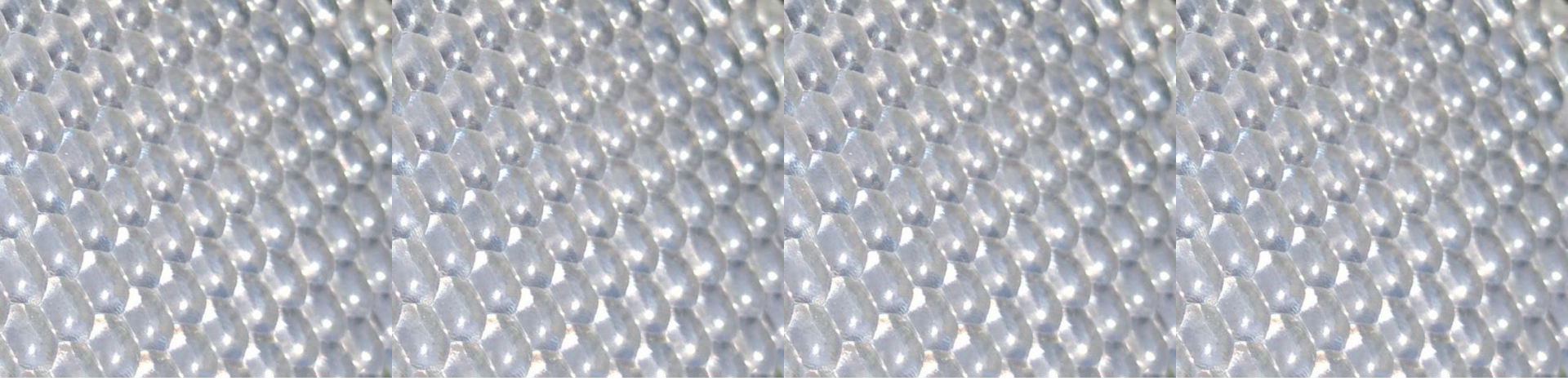

# Beam steering lens arrays for solar cooking

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CONSOLFOOD 2018
Faro-Portugal, 22-24 January, 2018

# Why tracking?

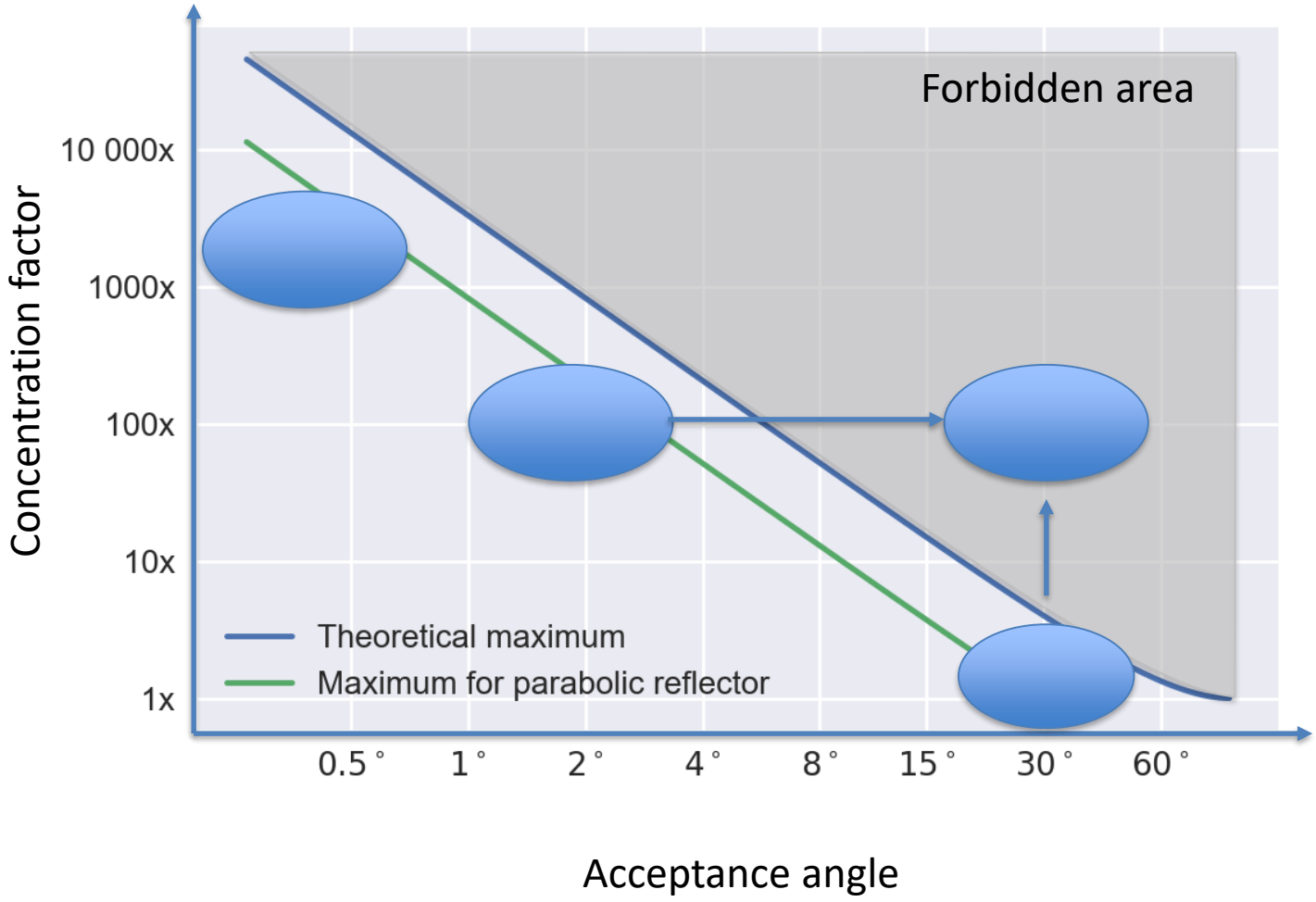
It is all about concentration

$$C_{max} = \left(\frac{1}{sin\theta}\right)^2$$

- The sine limit of concentration (rotationally symmetric system, flat receiver in air)
  - R. Winston, J. C. Minano, P. G. Benitez, *Nonimaging Optics*. Saint Louis : Elsevier Science, 2005

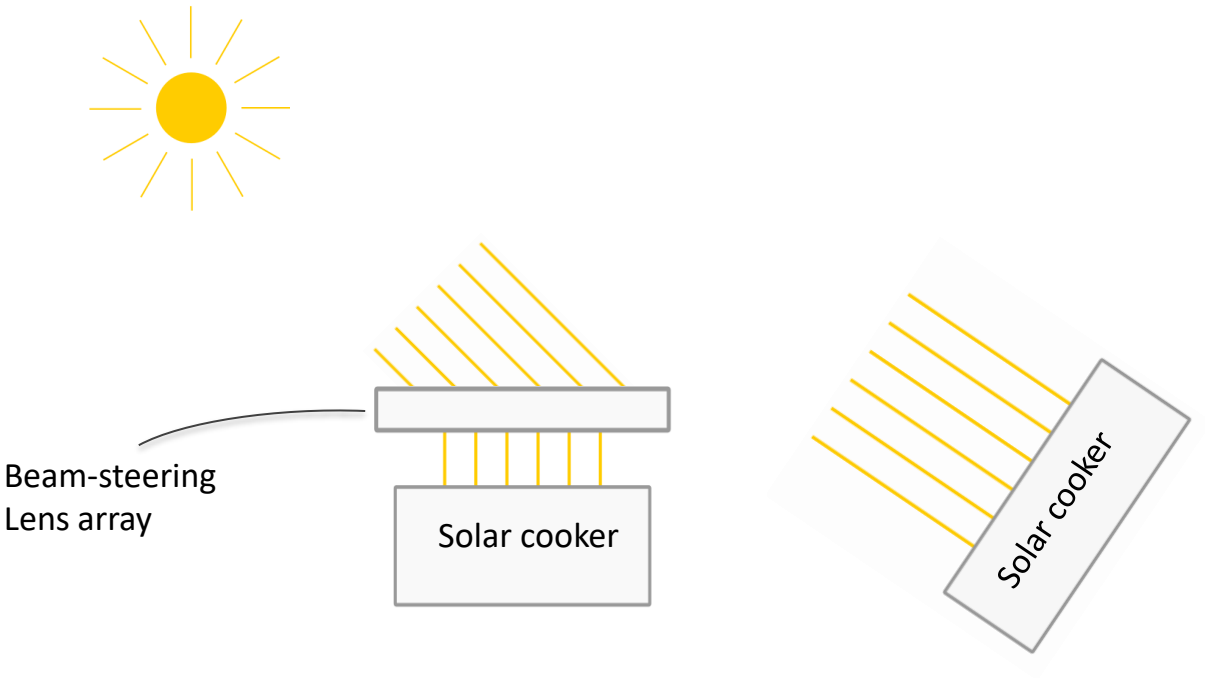
# Why tracking?

