# Modeling Heliostat Fields using *Radiance* and Mapping Heat Flux on the Central Receiver

**by**
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# Motivations & Objectives (1)

***Definition*** **: Solar Power Tower**

Solar power plant that concentrates the rays of sunshine through a **field** of mirrors called **heliostats** onto a **thermal receiver** built at the top of a **central tower**. Thus the captured thermal power is converted into electrical power through a chosen thermodynamic cycle that is still nowadays not different from other usual power plants.

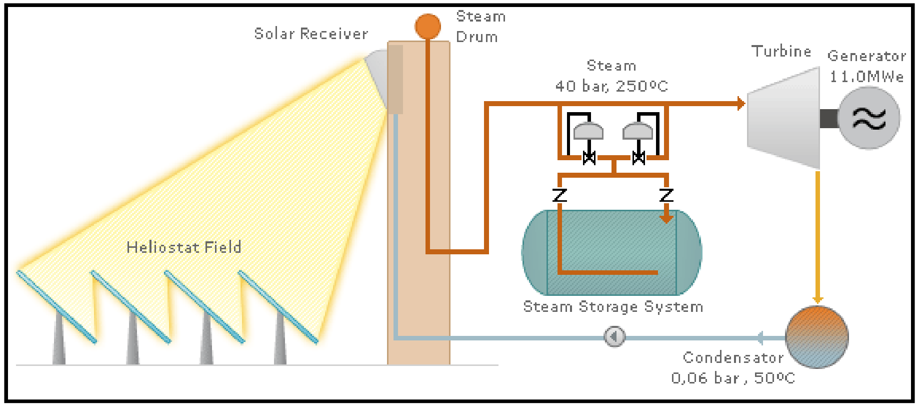
***Nowadays*** **: Typical Performance**

- ❑ 10 $MW_e$ for 50 $MW_{th}$

***Aims*** **:**

- ❑ Much higher **Performance** (up to 300 $MW_{th}$)
- ❑ Much lower **Specific Energy Costs**
- ❑ Low Visual Impact & High **Acceptance**

Solar Two, Barstow, California, 1995



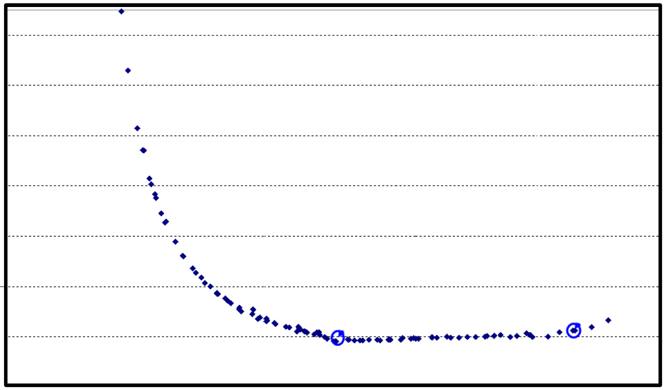

PS10, Sanlúcar la Mayor, Spain, 2007

# Motivations & Objectives (2)

**Thermo-economic Optimization of Heliostat Fields**

*Tool*

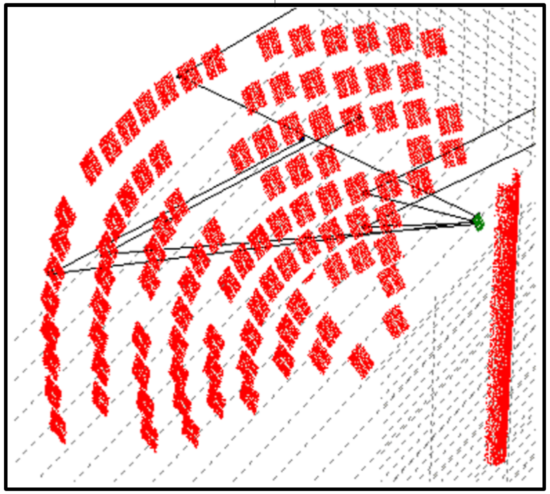
- Q-MOO Multi-Objective **Optimizer** (evolutionary algorithms)




