# Assessment of Photovoltaic Surface Texturing on Transmittance Effects and Glint/Glare Impacts

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U.S. DEPARTMENT OF ENERGY

National Nuclear Security Administration

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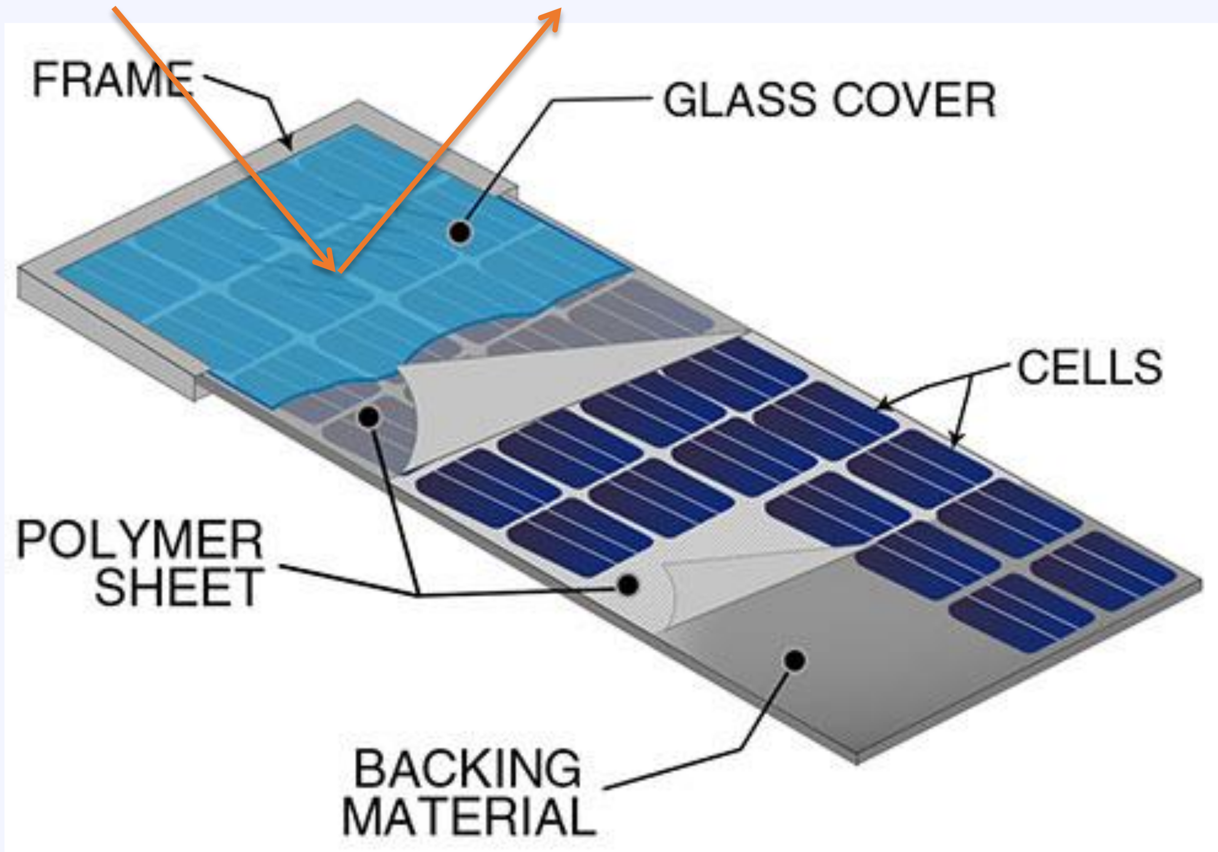
# Outline

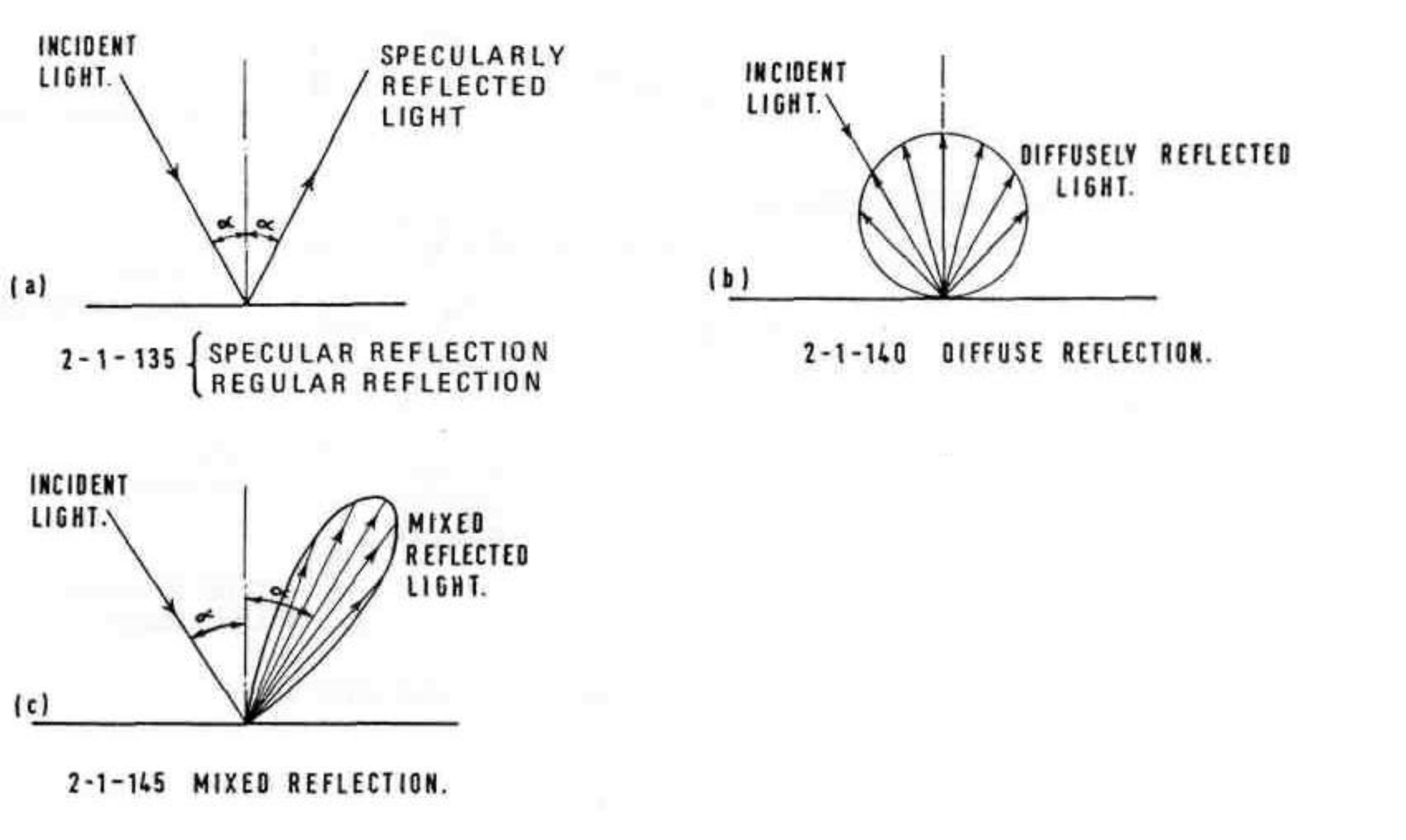
- Background
- Motivation for this work
- Approach
- Results and Discussion
- Conclusion & future work