It is all about concentration

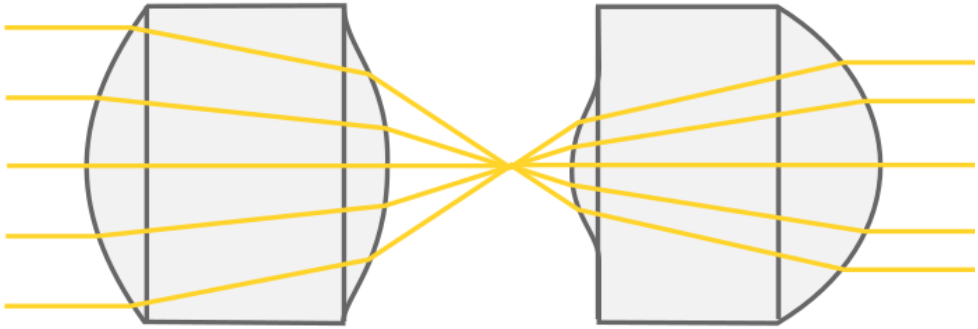


# Beam-steering lens array

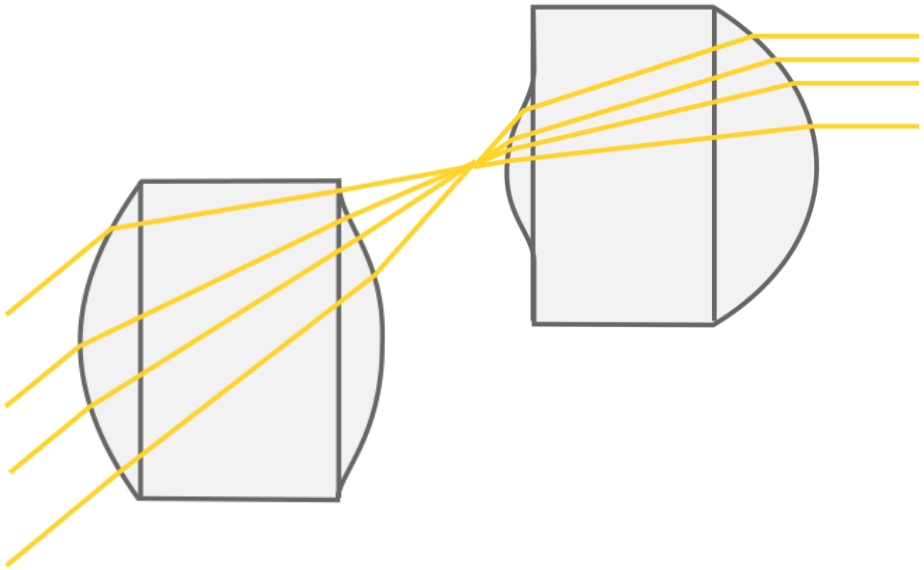
An alternative approach to solar tracking



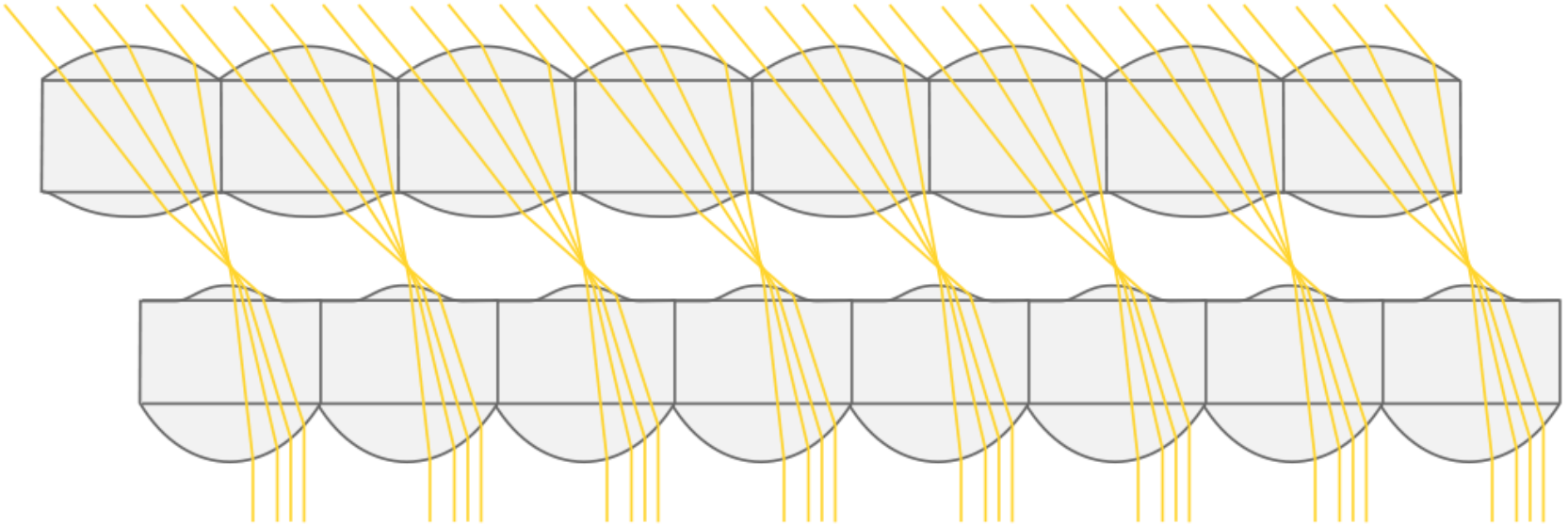
# What is a beam-steering lens array?



# What is a beam-steering lens array?



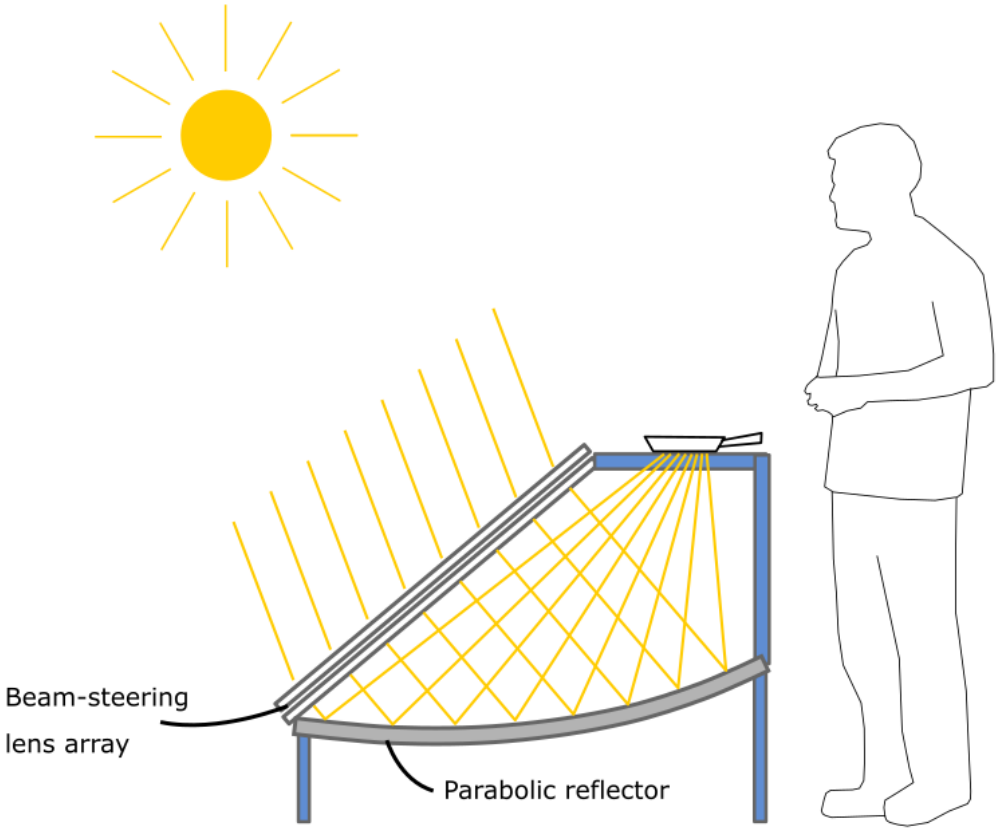
# What is a beam-steering lens array?



