High-Efficiency, High Concentration Photovoltaics through Advanced Optical Systems : System level challenges

ARPA-E Presentation March 2012

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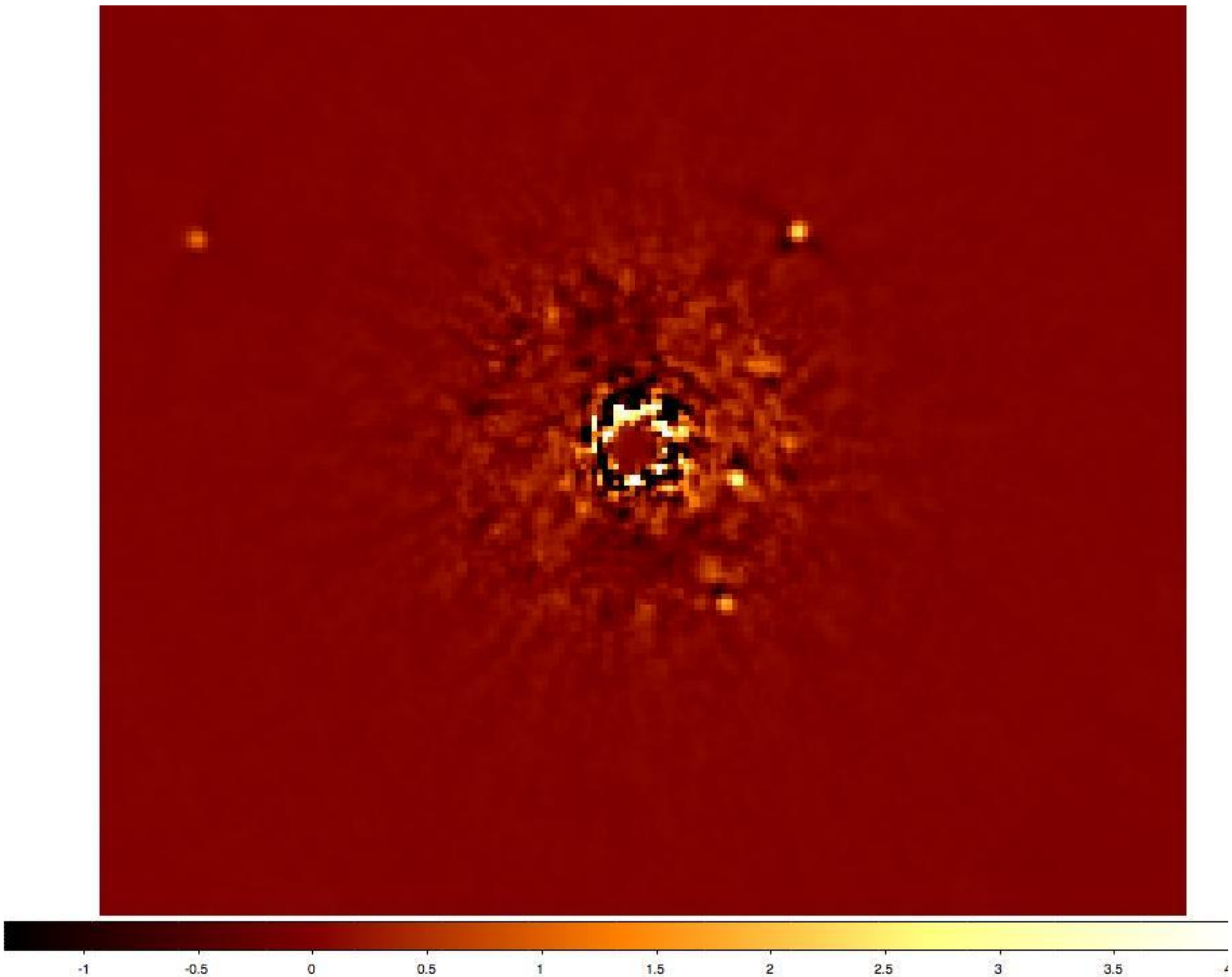
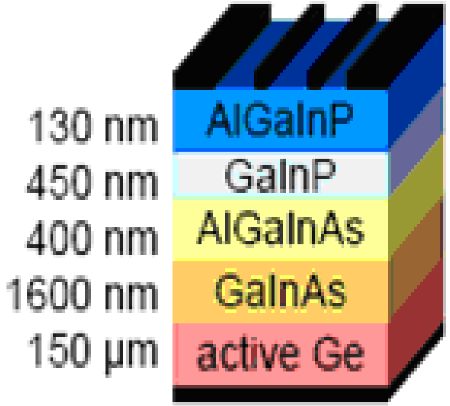
- Astronomy heritage - UA Mirror Lab
- Spectral splitting, concentration and angular divergence
  - Absorption
  - Refraction
  - Interference
- High concentration system at UA

