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Gemasolar as SKA? (Alan Roy, Olaf Wucknitz, Ivan Camara, ...)

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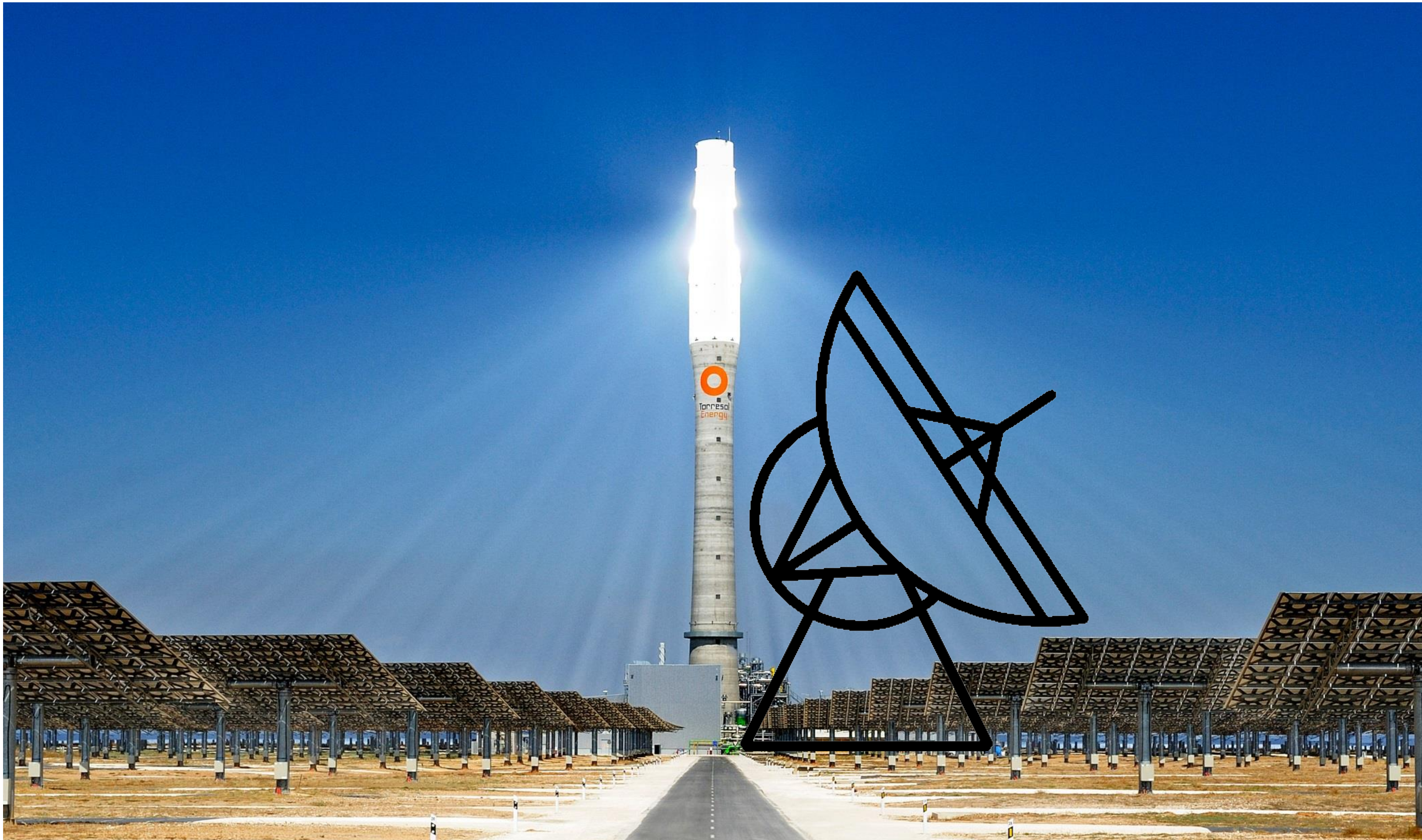
Gemasolar Size Comparison