# Background – PV Module Construction




www.solarquotes.com.au

# Background (2/2) – Reflections




http://www.iala-aism.org/wiki/dictionary/index.php?title=Mixed_Reflection

# Motivation

1. Solar glint/glare from PV modules is caused by reflections off PV glass covers – minimize this.

www.pagerpower.com

www.freerepublic.com

2. Maximizing transmittance through cover glass to solar cells can increase energy production.

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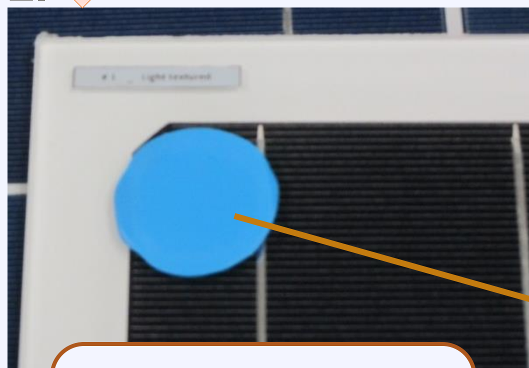
# Surface Roughness Measurements Process

1.

Prepare & clean the PV panel to be replicated

2.



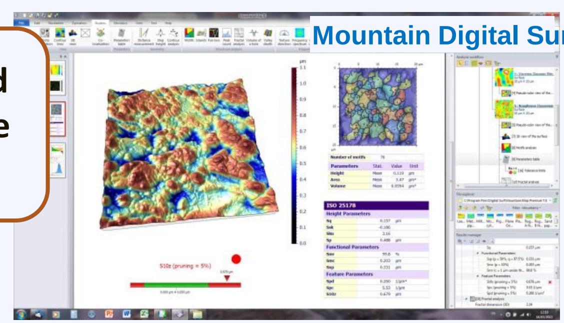
Replicate the PV panel surface with a 2-part rubber compound

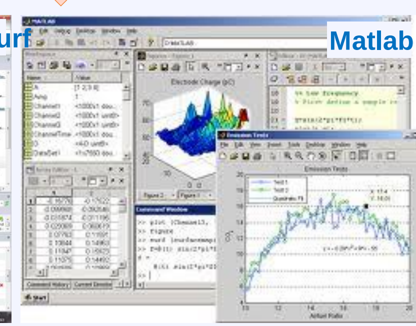
3.