# Where does this concept come from?

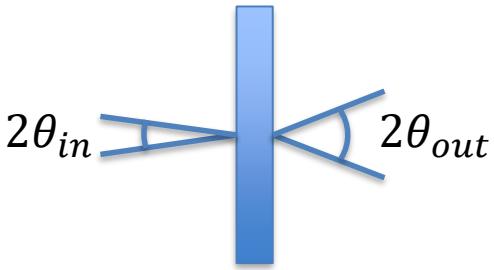
- Beam steering of laser beams
  - S. K. Gokce, S. Holmstrom, C. Hibert, S. Olcer, D. Bowman, and H. Urey, “Two-dimensional MEMS stage integrated with microlens arrays for laser beam steering,” Journal of Microelectromechanical Systems, vol. 20, no. 1, pp. 15–17, 2011.
- CPV micro-tracking
  - H. Apostoleris, M. Stefancich, and M. Chiesa, “Tracking-integrated systems for concentrating photovoltaics,” *Nature Energy*, vol. 1, p. 16018, Mar. 2016.
- Master’s thesis: Apply this research to solar cooking.
  - H. J. D. Johnsen, “Novel Low Cost Solar Thermal Energy Concepts for Developing Countries,” *NTNU*, 2017 [Online]. Available: http://hdl.handle.net/11250/2454573.

# **Beam steering lens array solar cooker**
Illustration of complete system



# Drawbacks

- Lower efficiency
- Need electronics for tracking
- Increased divergence



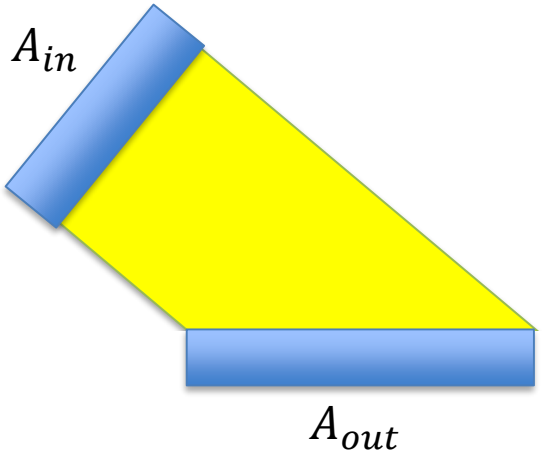

Beam-steering
Lens array

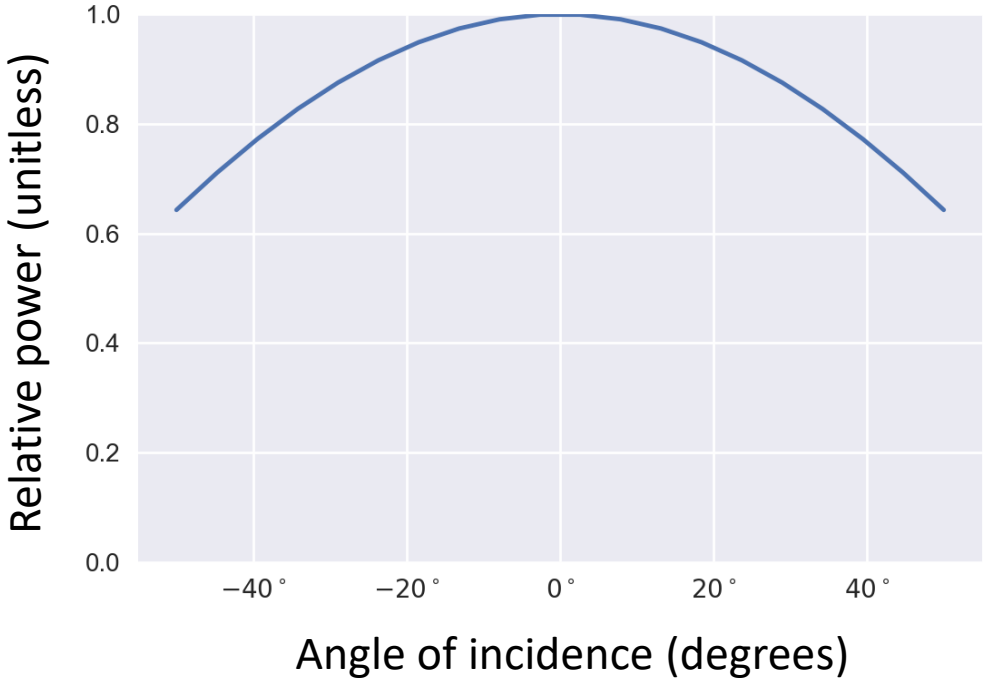
$\theta_{in} = 0.27°$

$\theta_{out} \approx 1° \; to \; 3°$

- Cosine projection loss

# Cosine projection loss



# Benefints

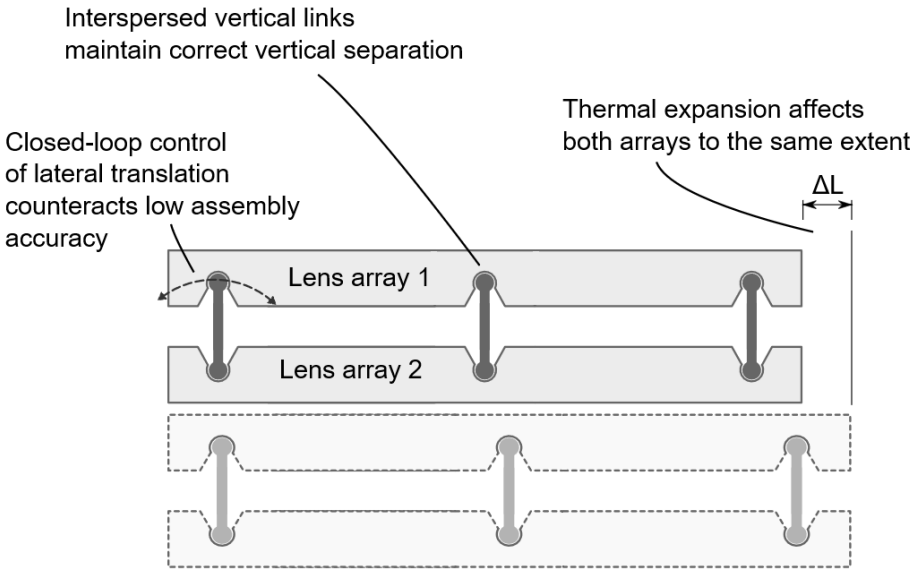
- No rotating movements, only millimeter-scale lateral translations.
- High performance.
- Easy to use.
- Robust

# FAQ: Production tolerances?

- Lens array molds requires strict tolerances and high surface quality.
- Ballpark figures:
  - Surface roughness: a few hundred nanometers
  - Waviness: 5-10 micrometers
  - Form error (single lenslet): 20-40 micrometers
  - Form error across array: ~100 micrometers
  - (accuracy within a few millimeters)

# FAQ: Production tolerances?

- Not suitable for homemade solar cookers
- Strict requirements are localized to the lens array
  - The tracking system compensates for assembly errors.



# FAQ: Costs

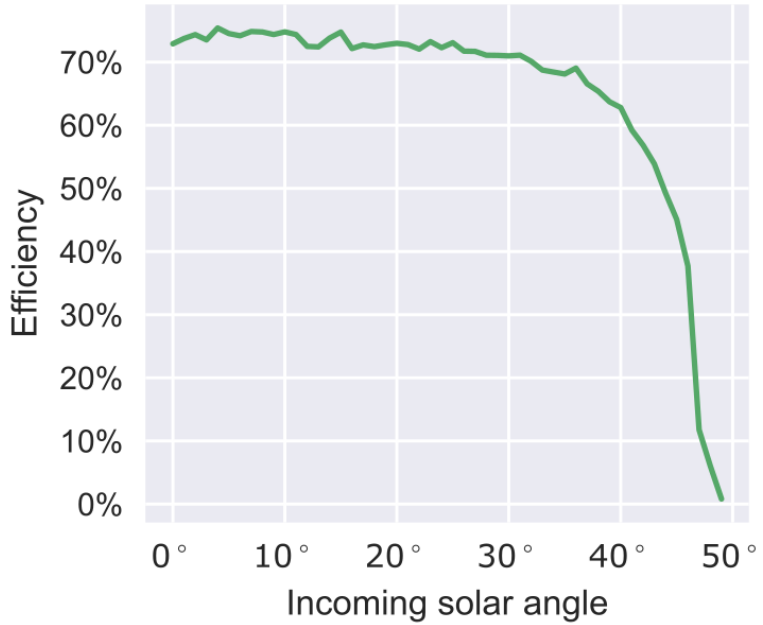
- Lens arrays
  - High investment costs for mold manufacturing
  - Low cost per item
    - Casting
    - Injection molding
  - Reference price, 3mm PMMA sheets (Plexiglass/acrylic) [1]:
    - Extruded: 32€/m2
    - Cast: 38€/m2
    - Patterned: 41€/m2 *
- Actuators, battery, solar panel, electronics
- No need to rotate parabolic mirror