**Heliostat Field Visualization & Heat Flux Mapping on the Central Receiver**

*Specific **Existing** Tools*

- *UHC*, *DELSOL*, *HFLCAL*, *MIRVAL*, *HELIOS*, *FIAT LUX*, *SolTRACE*



*Aim*

- Use ***Radiance***

*Reasons*

- **Multipurpose**
- **Free** Software
- Operating on ***Linux***

# *Radiance* Model (1)

## Generating the Sun

*Inputs*

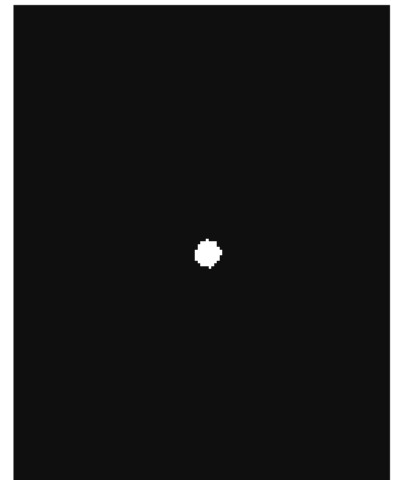
- Sun **Elevation** Angle (ex.: 75°)
- Sun **Azimuth** Angle (ex.: 0°)
- Sun Horizontal **Direct Radiation** (ex.: 800 W/m²)

*Tool*

- `gensky -ang 75 0 -R 800`

*Output*

- `sun.rad`



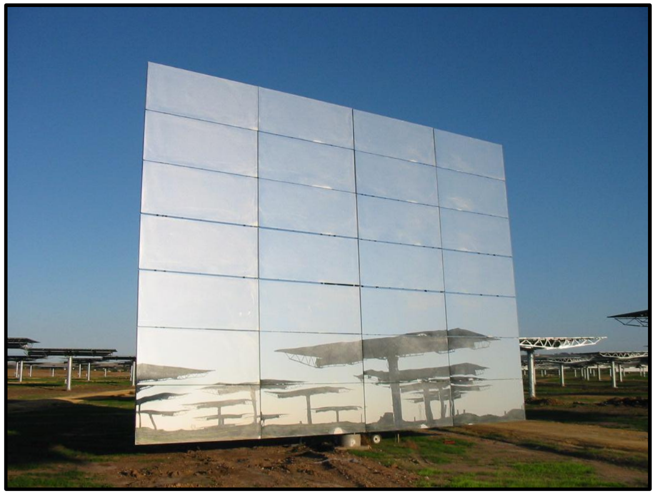
*Only direct radiation is relevant: no sky needed*

# *Radiance* Model (2)

## Creating, Positioning & Orienting a Single Heliostat (1)

*Inputs*

- Heliostat **Dimensions** wxh (ex.: 12.94m x 10.12m)
- Heliostat **Subdivision** (ex.: 4x7 facets)
- Heliostat **Base** (ex.: 1m)
- Heliostat **Position** (ex.: 0m W-E, 100m S-N)
- Heliostat **Distance** to Aim Point (ex.: 137.55m)
- Mirror **Reflectivity** (ex.: 88%)
- Atmospheric **Transmission** (ex.: 98%)
- Standard Deviation of **Tracking Error** (ex.: 1.3mrad)
- **Sun** Position (ex.: 75°,0°)
- **Aim Point** Height (ex.: 100.5m)


Sanlucar 120, PS10, Sanlúcar la Mayor, Spain, 2007

## Creating, Positioning & Orienting a Single Heliostat (2)

*Tool*

- ```
  void mirror hel_mat
  0
  0
  3 0.86 0.86 0.86
  ```
  (reflectivity x transmission)

  ```
  !gensurf hel_mat hel

  '(s-.5)*12.94'

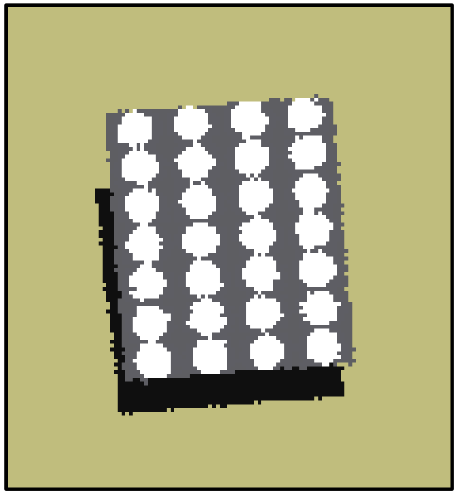
  '(t-.5)*10.12'

  '-sqrt((2*137.55)^2-(s-.5)^2*12.94^2-(t-.5)^2*10.12^2)+2*137.55' 4 7

  | xform -n hel -rx 24.31 -rz 0 -t 0 100 6.94
  ```

