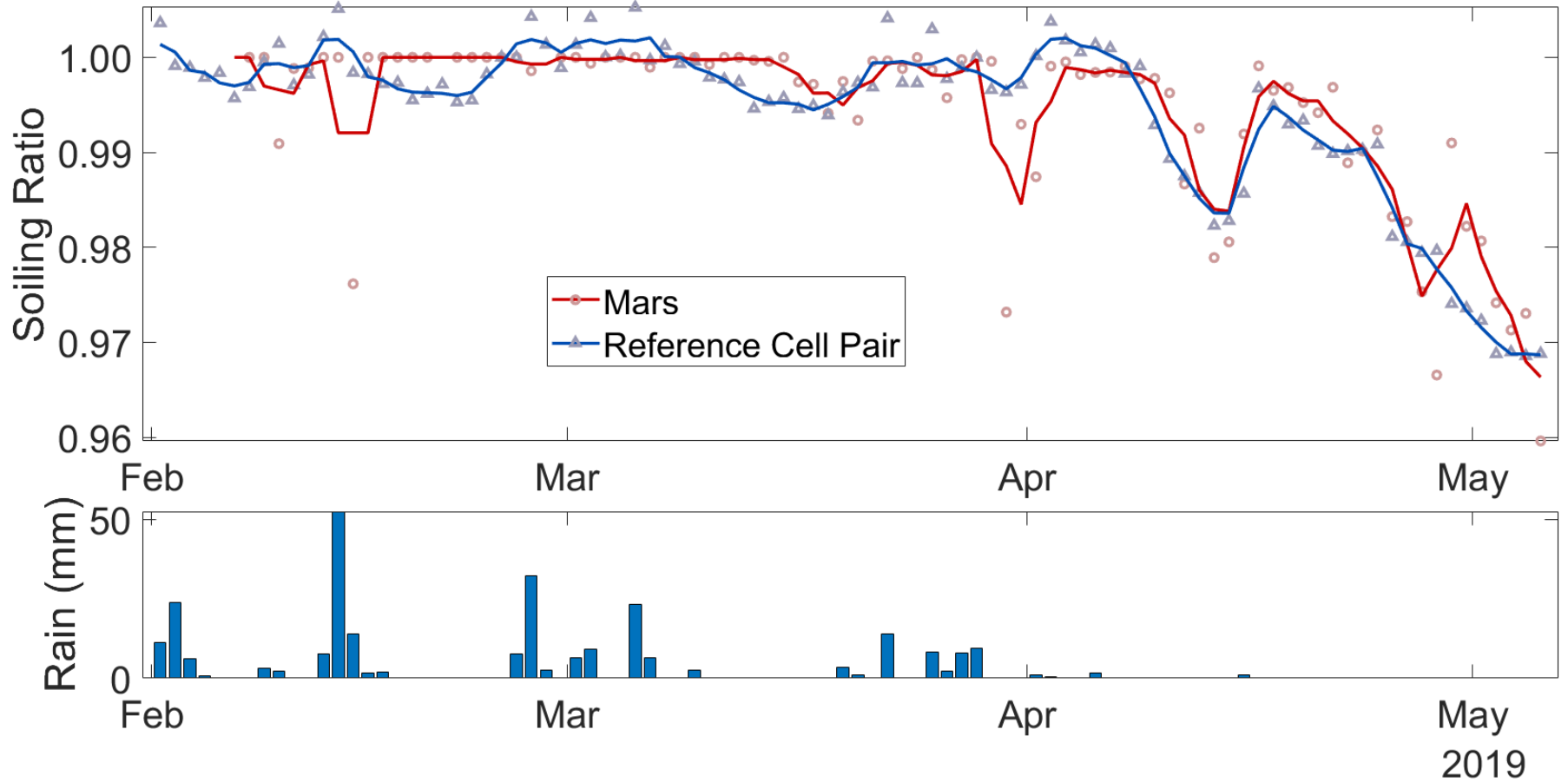
Lab Test Results



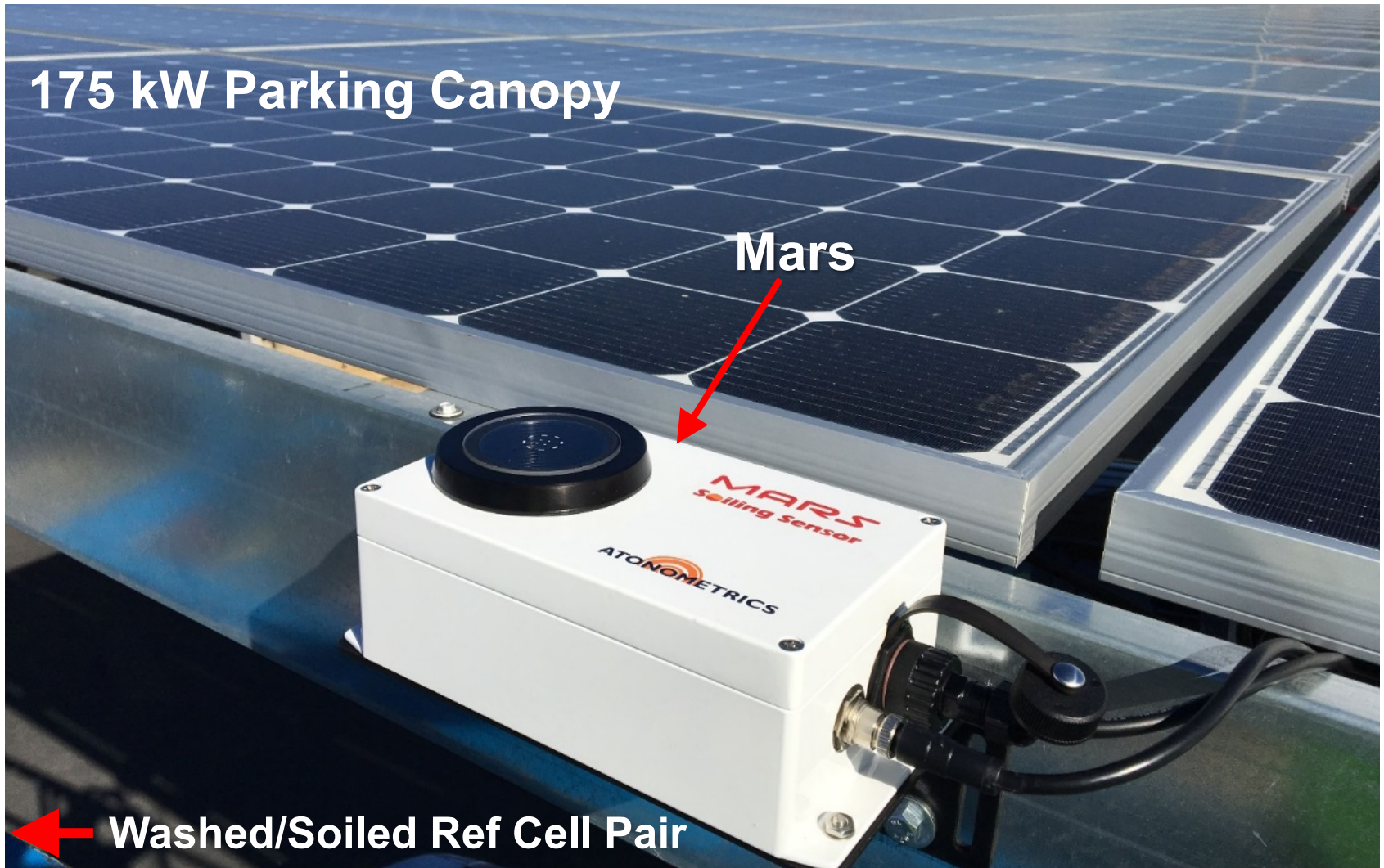
Field Trial – Site 1



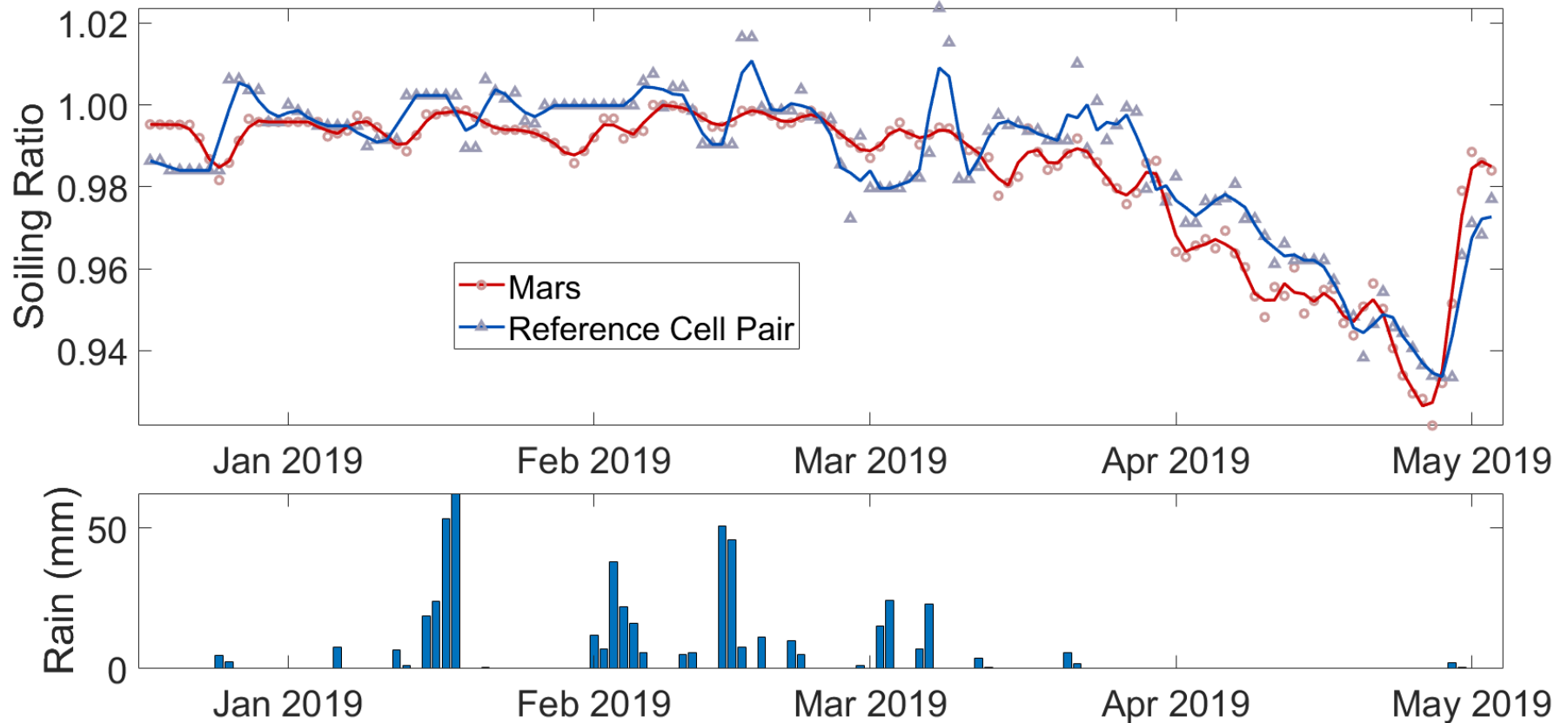
Field Results – Site 1



Field Trial – Site 2



Field Results – Site 2



Conclusions

- Mars™ Soiling Sensor allows measuring soiling with no water, no moving parts, no maintenance
- Lab tests show good correlation results, with equal sensitivity to different dust colors
- No dust-specific calibration required
- Field tests underway show good correlation to traditional clean / dirty PV pair measurements
- Promising solution for lower-cost soiling measurement