Torresol
Energy


Torresol
Energy

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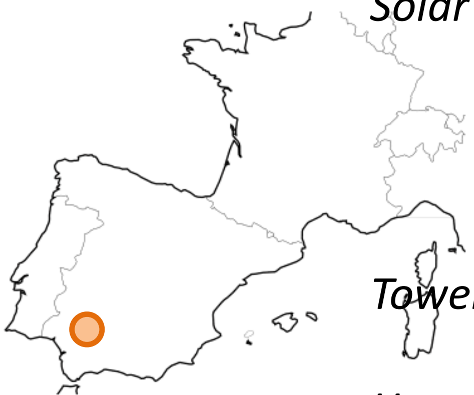
Gemasolar Basics



Solar field:	2650 heliostats, each 120 m^2, total 304 750 m^2, equivalent to **620 m** diameter single dish
Tower height:	140 m
Heat-Transfer Fluid:	Molten salts (sodium + potassium nitrate)
Receiver inlet temp:	290 °C
Receiver outlet temp:	565 °C
Turbine capacity:	19.9 MW
Construction cost:	230 M€ (5 M€ from EU FP5, 80 M€ loan EIB)
Timeline:	2007 begin, 2011 online
Electricity sales:	110 000 MWh/yr = 30 M€/yr
Ownership:	Torresol Energy, subsidiary of consortium: 60 % SENER Grupo de Ingeniería (private company, Spain) 40 % MASDAR (alternative energy company of Abu Dhabi)