Measure the small replica with an optical profilometer

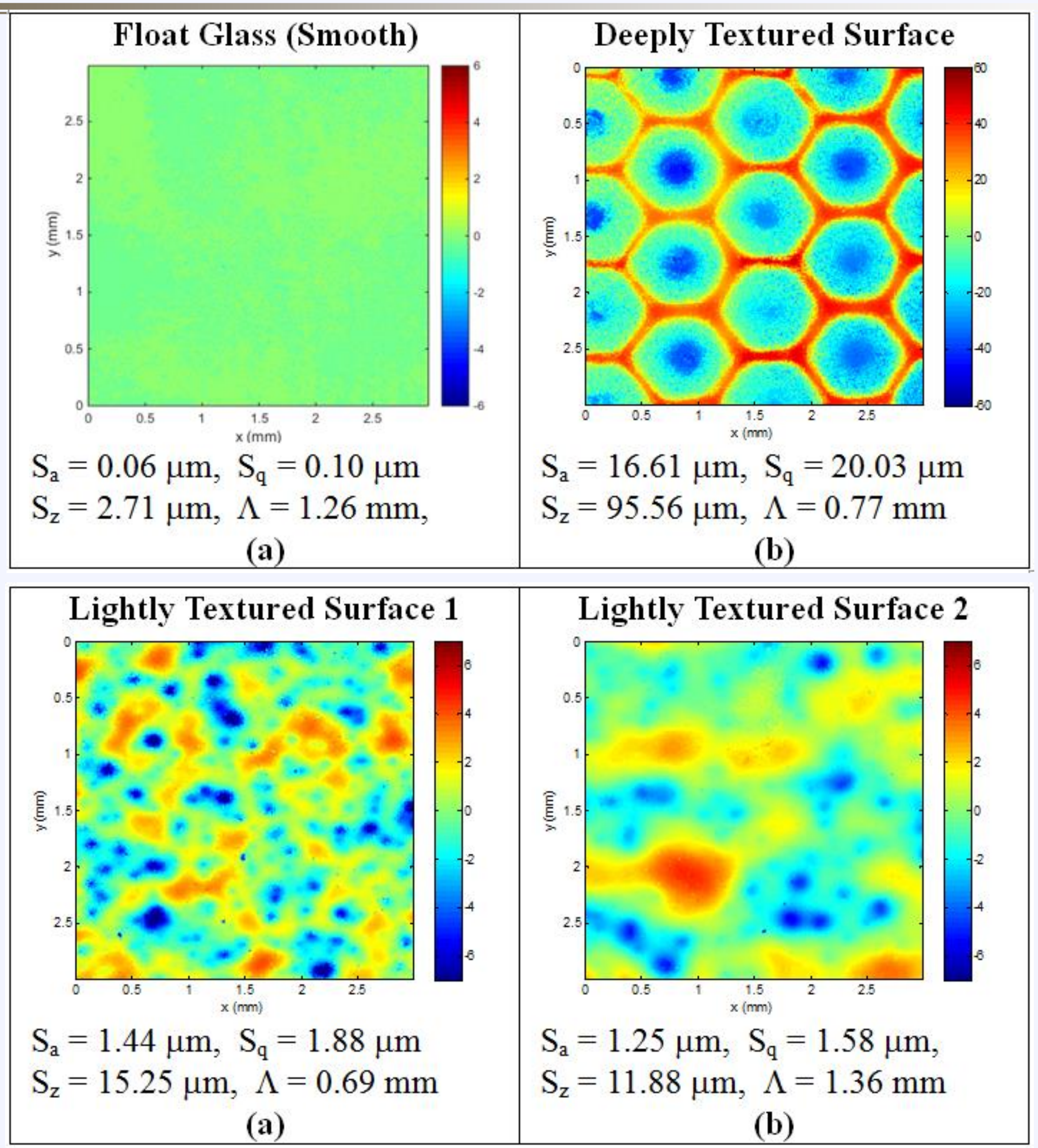
4.