*Output*

- `hel.rad`



*Sphere whose radius is twice the focal length (approximating parabolic shape)*
  ```

# *Radiance* Model (4)

## Generating a Heliostat Field

*Input*

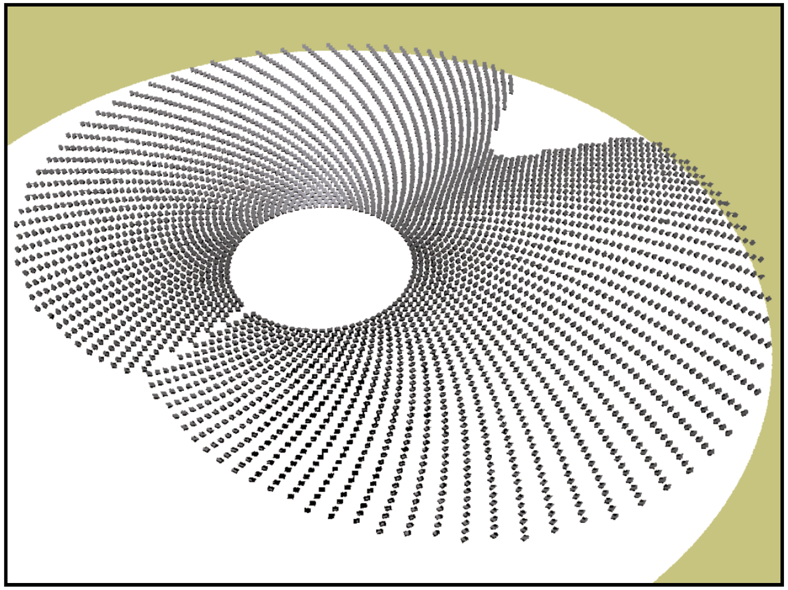
- Field **Layout** (**X** W-E, **Y** S-N)

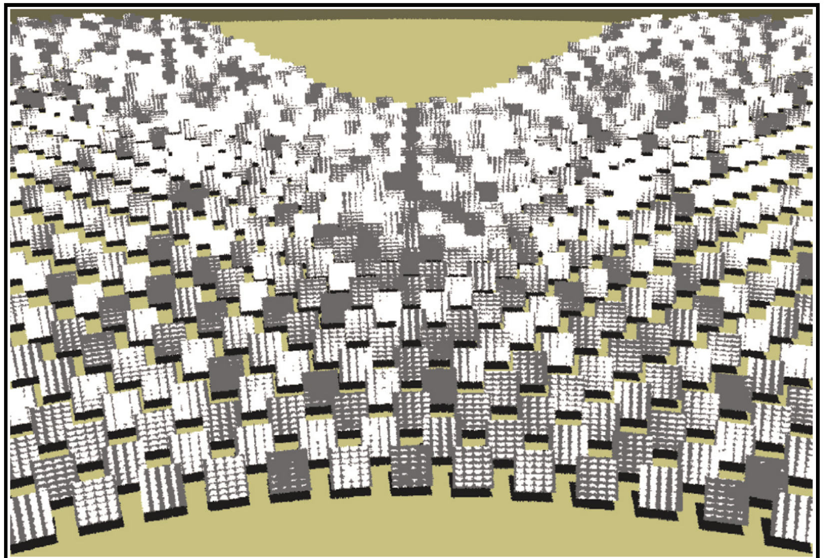
*Tool*

- Same Process
  as for 1 Single Heliostat

*Output*

- `field.rad`





Field 4000Hel in *Radiance* (approximately spherical heliostats - 4x7 facets; random error)

## Creating a Meshgrid for Measurements on the Receiver

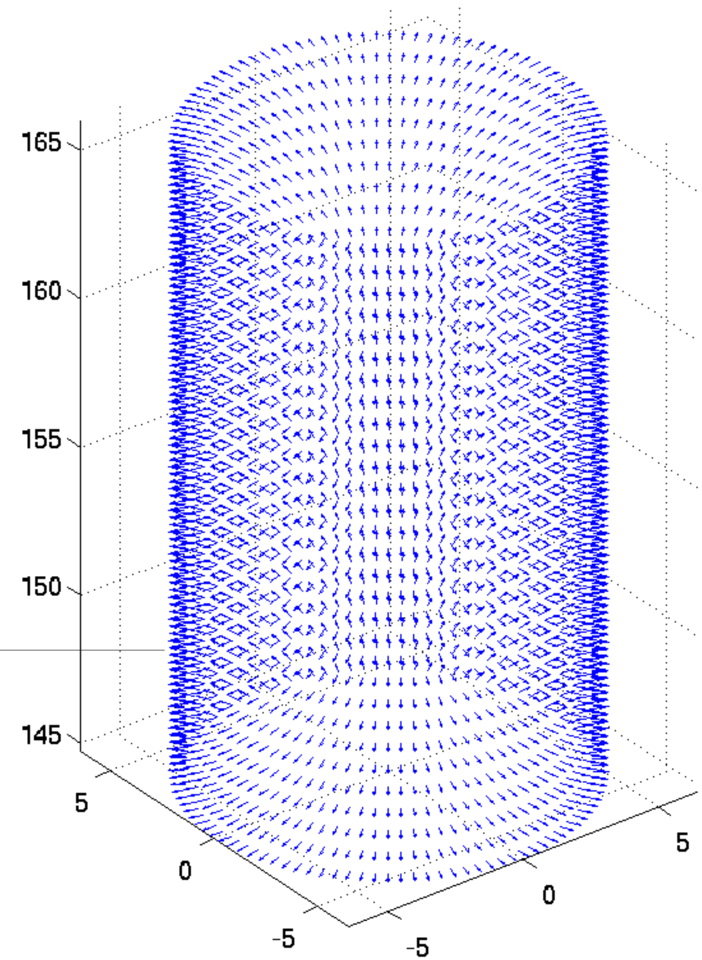
*Input*

- Cylinder **Diameter** (ex.: 16m)
- Cylinder **Height** (ex.: 22m)
- **Aim Point** Height (ex.: 157m)
- Number of **Finite Elements** (circumferentially x heightwise) (ex.: 100 x 30)