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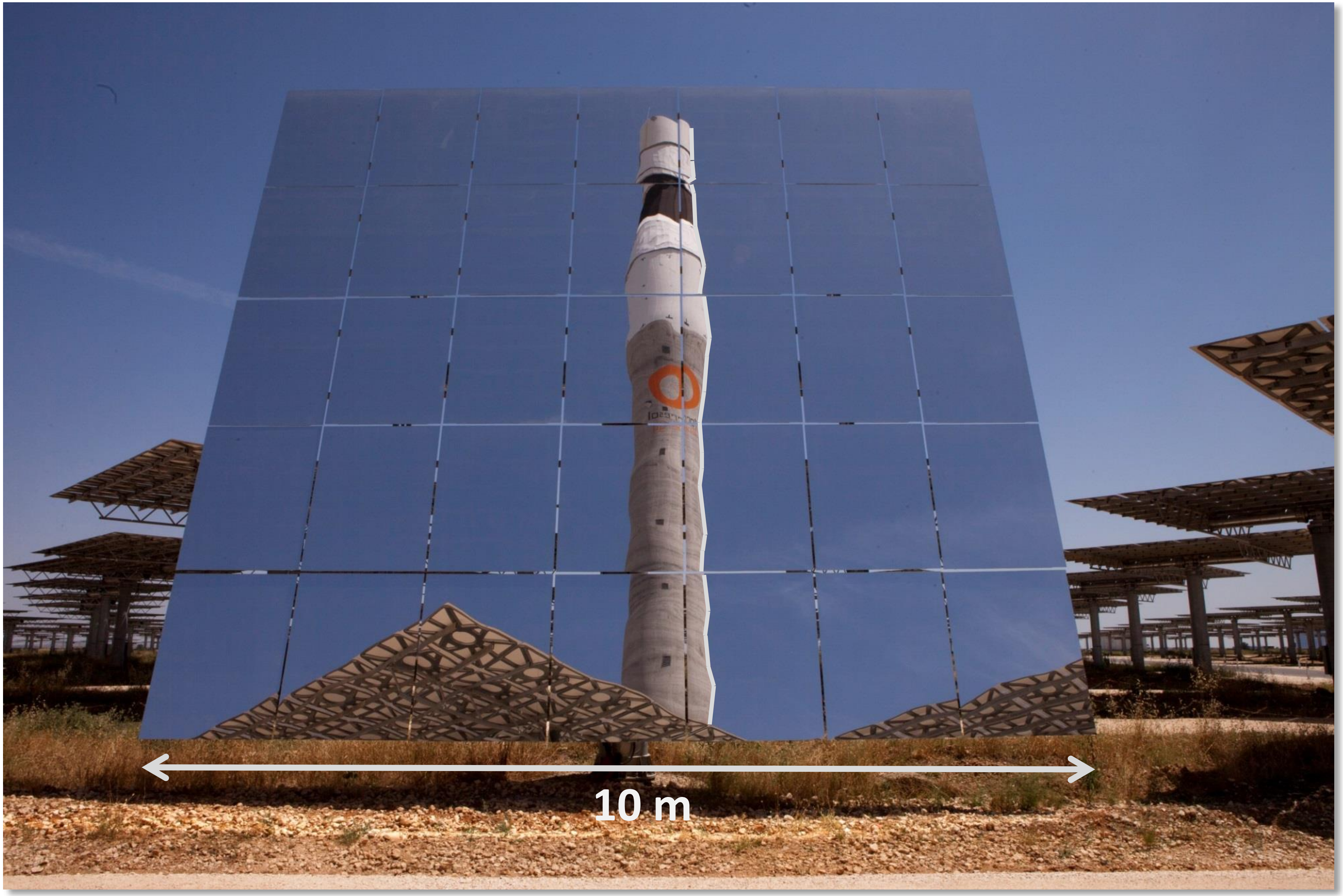
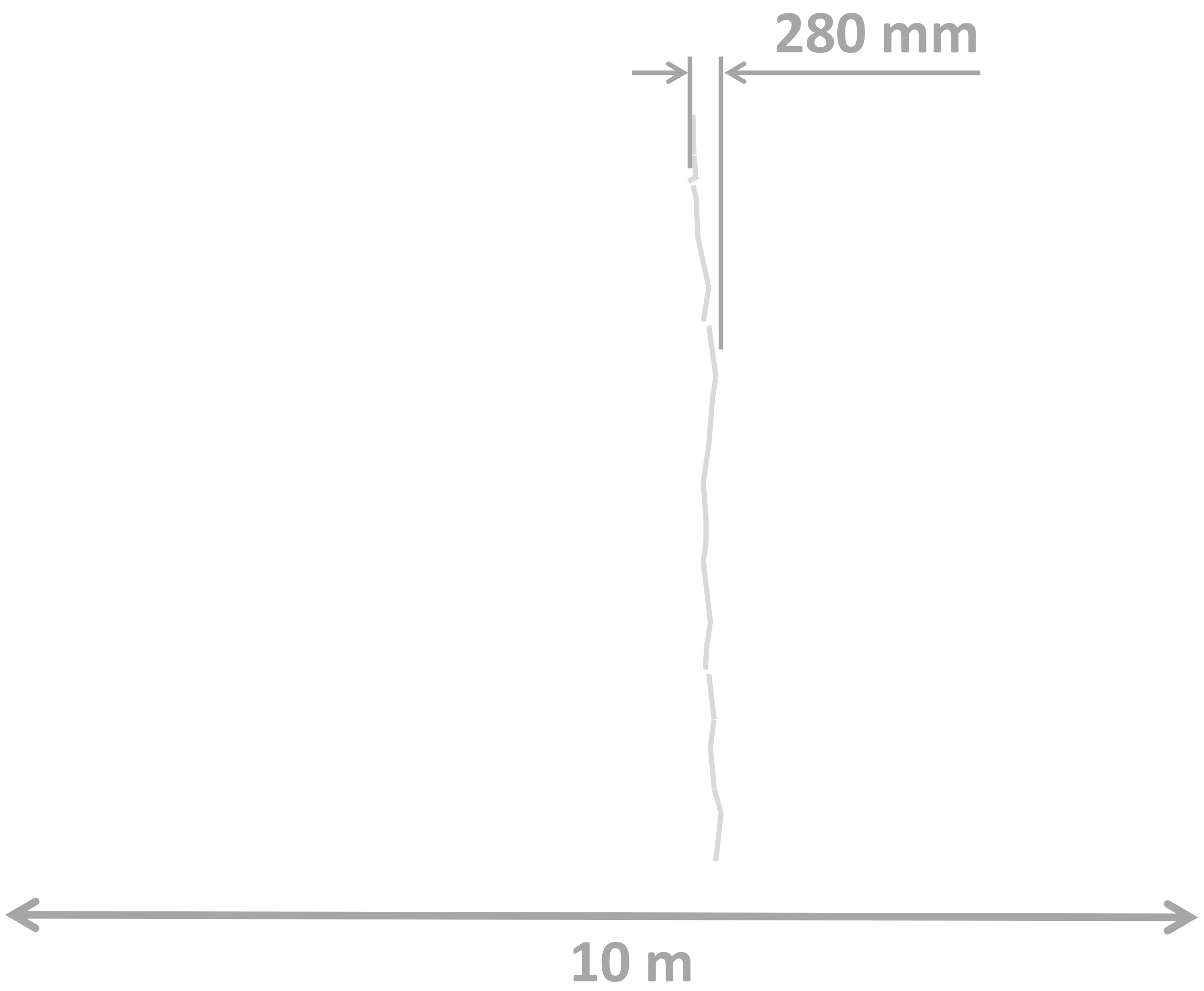
Mirror Surface Accuracy