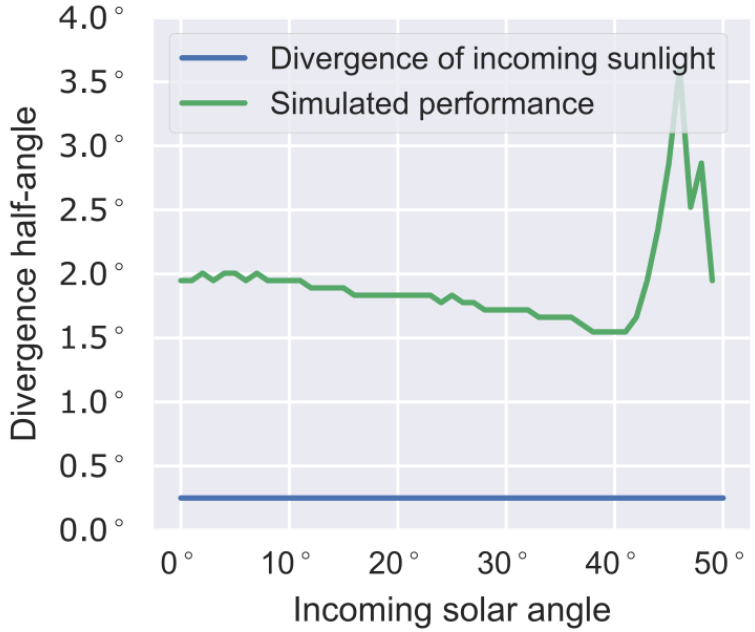
[1] From Norwegian supplier Vink http://www.vink.no/nb-NO/LAST-NED/Prislister/produktoversikt.aspx (accessed: 16 January 2018)

* Not directly available, but compared to 6mm price

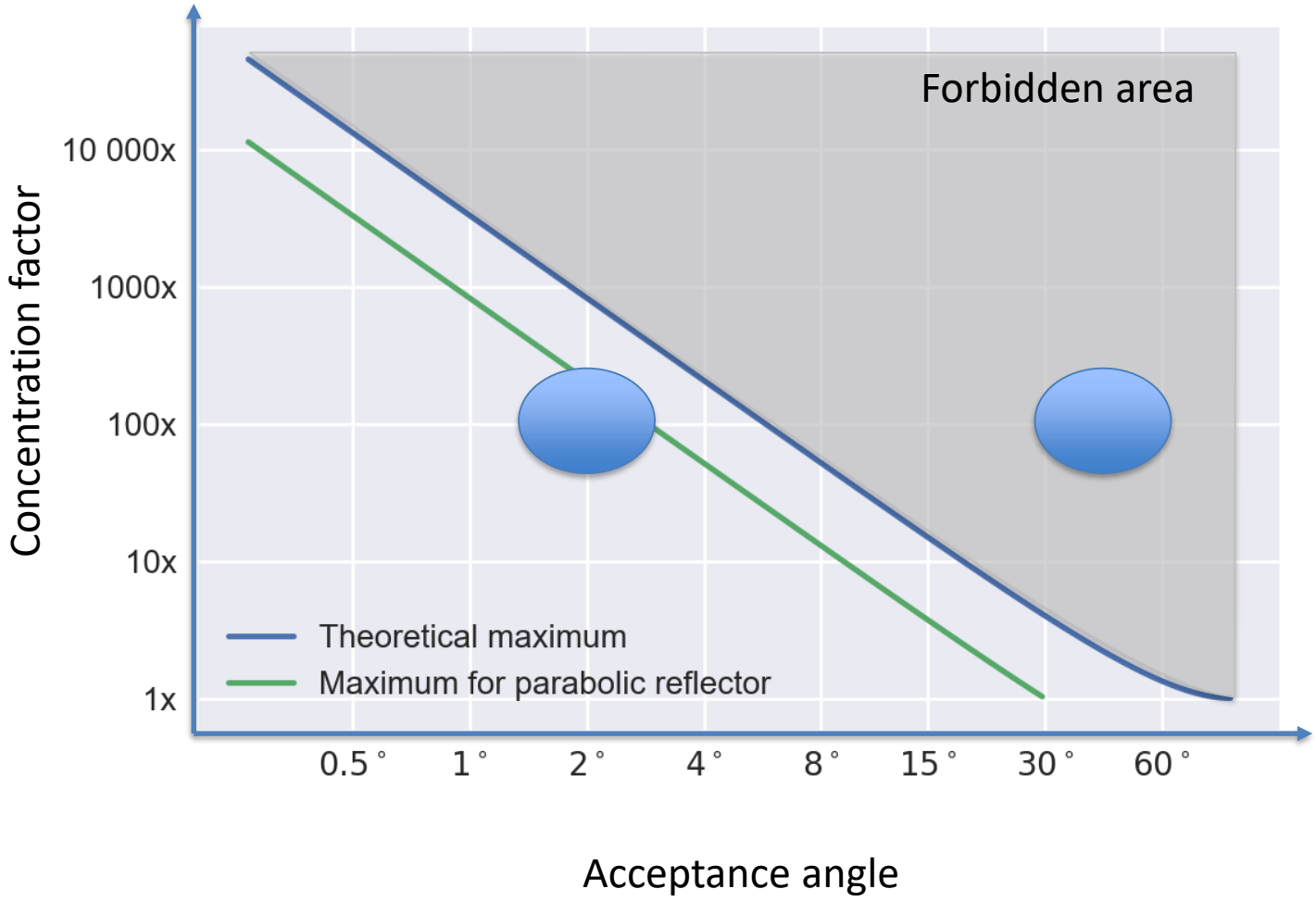
# Prototype – Simulating and optimizing geometry

- Geometry is simulated and optimized in Zemax OpticStudio
- Optimized for ±40° incoming angle
- Material: PMMA