Analyze the measured surface data to get the surface statistics

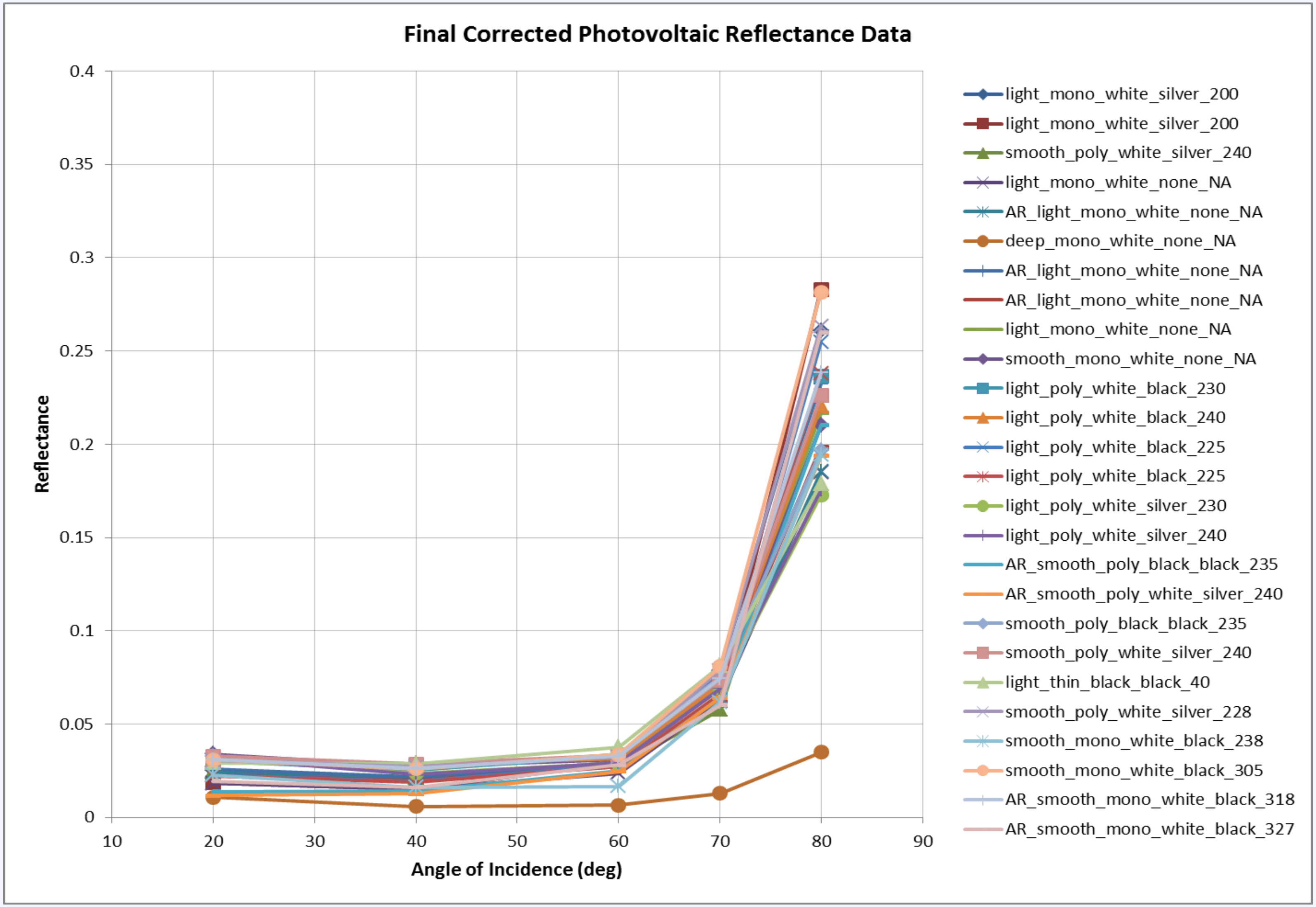


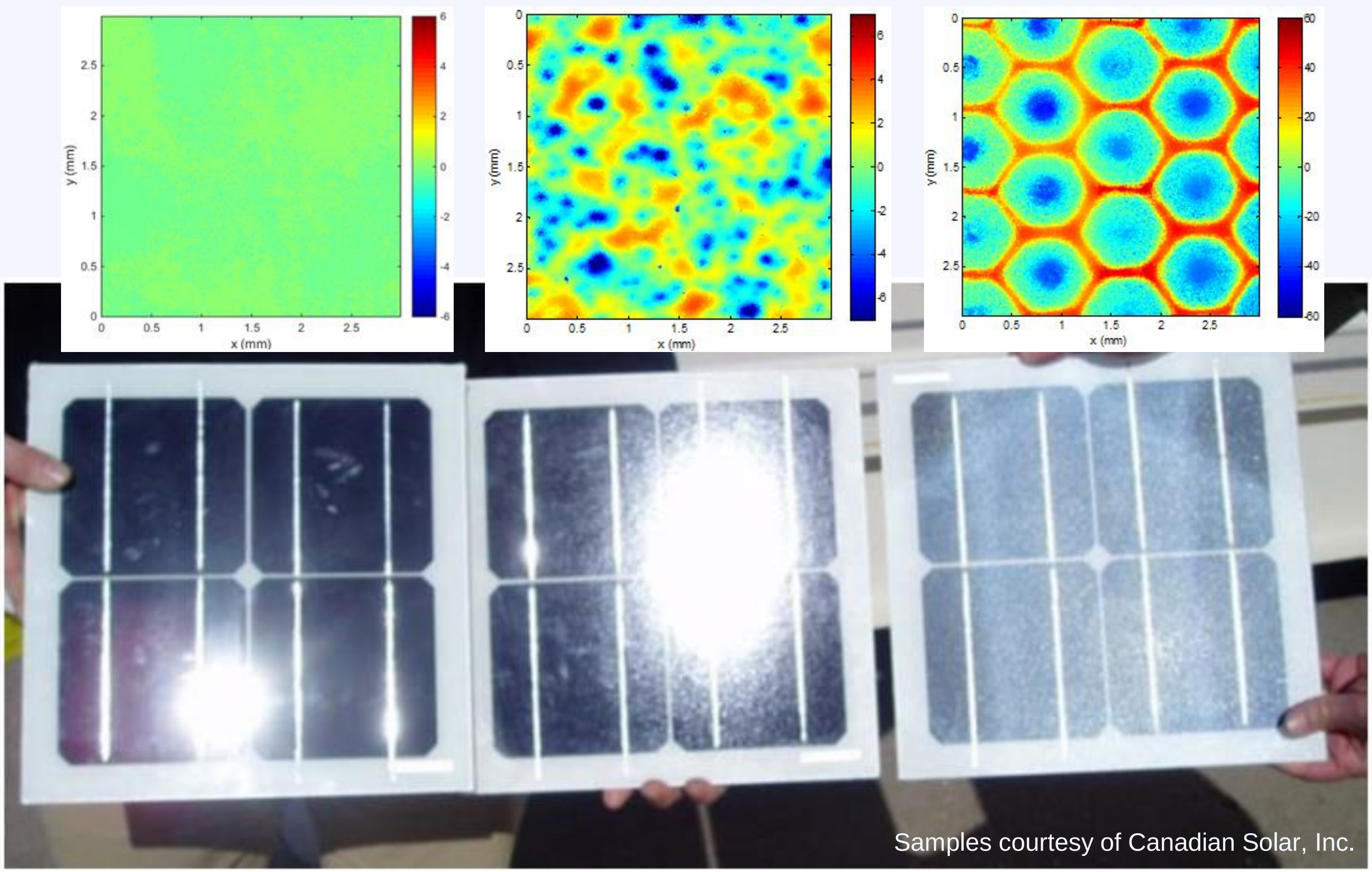
# Surface Roughness Measurement Data



# Reflectance Measurements