Mirror Surface Accuracy



Mirror Surface Accuracy



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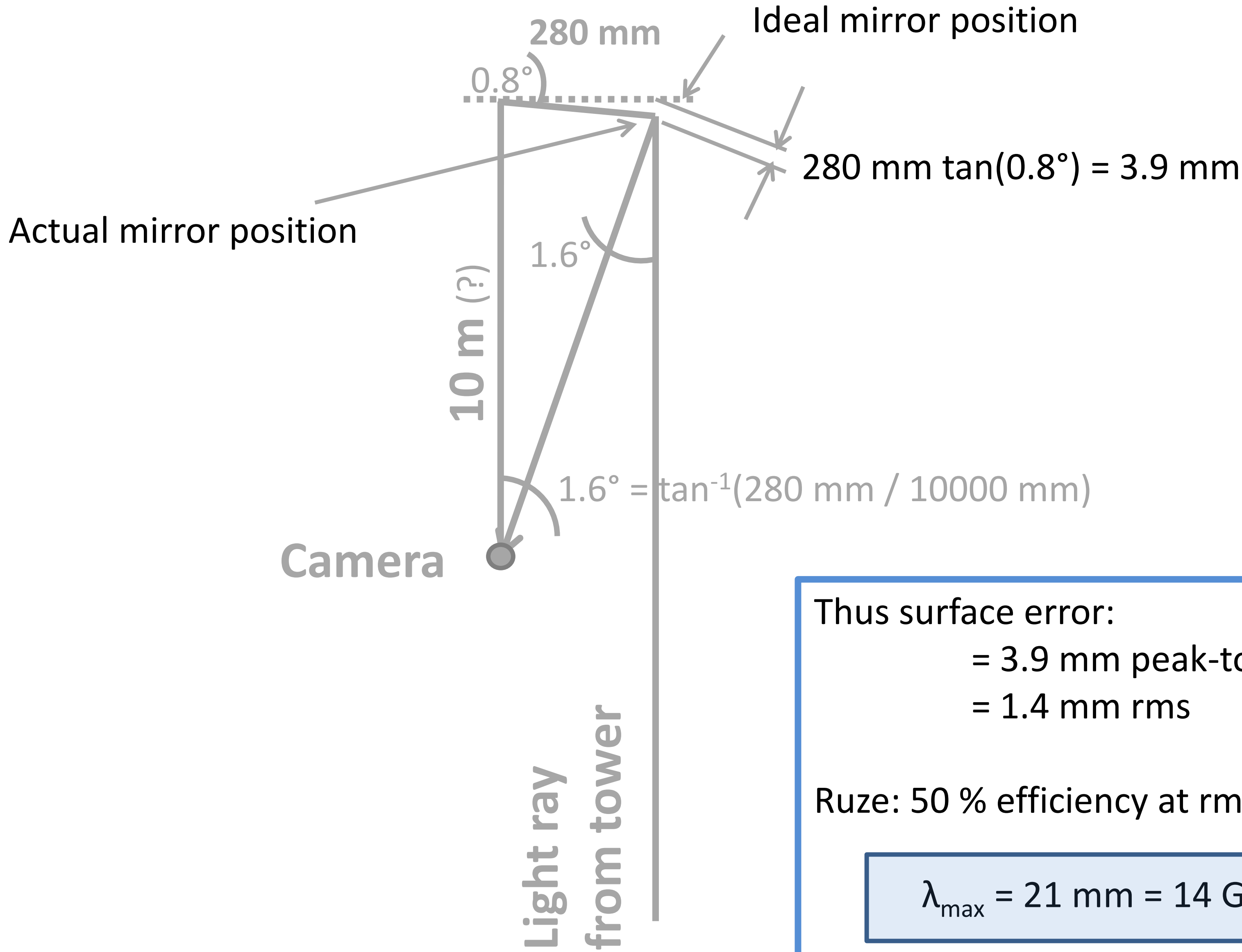
Mirror Surface Accuracy