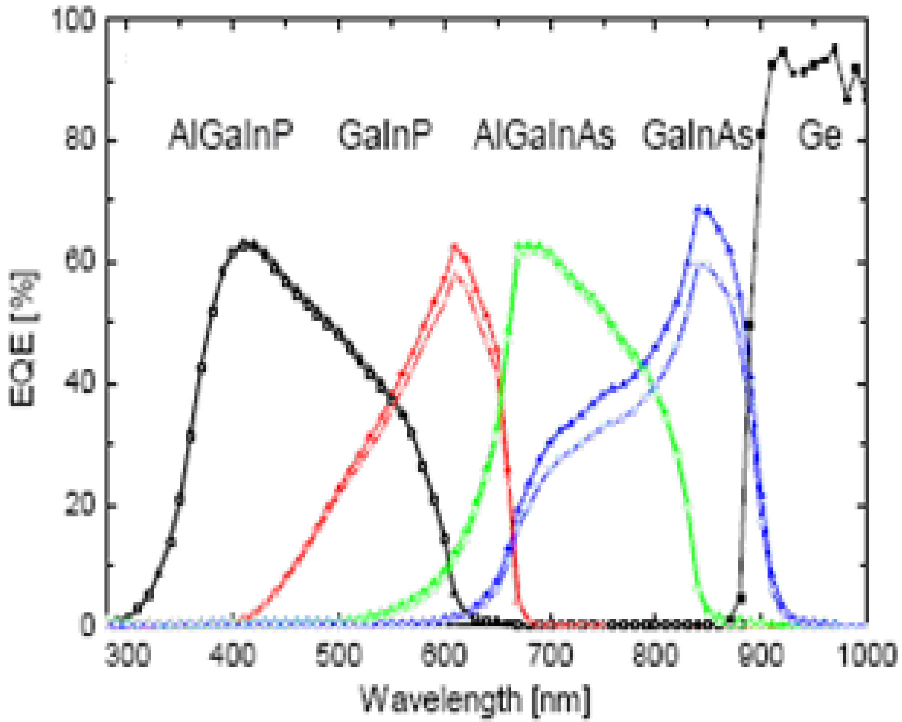
First 8.4 m from the Mirror Lab (LBT)

This mirror making diffraction-limited images - four planets around the star HR 8799 (Hinz, Skemer et al. in preparation)



Spectral splitting by absorption





- Good at very high concentration

because it is independent of ray angle

Spectral splitting by refraction

- needs to be done at the entrance pupil - angular divergence ½ degree
- Practical at large aperture with grooves on entrance window
- Grooves can be as narrow as 50 microns without diffraction penalty
- Following lens or mirror will yield a spectrum at the focus
- Pick off different bands
- Tracking errors will translate into spectral errors

Optical splitting by interference

- Wavelength depends on angle
- Sharpness of splitting depends on angular divergence
- Divergence depends on concentration
- Optical etendue
- Solid angle of divergence increases in proportion with concentration
  - Sun 10^{-4} sterad, with pointing errors 10^{-3} sterad
  - At 1000x, increased to 0.1 sterad to 1 sterad
- Upper bound set by second law of thermodynamics
  - like Carnot cycle – hard limit