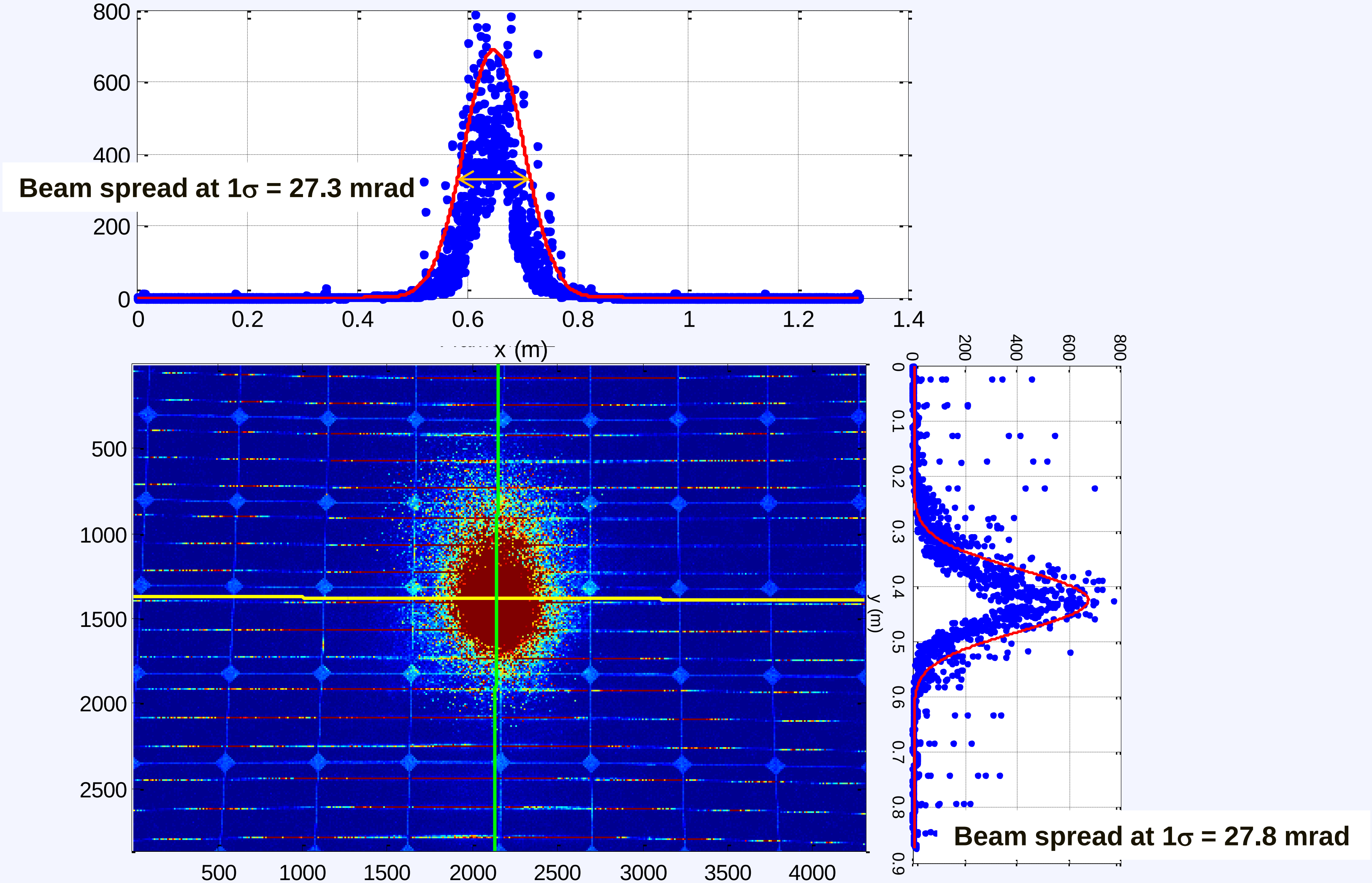


# Reflected Solar Beam Spread Measurements

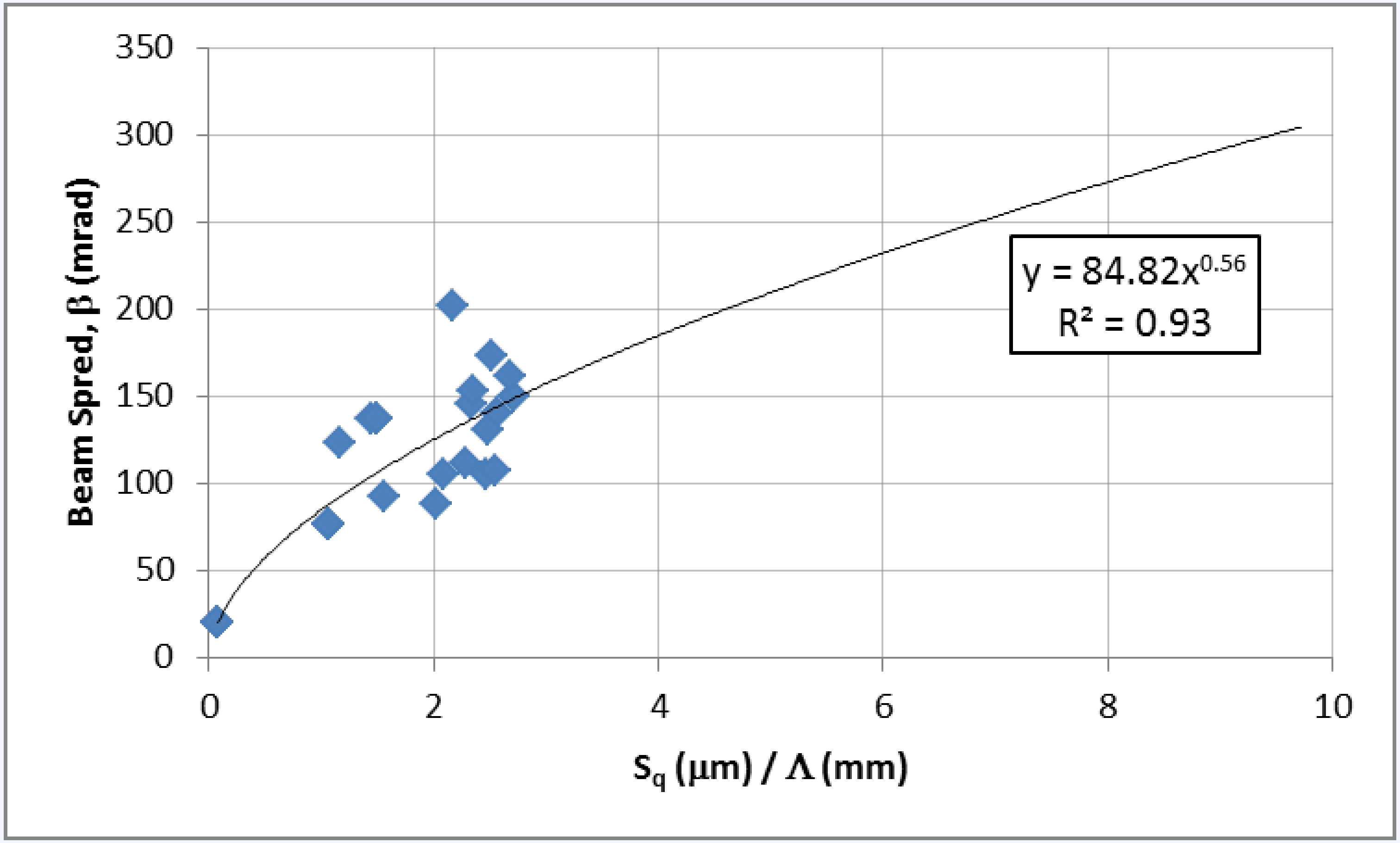



Smooth (float) glass, Lightly textured glass, Deeply textured glass

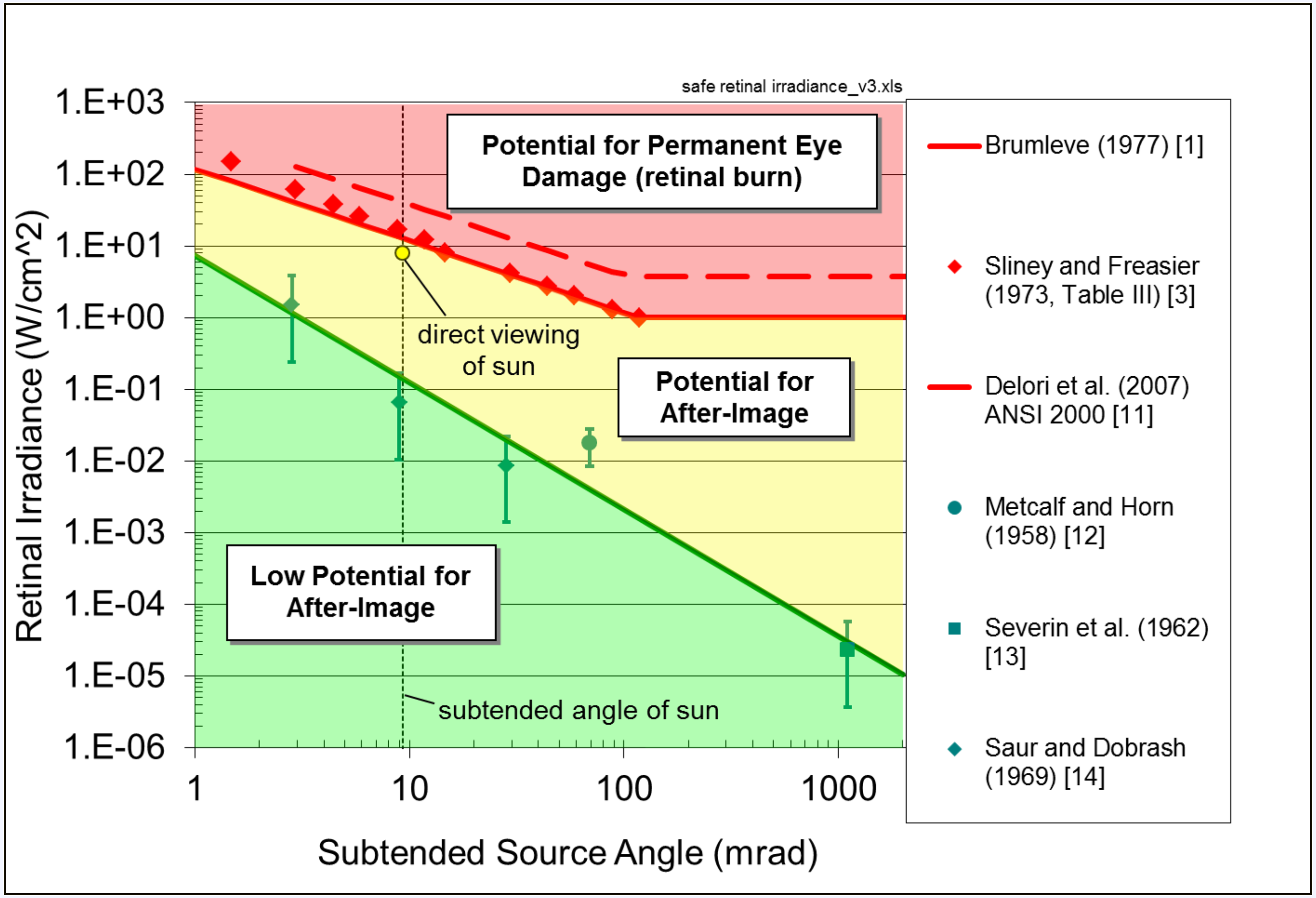
# Beam Spread Calculations



# Results on Surface Roughness & Beam Spread



# Ocular Hazards Study




Irradiance on the retina:

$$E_r = \left(\frac{\rho E_{DNI}}{\beta^2}\right)\left(\frac{d_p^2 \tau}{f^2}\right)$$