Thus surface error:

= 3.9 mm peak-to-peak

= 1.4 mm rms

Ruze: 50 % efficiency at rms = λ / 15

λ_{max} = 21 mm = 14 GHz

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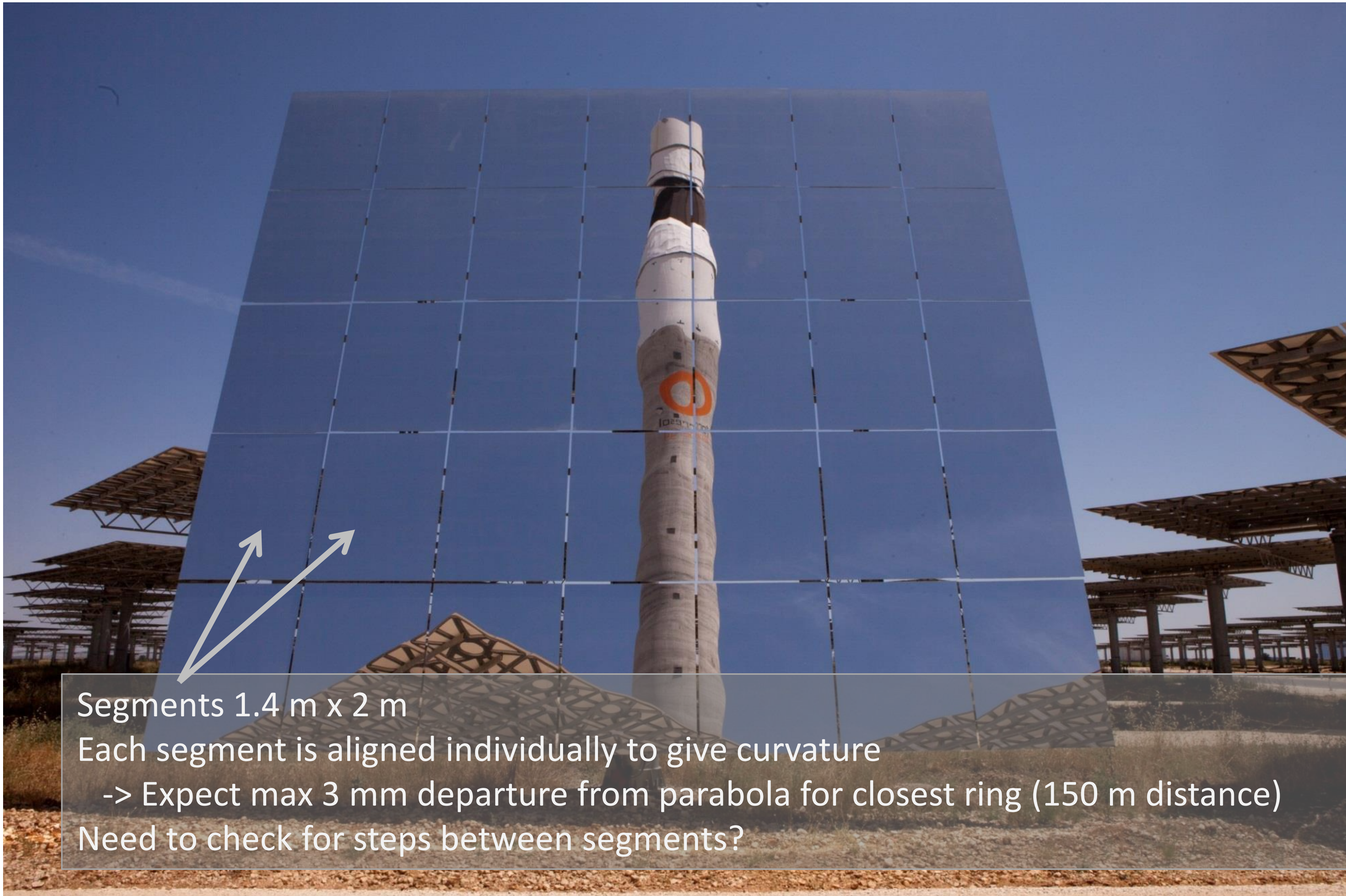
Mirror Deviation from Parabolic