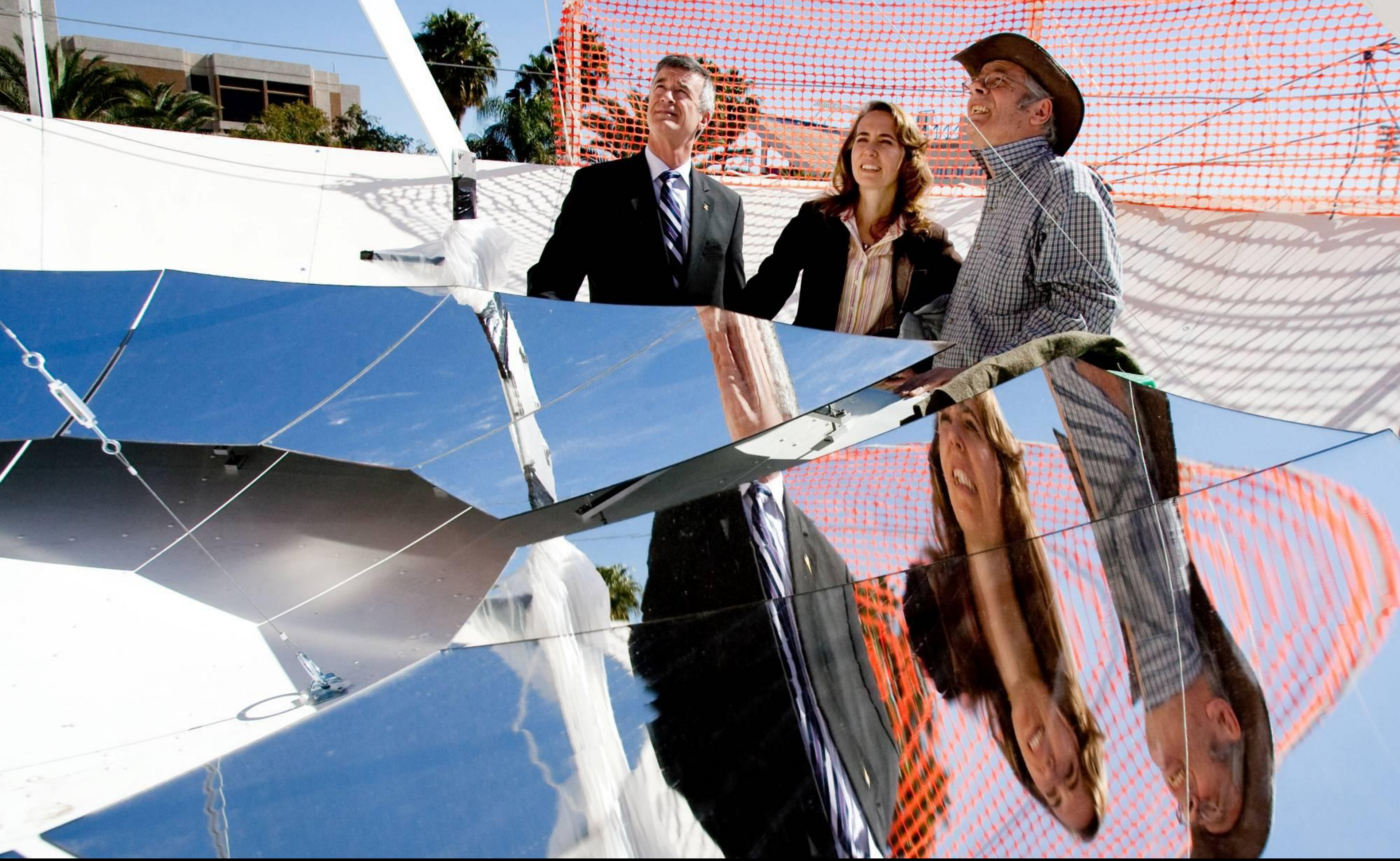
Angular dependence of spectral separation for interference

- As solid angle for near normal incidence
- As square root solid angle for 45 degrees