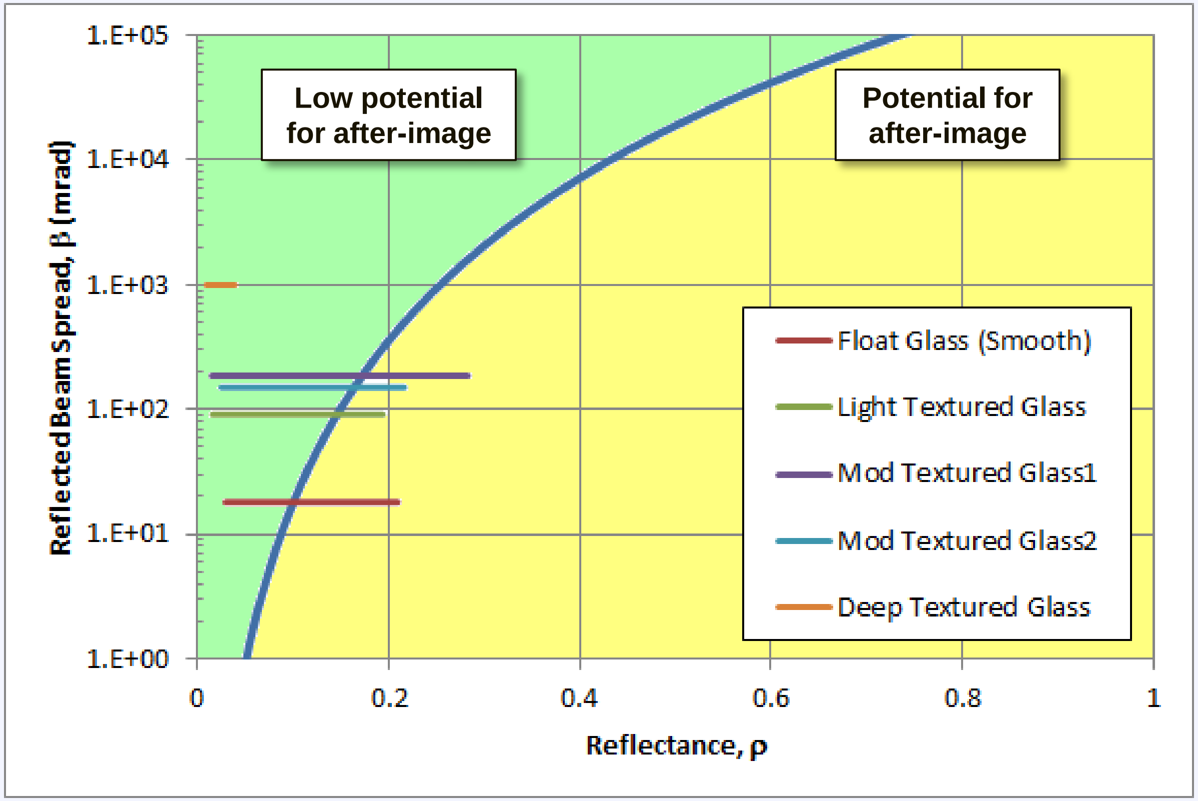
Irradiance threshold for after-image potential:

$$E_{r,flash} = \frac{3.59 \times 10^{-5}}{\omega^{1.77}}$$

# Ocular Impacts From PV Surface Texturing

$$E_r < E_{r,flash}$$

$$\beta(\rho) > \left(\frac{\rho E_{DNI} d_p^2 \tau}{f^2 3.59 \times 10^{-5}}\right)^{\frac{1}{0.23}}$$

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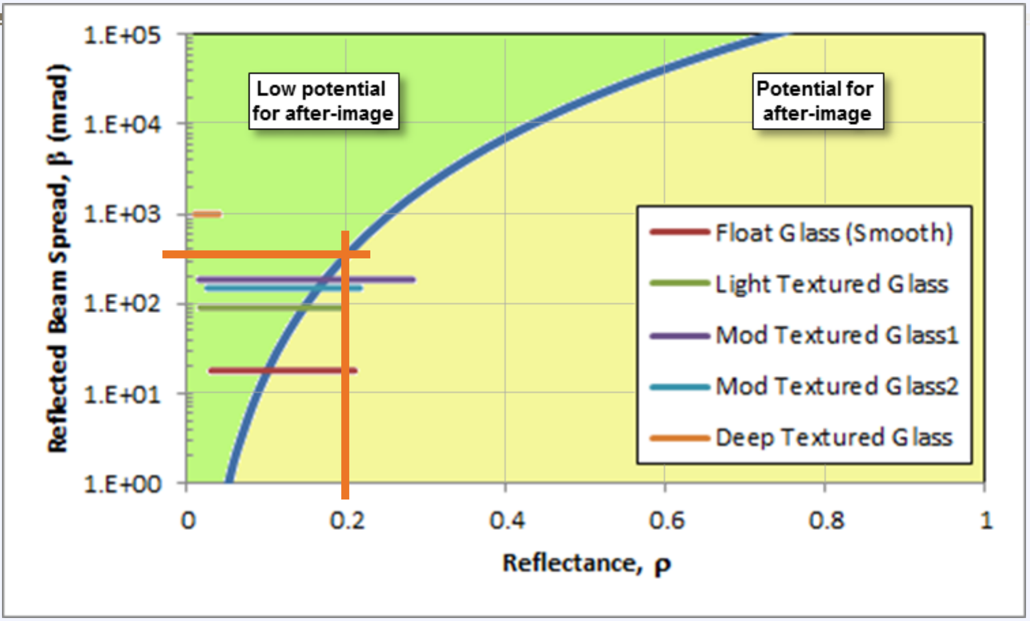
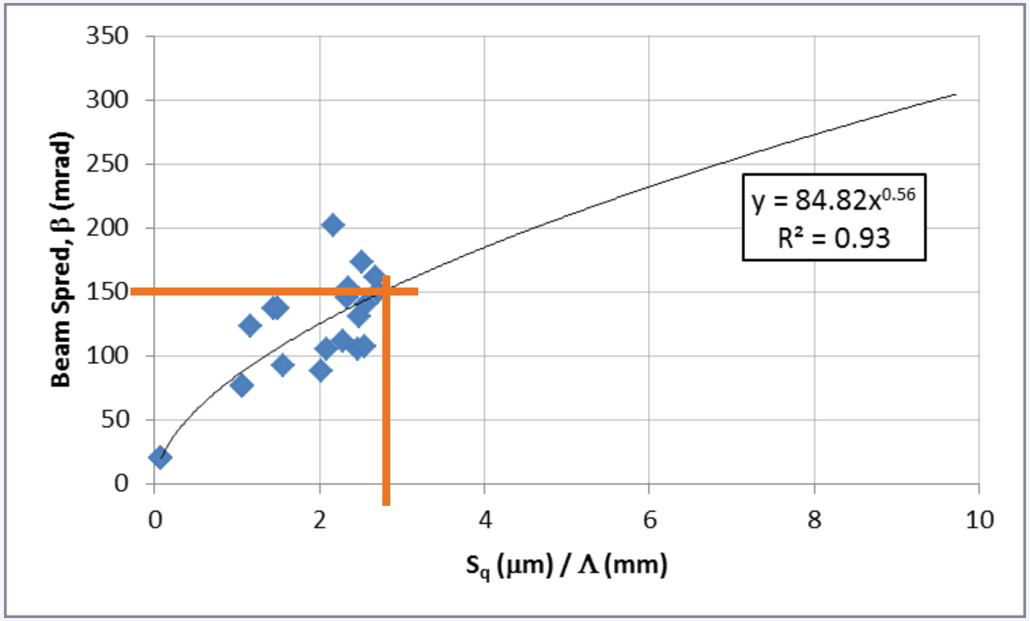
# Example of PV Cover Glass Design