*Output*

- `meshgrid.dat`

| X | Y | Z | Xdir | Ydir | Zdir |
|---|---|---|---|---|---|
| 0 | 8 | 146 | 0 | 1 | 0 |
| . | . | . | . | . | . |
| . | . | . | . | . | . |
| . | . | . | . | . | . |



# *Radiance* Model (6)

## Measuring Heat Flux on the Receiver thanks to *rtrace*

*Input*

- ❑ `meshgrid.dat`
- ❑ `fieldscene.oct`

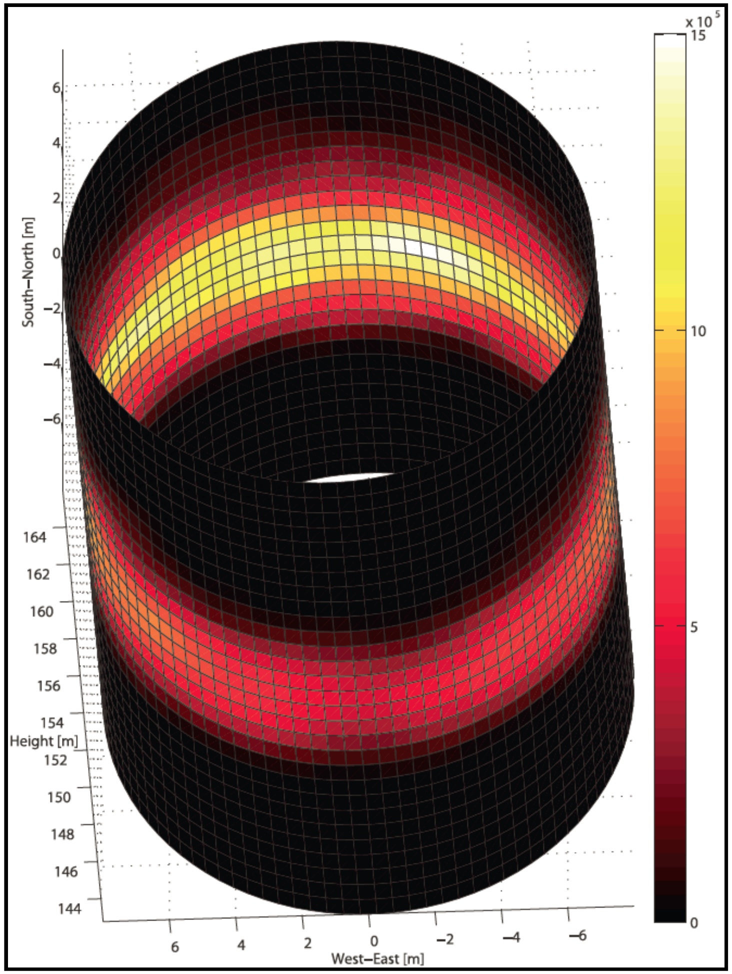
*Tool*

- ❑ **rtrace** `-I -ov -h fieldscene.oct < meshgrid.dat`

  `| rcalc -e '$1=0.265*$1+0.670*$2+0.065*$3;'`

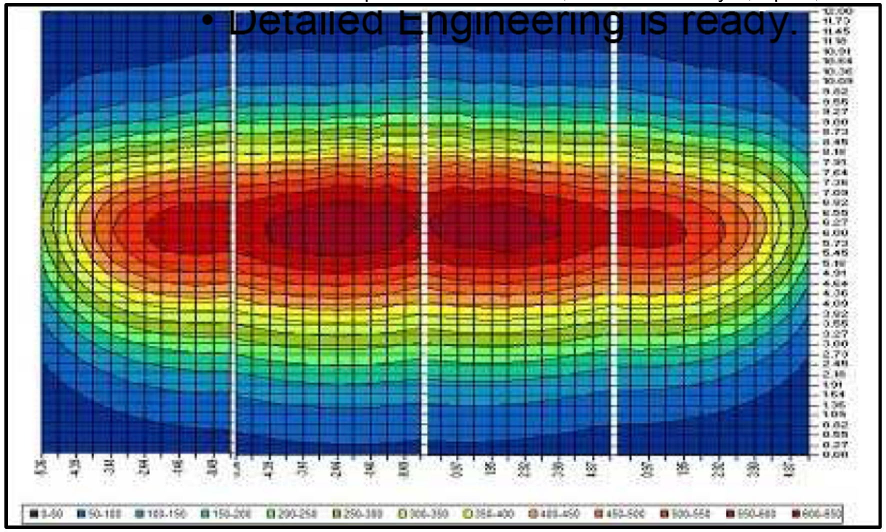
*Output*

- ❑ `>> heatflux.dat`



# Validation

PS10 published Simulation, Sanlúcar la Mayor, Spain, 2007

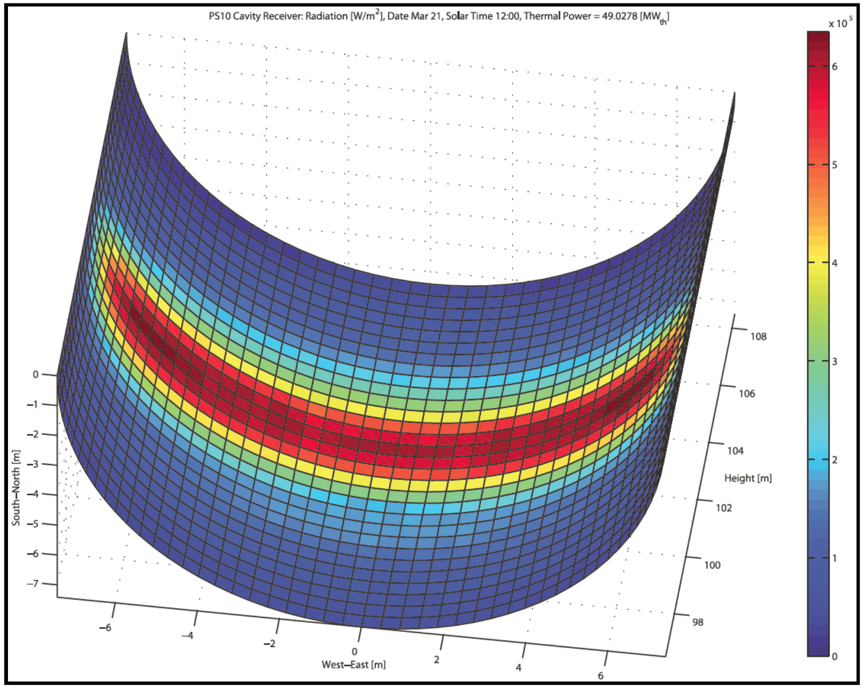