Difficult to separate bands with near normal incidence reflection

cross coupling of tracking and splitting wavelength

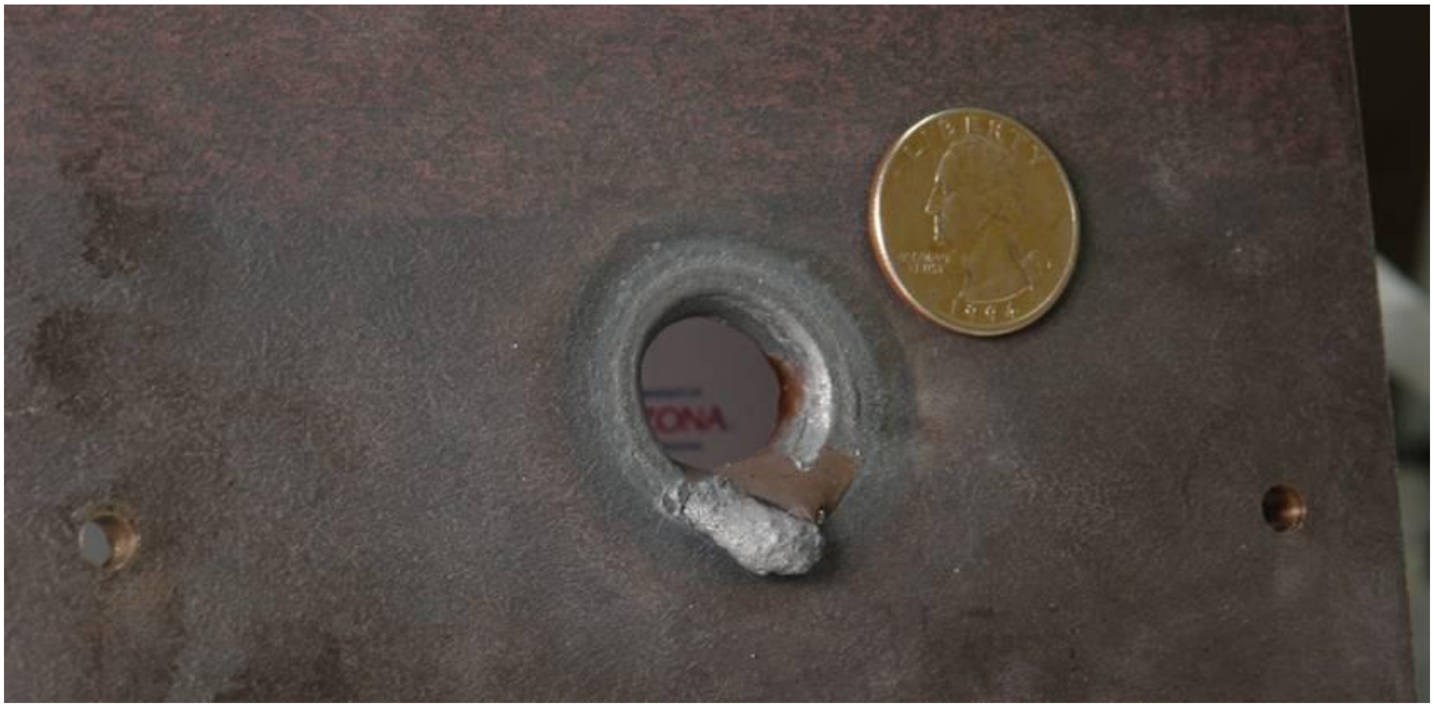
Example of a very high concentration system