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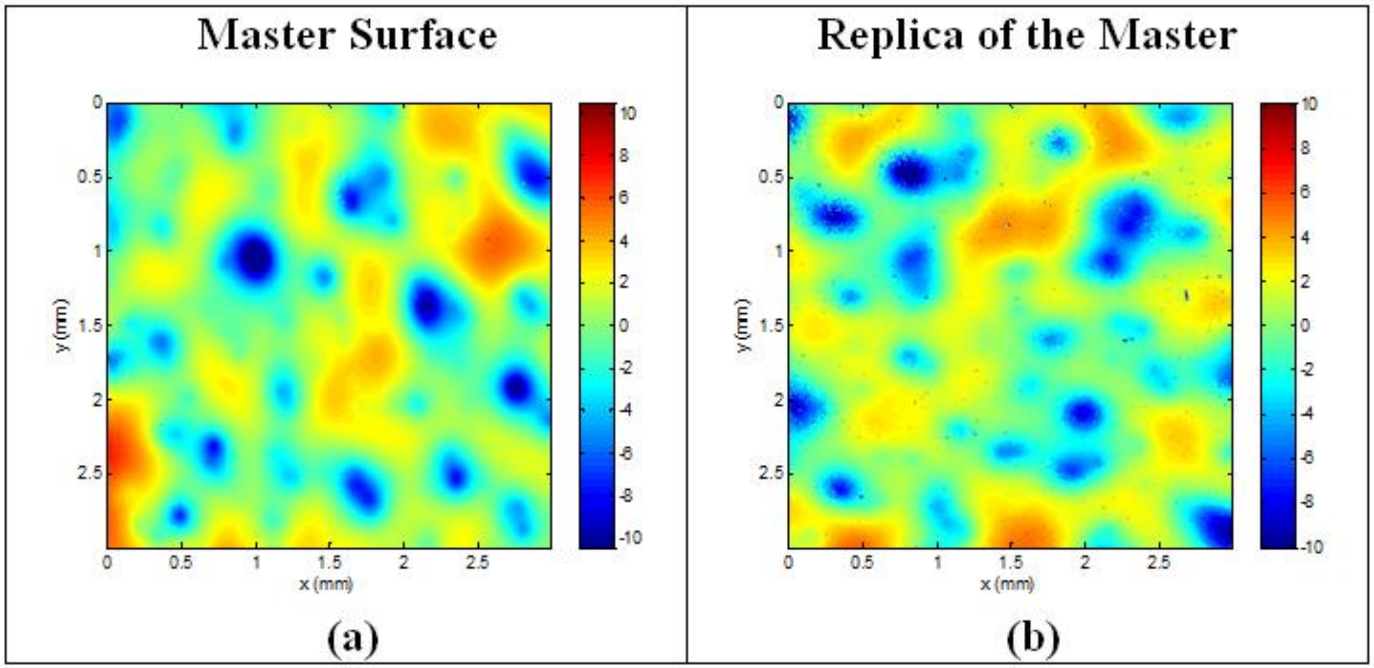
# Conclusions & Future Work

- Measured reflectance, surface roughness, and solar beam spread from several PV modules
- We attempted to correlate the beam spread to the surface roughness
- Developed a design method to minimize glint/glare from PV modules and maximize transmittance
- Results were incorporated in the SGHAT code

- Would like to study soiling effects on textured surfaces
- Build engineered surface texturing for PV and evaluate

# Extra Slides

# Replication Accuracy & Verification




| | Master Avg. Measurement | Replica Avg. Measurement | % Error |
|---|---|---|---|
| AVG Surface Roughness, $S_a$ (µm) | $1.85 \pm 0.18$ | $2.00 \pm 0.05$ | 7.7 |
| RMS Surface Roughness, $S_q$ (µm RMS) | $2.45 \pm 0.24$ | $2.61 \pm 0.13$ | 6.6 |

# Slope Error Calculation From Glare Measurements

- The angular beam spread after reflection is defined as:

$$\sigma_{\mathrm{BeamSpread}} = \sigma_{\mathrm{Sun}} + \sigma_{\mathrm{Total\_SlopeError}}$$

Note that σ can be one-sided or two-sided. In this analysis, a two-sided σ is used, which gives the full beam spread.

  – where the Sun subtended angle ($\sigma_{\mathrm{Sun}}$) is about 9 mrad

- The 'Total Slope Error' quantity is a combination of the panel surface slope error and specularity due to surface texturing; it's typically defined as:

$$\sigma_{\mathrm{Total\_SlopeError}} = \sqrt{4\sigma_{\mathrm{SE}}^2 + \sigma_{\mathrm{Sp}}^2}$$

  – where $\sigma_{\mathrm{SE}}$ is from the surface slope errors, and $\sigma_{\mathrm{Sp}}$ is the specularity from the surface texturing (i.e. surface roughness); the factor of 4 is because the surface slope errors are measured at the surface, whereas the specularity is measured at the reflected beam – <u>note that with a single glare measurement, these two quantities are difficult to decouple</u>