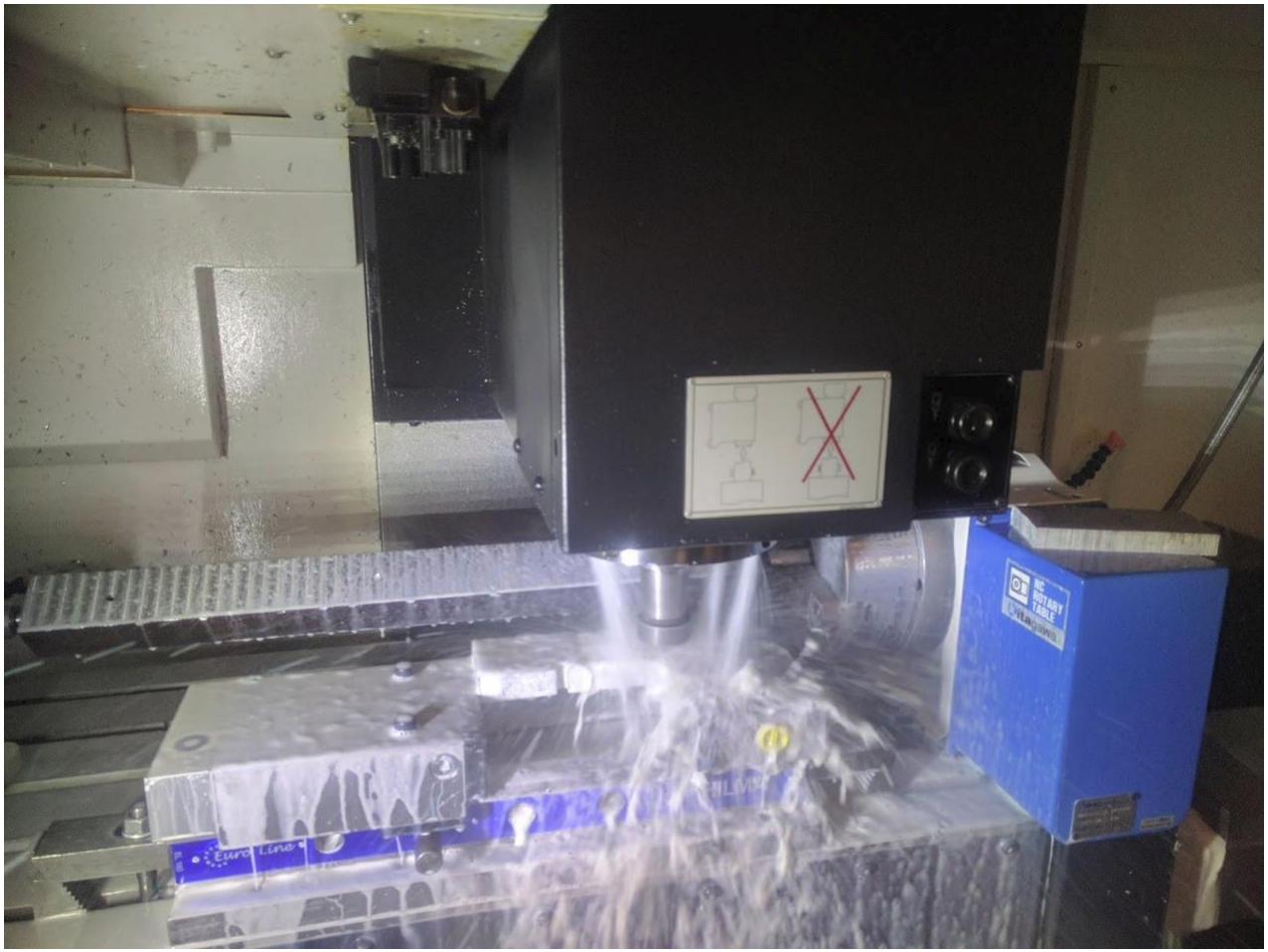


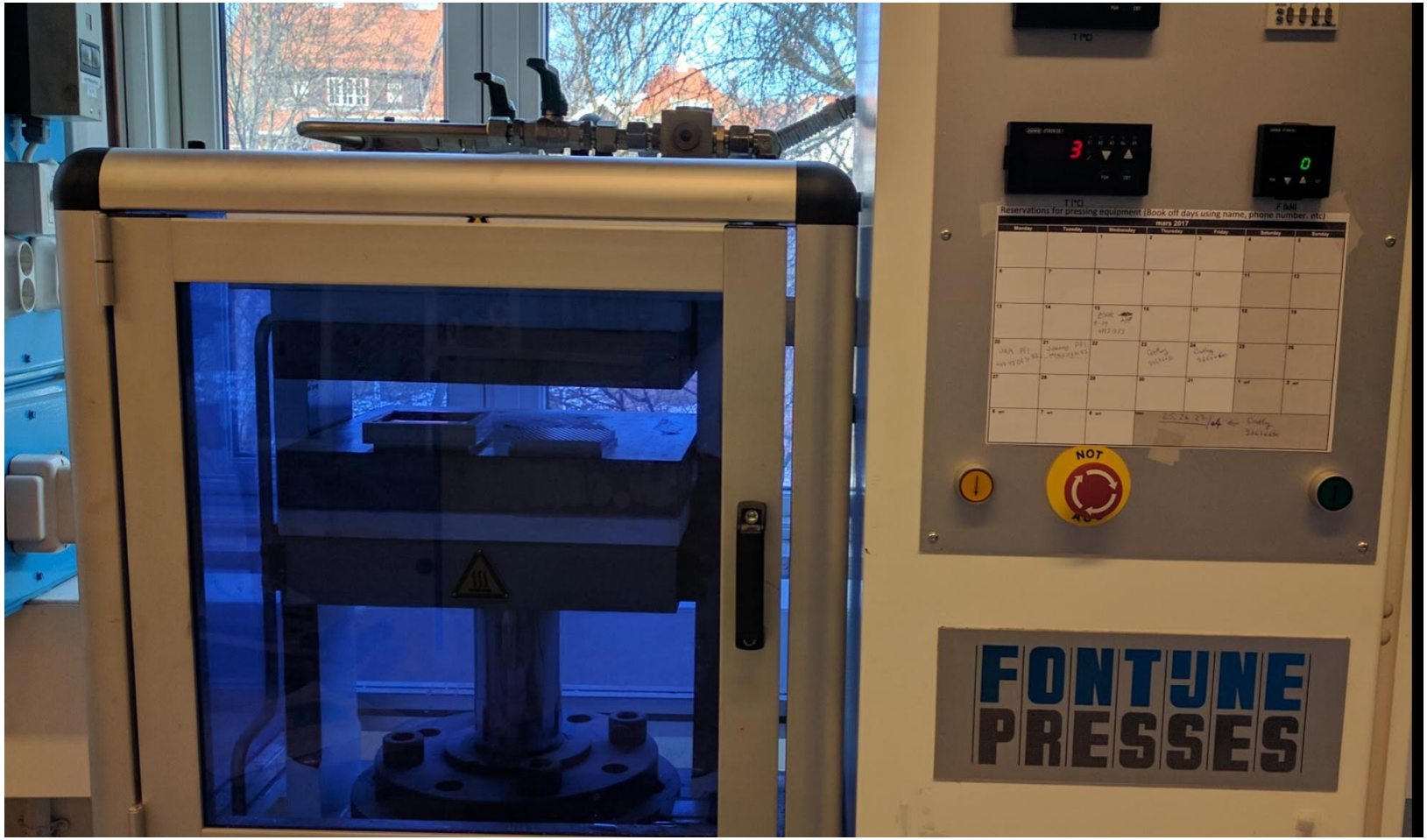
# Prototype – Expected performance



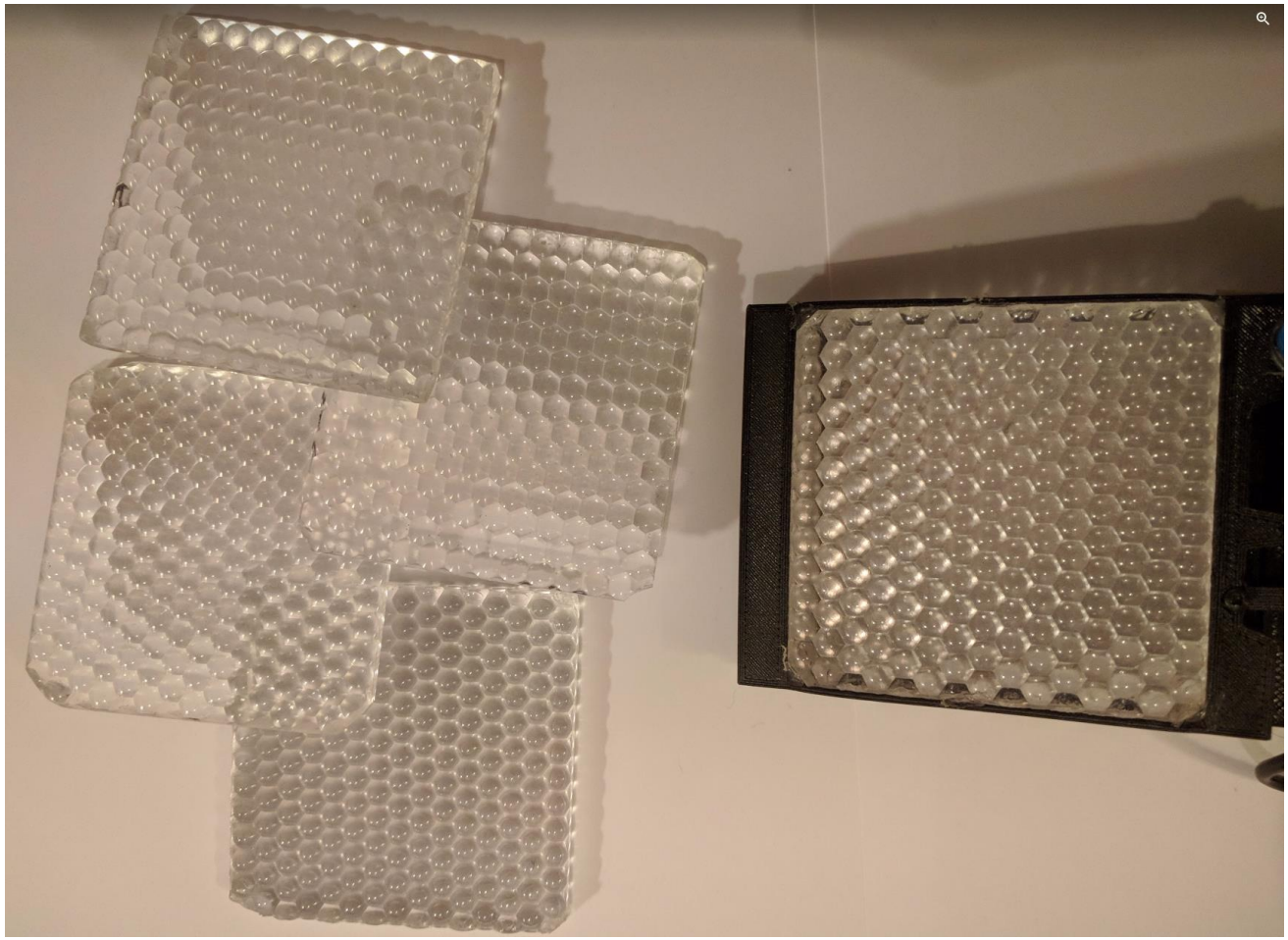