Early experimental dish made at the U. Arizona Mirror Lab

with Rep Gabrielle Giffords

good point focus achieved –
15 sec solar exposure on 6 mm steel



– melts a quarter-sized hole
– don't try this with your own 3-m telescope

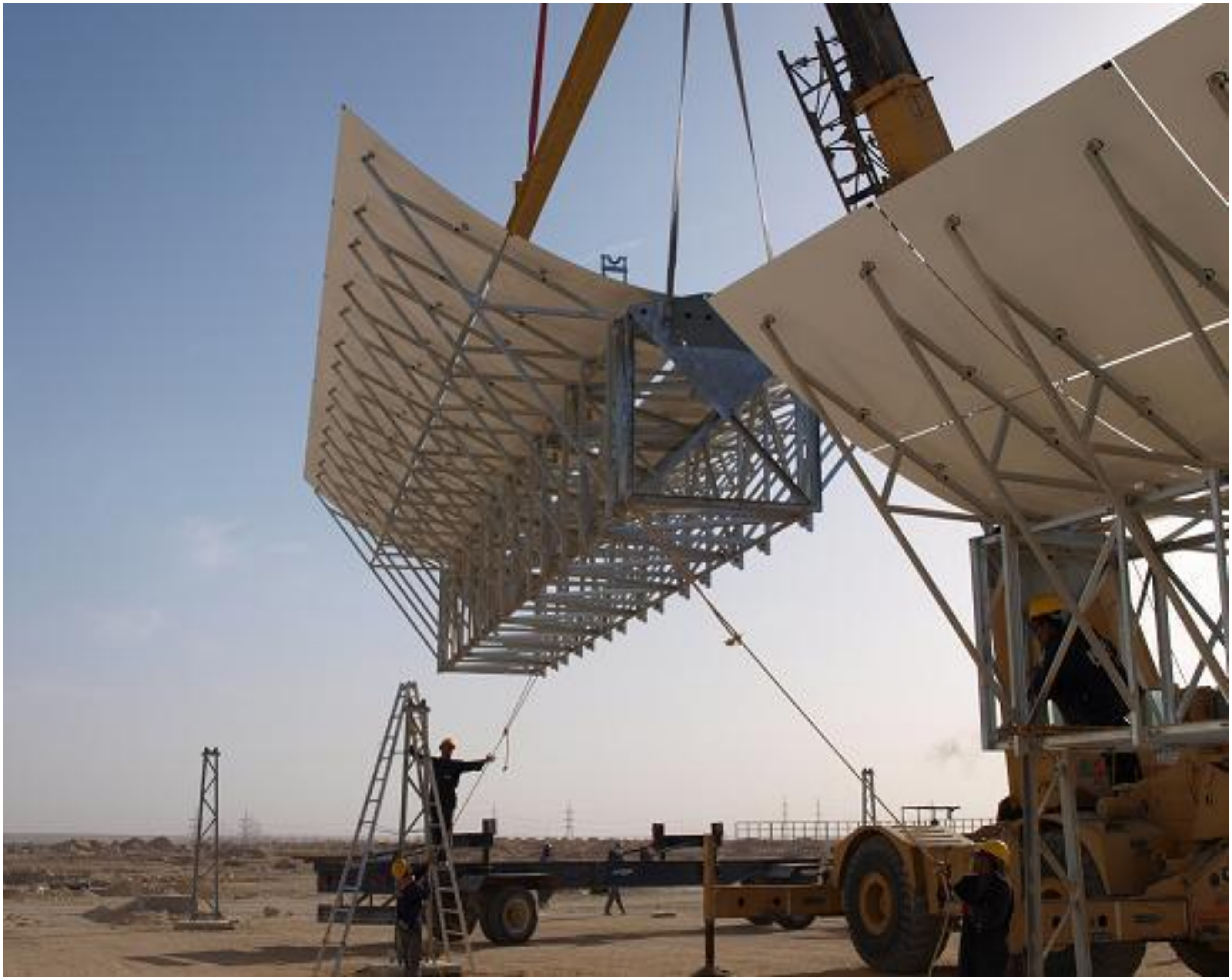
Cells at high concentration?

- At 10,000 x you are working at an image of the sun
- Sensitive to optical errors and tracking errors
- Issue that cells need to see the same flux for series connection
- Idea of entrance and exit pupil
  - Telecentric system conserves etendue
  - (reaches thermodynamic limit)

System design

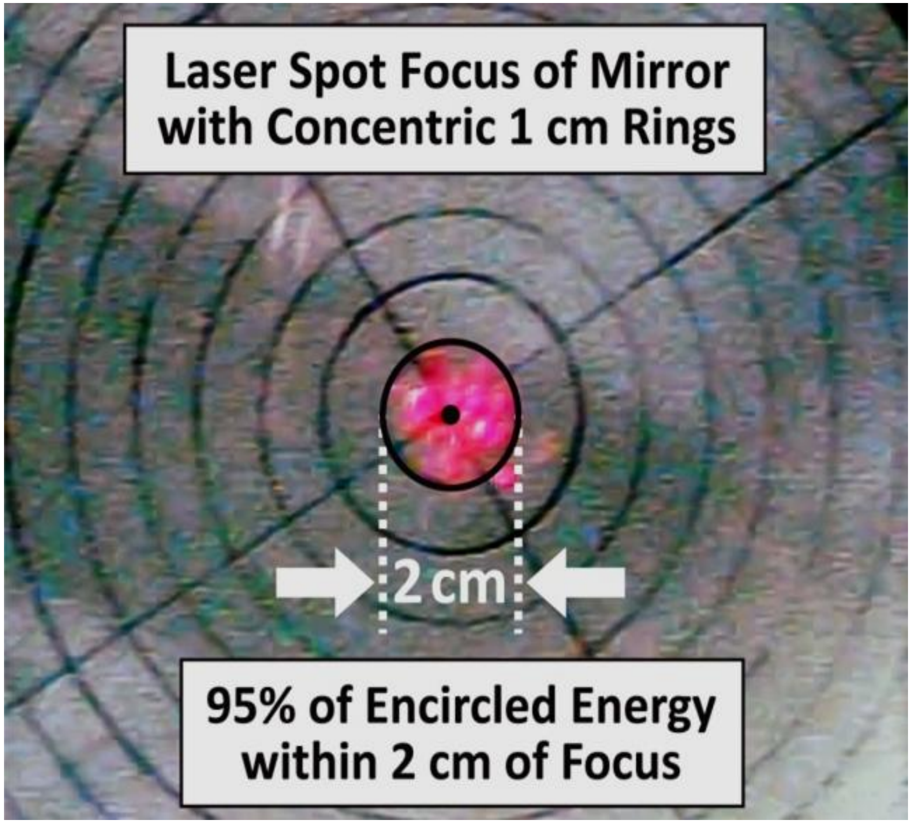
- Separation of large collectors and small cells
- Can afford to replace cells with better ones when they degrade – increase lifetime from 20 – 40 years