## Comparisons with some Published Experimental Results & Simulations

- ❑ Total **Power** is higher
  (between 5 and 10%)

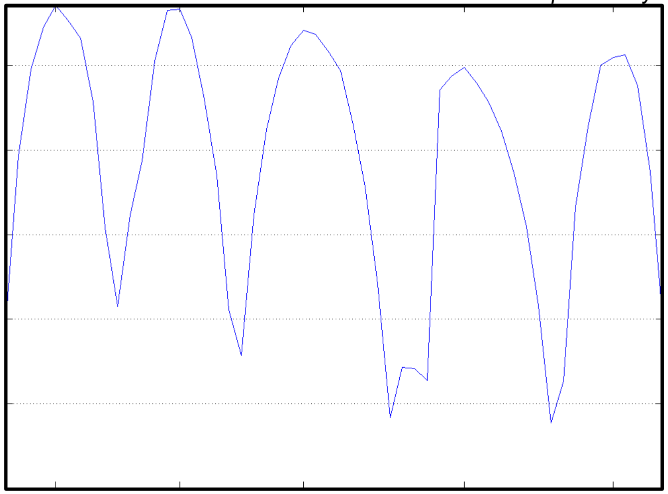
- ❑ Overall **Aspects**
  of the Heat Flux Distribution match

- ❑ Heat Flux **Gradient** and **Peak**
  are much higher
  (often twice higher)




*Radiance* Model

## Conclusions & Future Tasks

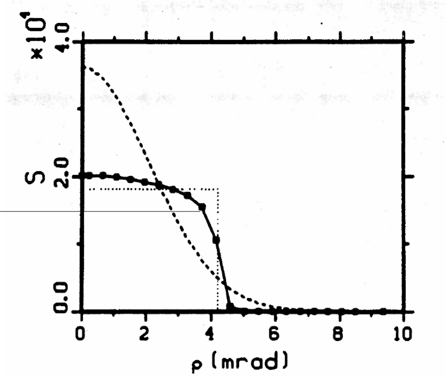



### Overall Observations

- The model is **reliable** concerning **total thermal power**
- Still needs validation of the heat flux distribution

### Potential Improvements

- Implement Facet **Waviness**
- Generate **Curved** Facets
- Replace Pillbox Sunshape with a **Kuiper Sunshape**



# Main References for the Presentation


[1] Abengoa Solar New Technologies, Spain, www.abengoa.es

[2] Dr. Valerio, PS10: a 11.0-MWe Solar Tower Power Plant with Saturated Steam Receiver (Slides), Solucar, 2006

[3] G. W. Larson and R. Shakespeare, Rendering with Radiance, The Art and Science of Lighting Visualization, Morgan Kaufmann Publishers, San Francisco, California, 1998

[4] H. Zhang, Multi-objective thermoeconomic optimisation of the design of heliostat field of solar tower power plants, 2007

[5] J. Fernàndez Reche, Reflectance measurement in solar tower heliostats fields, Solar Energy 80 (2006) 779786

[6] M. Sanchez and M. Romero, methodology for generation of heliostat field layout in central receiver systems based on yearly normalized energy surfaces, Solar Energy, 80 (2006):861-874