# Prototype – Machining a mold



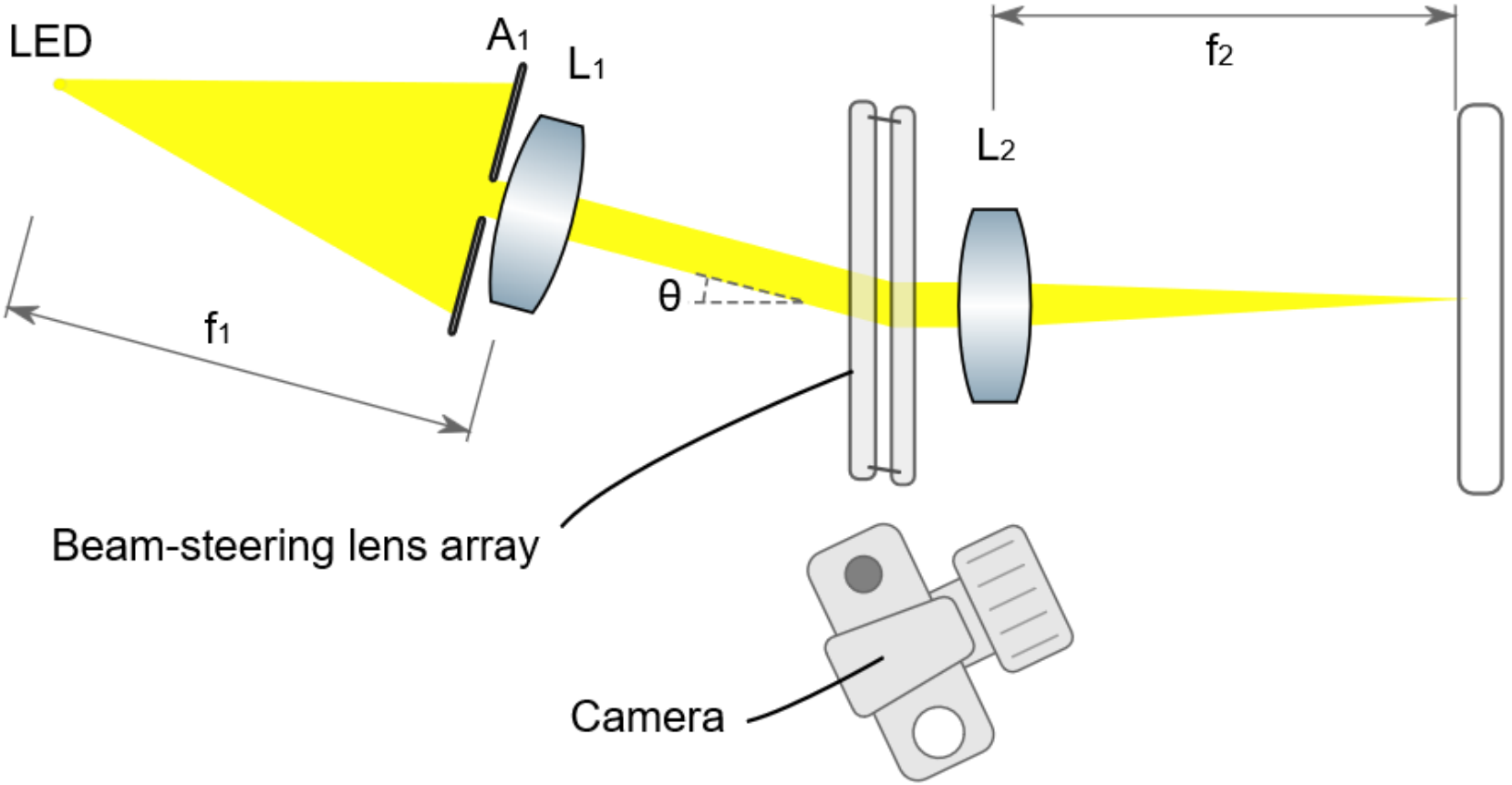
# Prototype – Compression molding lens array