Lowest cost reflector systems use self-supporting glass mirrors on simple steel support structure

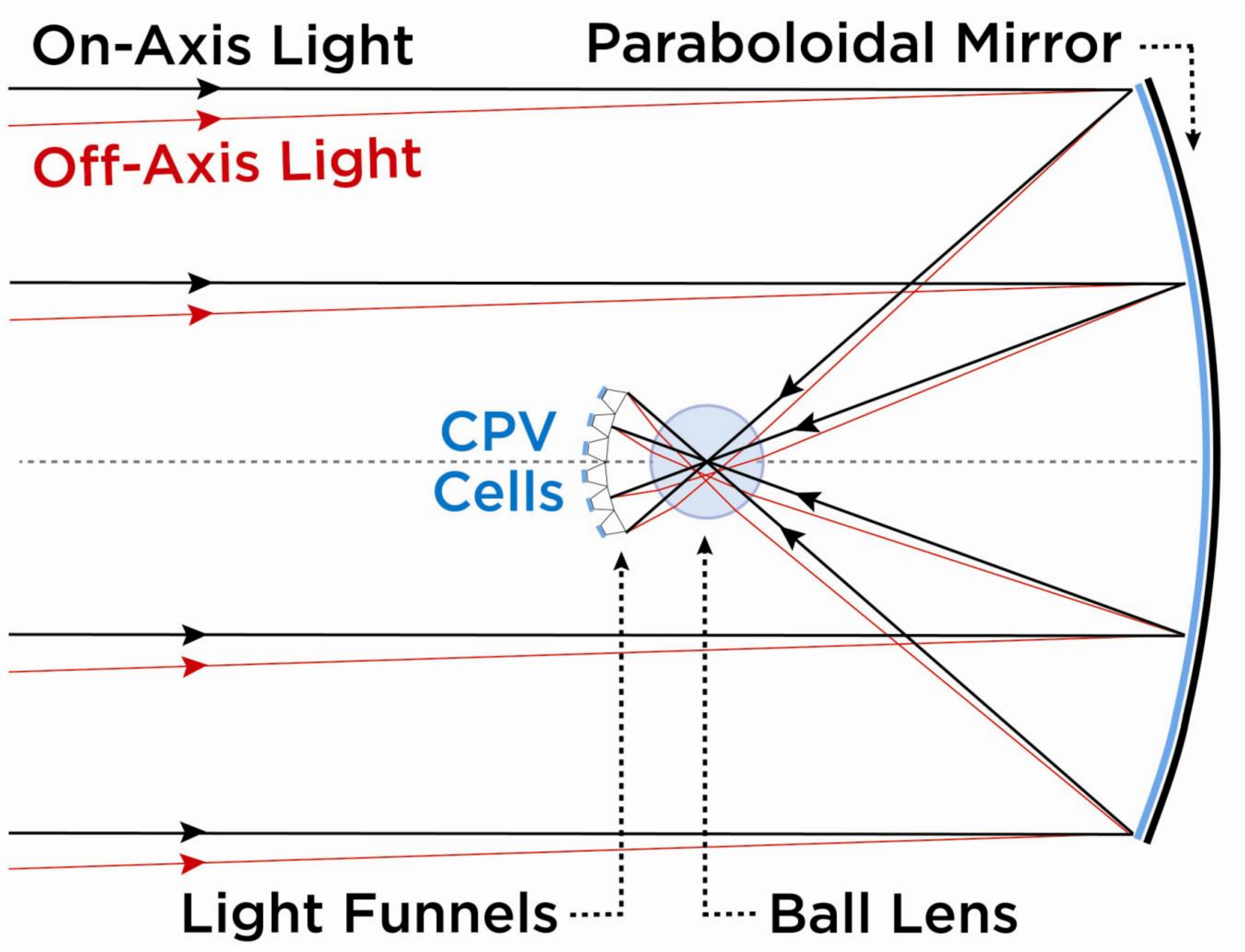


New UA technology used for bending such mirrors in 2-dimensions for high concentration point focus

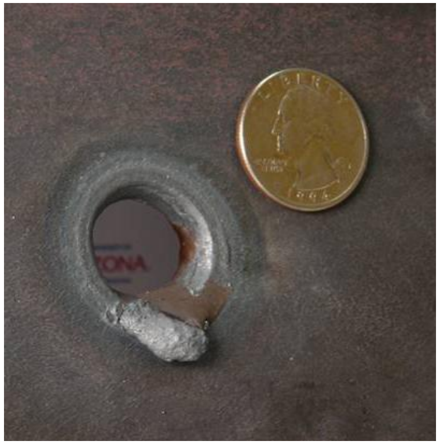
Lab test of 10 m^2 mirror focusing to 2 cm diameter spot – 30,000 concentration



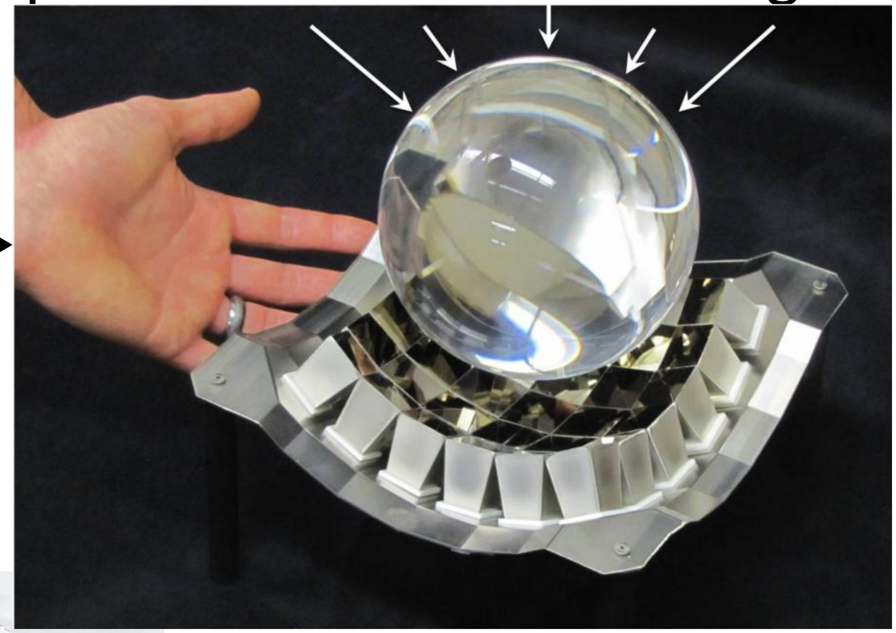
A way to spread light concentrated by a big dish uniformly over multiple cells. The ball lens forms a stabilized 400x exit pupil at the funnels