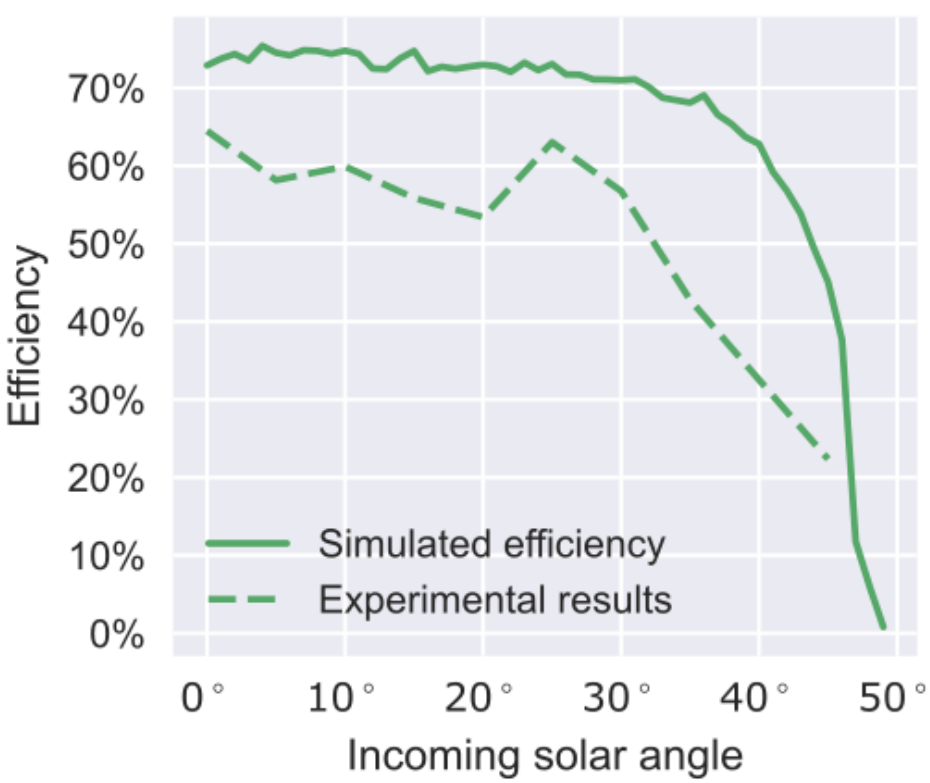
# Prototype – finished lens arrays

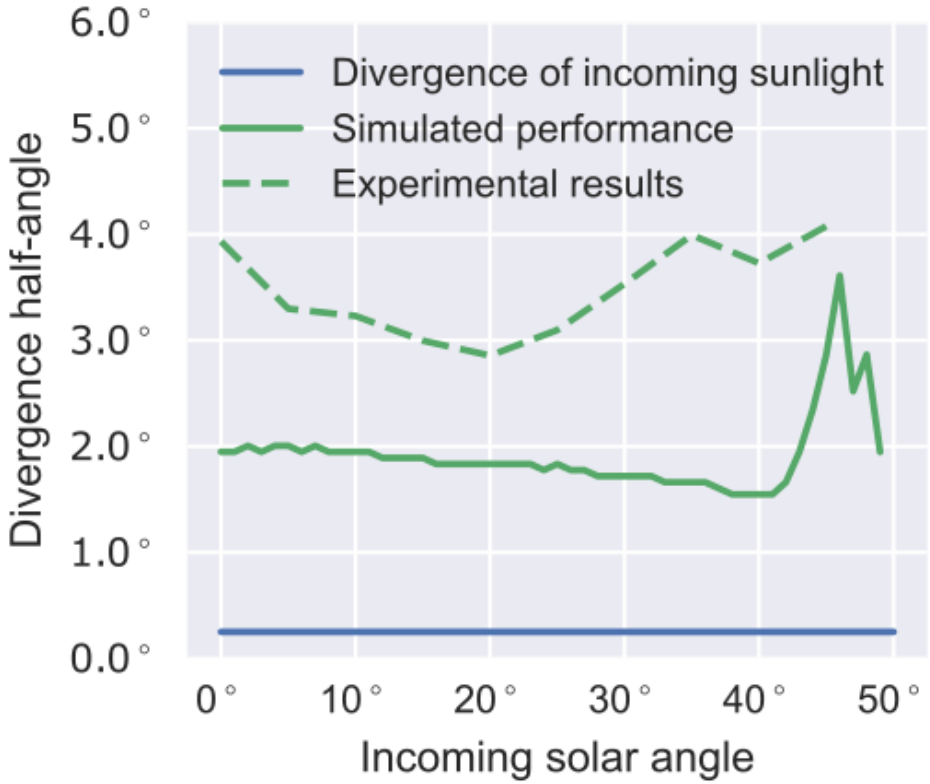


# Prototype – Test setup for beam-steering lens array

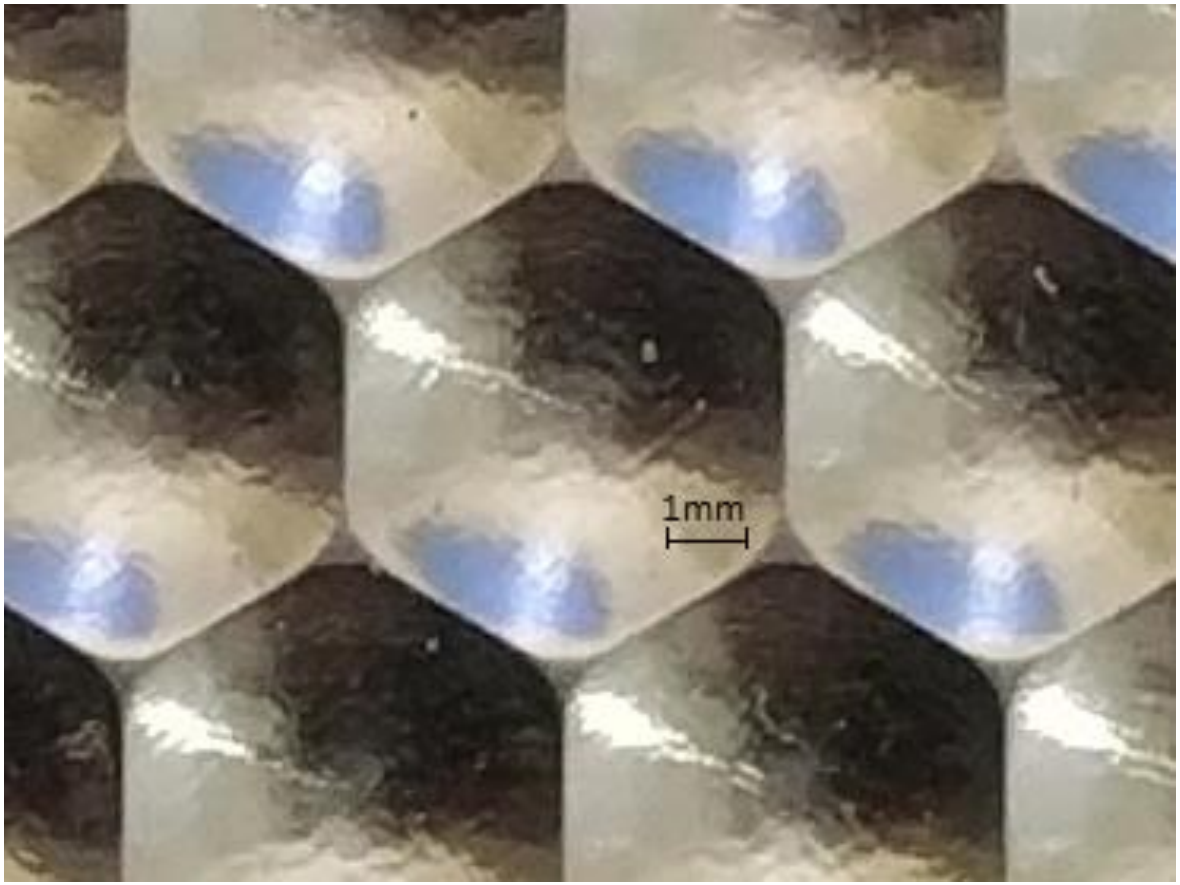


# Performance of physical proof of concept



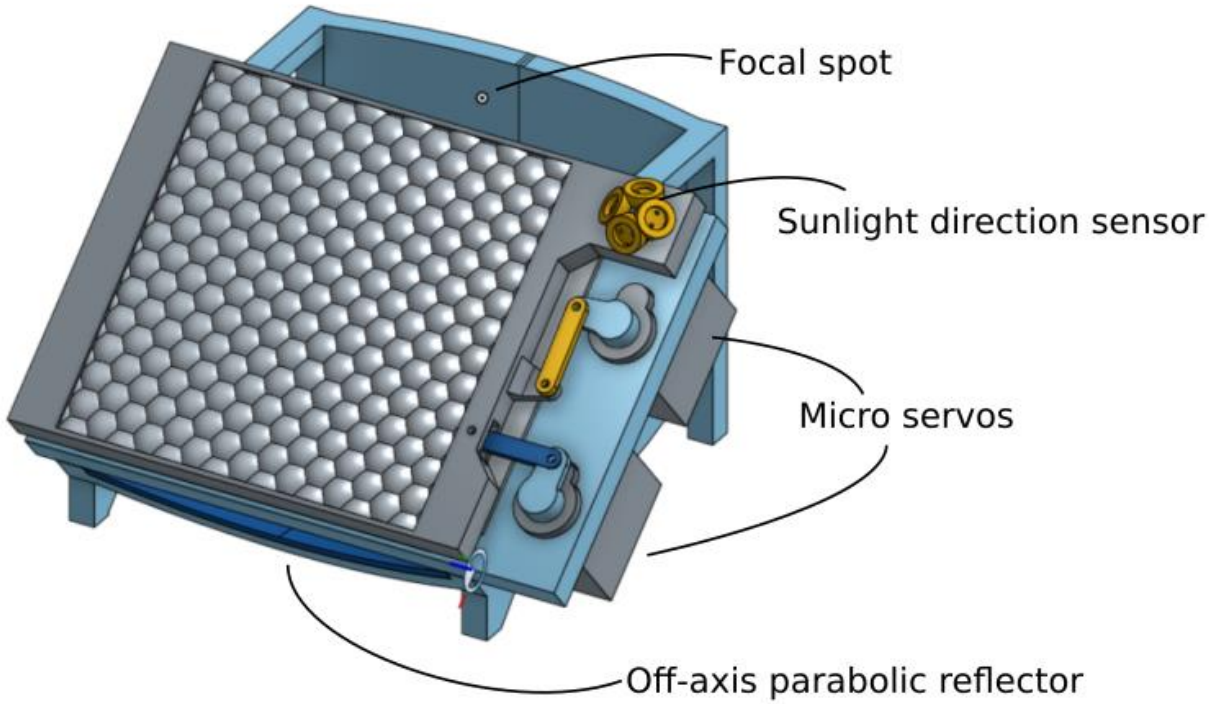



# Prototype – Aluminum mold surface



# Prototype - Complete system

- 7.2cm x 7.2cm lens array, attached to tracking system and reflector



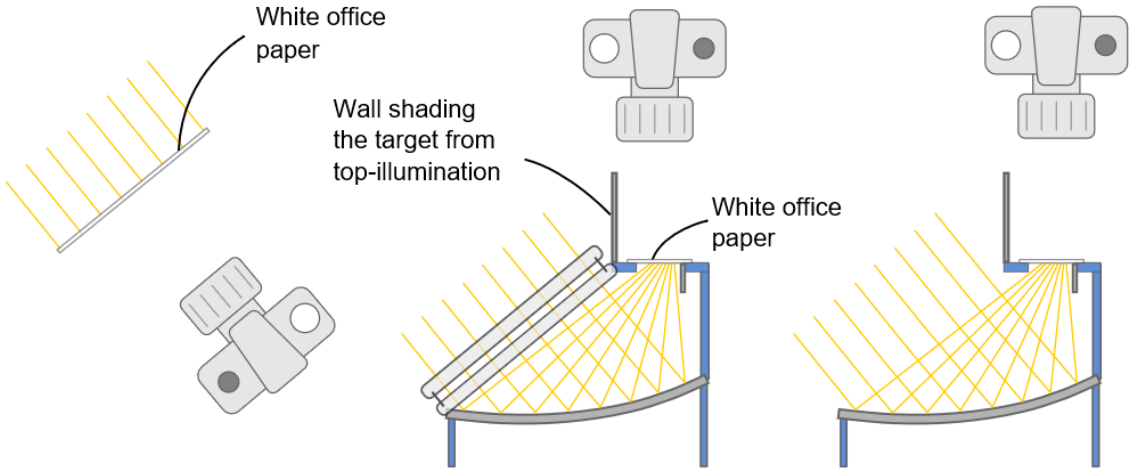
# Prototype - Complete system

Video available online:
https://goo.gl/photos/NnLbPxVNbTavEKsZ6

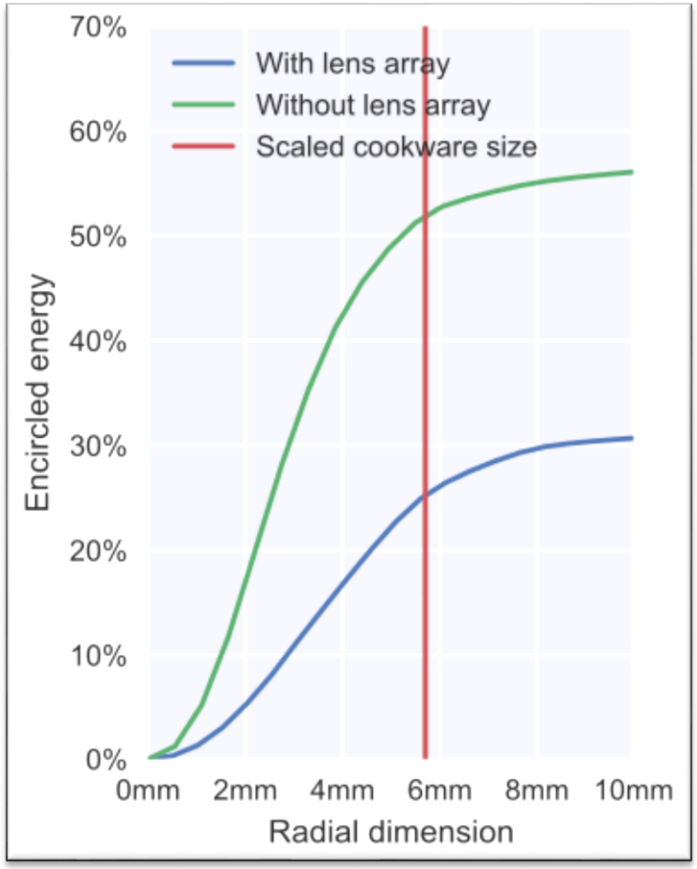
Video available online:
https://goo.gl/photos/NnLbPxVNbTavEKsZ6