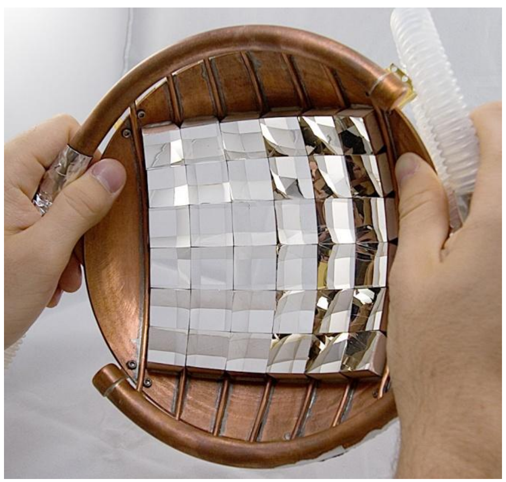


a unique way to control high power concentrated sunlight

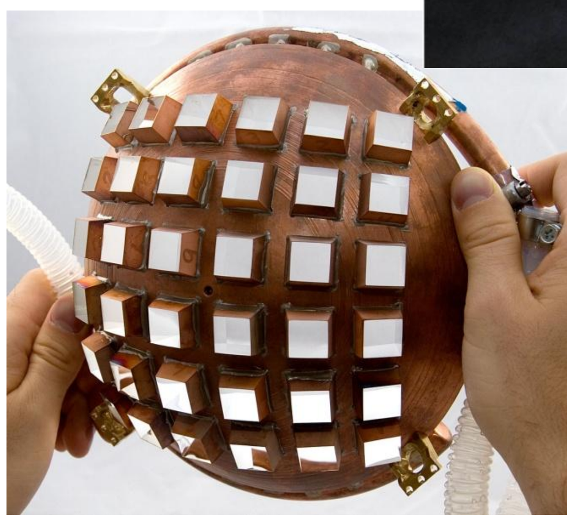


Place the focus at the center of a ball lens





The ball puts all the energy into a sharp square image of the dish



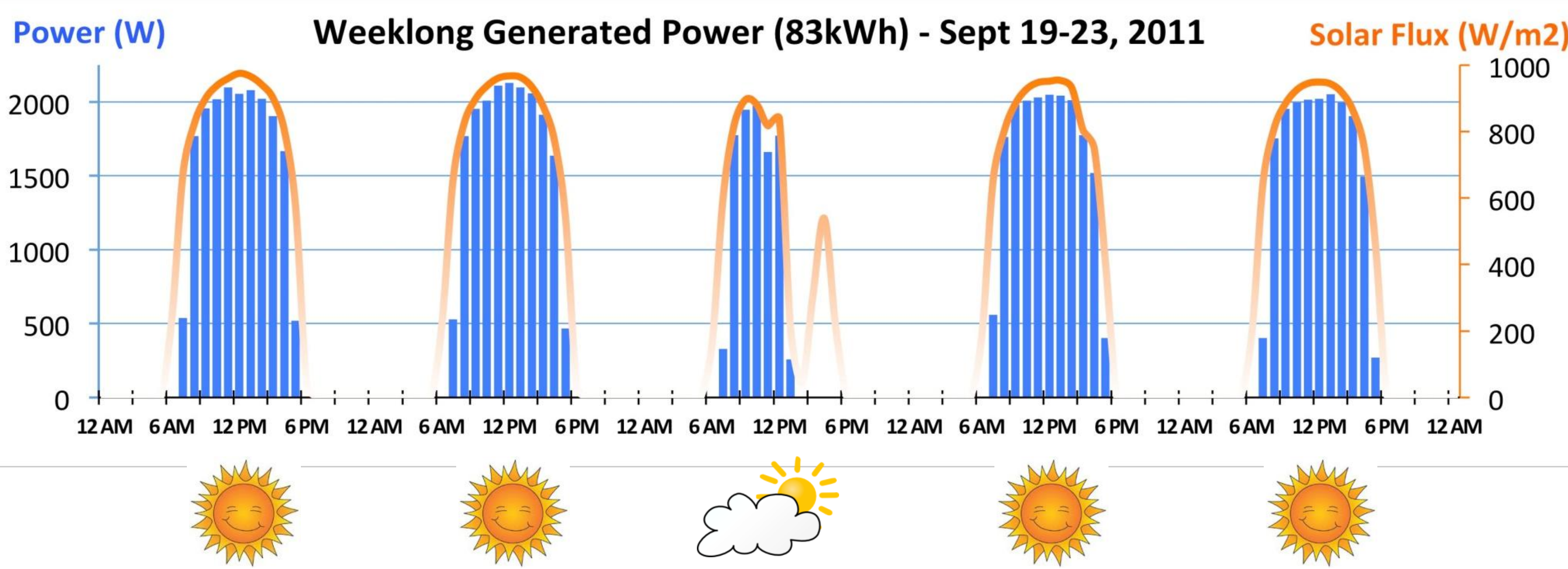
optical funnels reformat the image into 36 equal strength square patches

The light lands on a concave array of cooled cells placed immediately behind

Nearly ready for action – cells in receiver box with cover and ball removed

Now on-sun,
Ball lens at the focus is feeding the light to a concave array of cells

It works –
over 200 hours on-sun



- First end-to-end test (solar flux of 1 kW/m^2) yielded 2.2 kW

- Tune up with 37% cells and better optics – expect 2.5 kW
- With 50% efficient cells, projected in a few years 3.5 kW

(35% overall AC conversion efficiency)