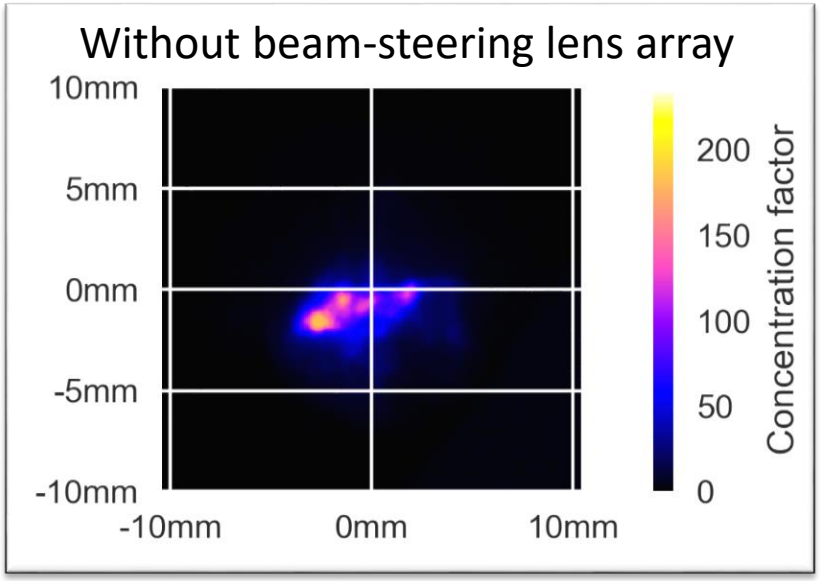
# Prototype - Performance

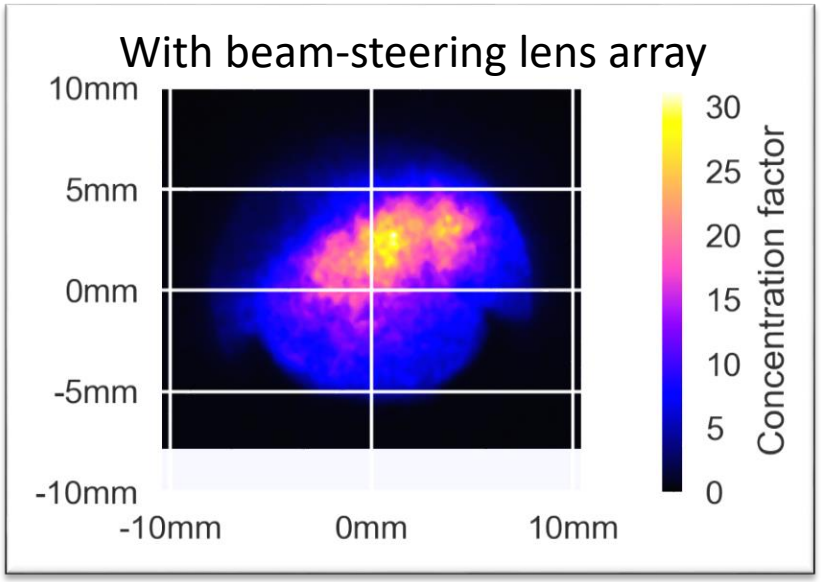
- Performance measured using image analysis



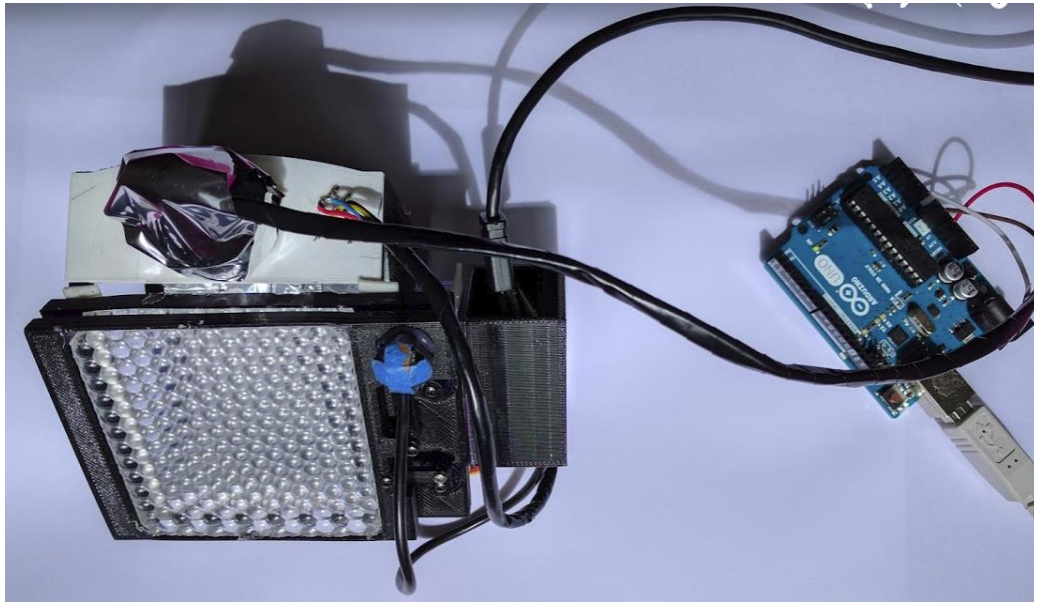
# Prototype Performance

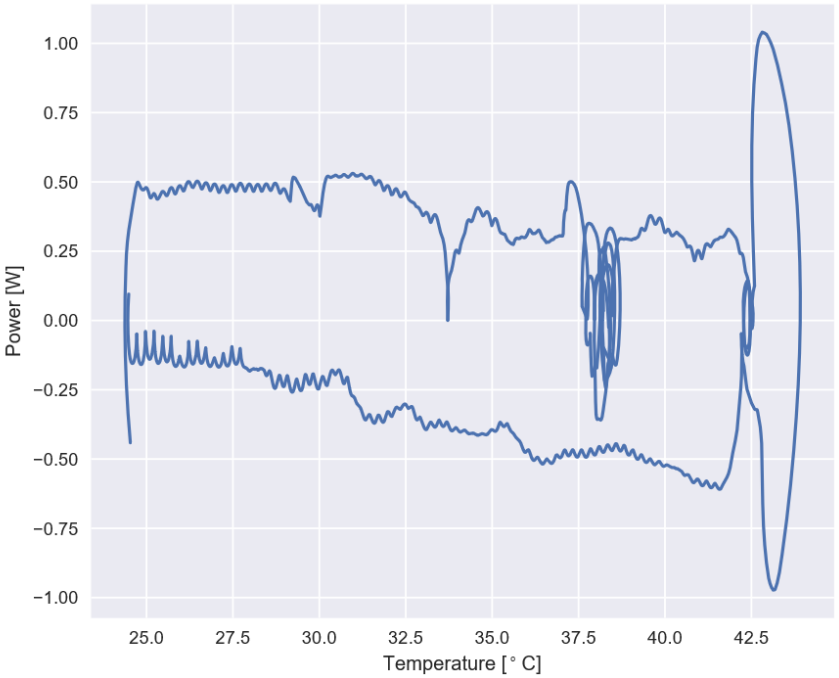


# Prototype – Thermal performance






Approximate efficiency: 16% (assuming 900W/m2 solar irradiance)

Previous version of parabolic surface. No accurate reference of solar irradiance.

# Summary

- New solar cooking concept for high performance user-friendly solar cookers.
- Higher cost, not suitable for homemade production.
- Increased performance and user-friendliness might open new markets for solar cooking.
- Cost can be brought down by mass production.

# The way forward

- Optimizing lens geometry.
- Anti-reflective surfaces.
- Improved manufacturing methods.
- Improving tracking system.
  - Passive tracking?
- Heat storage?
- Other applications

- Collaborate with us?
  Contact me: hakon.j.d.johnsen@ntnu.no

# Thank you!

- Questions?