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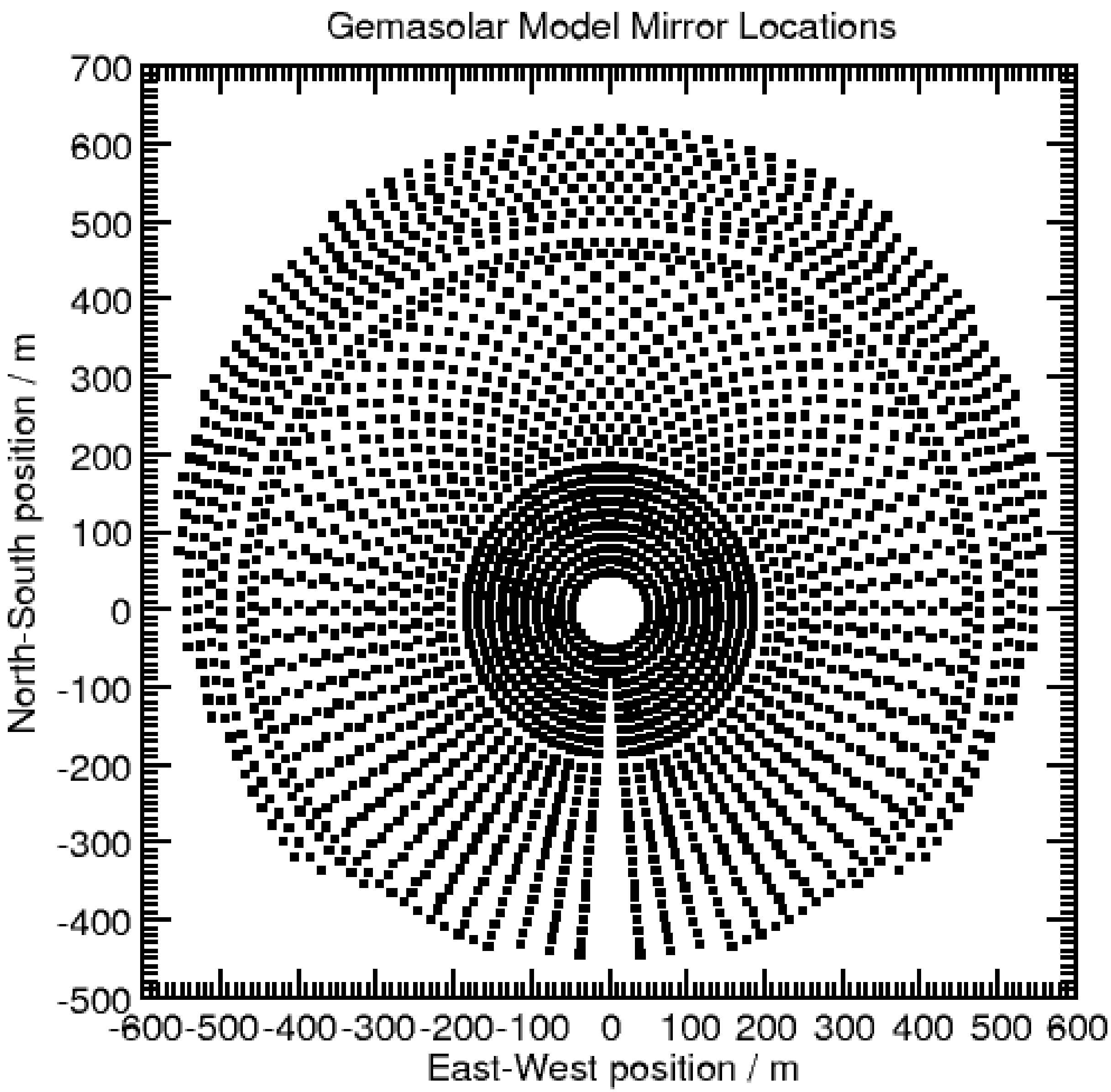
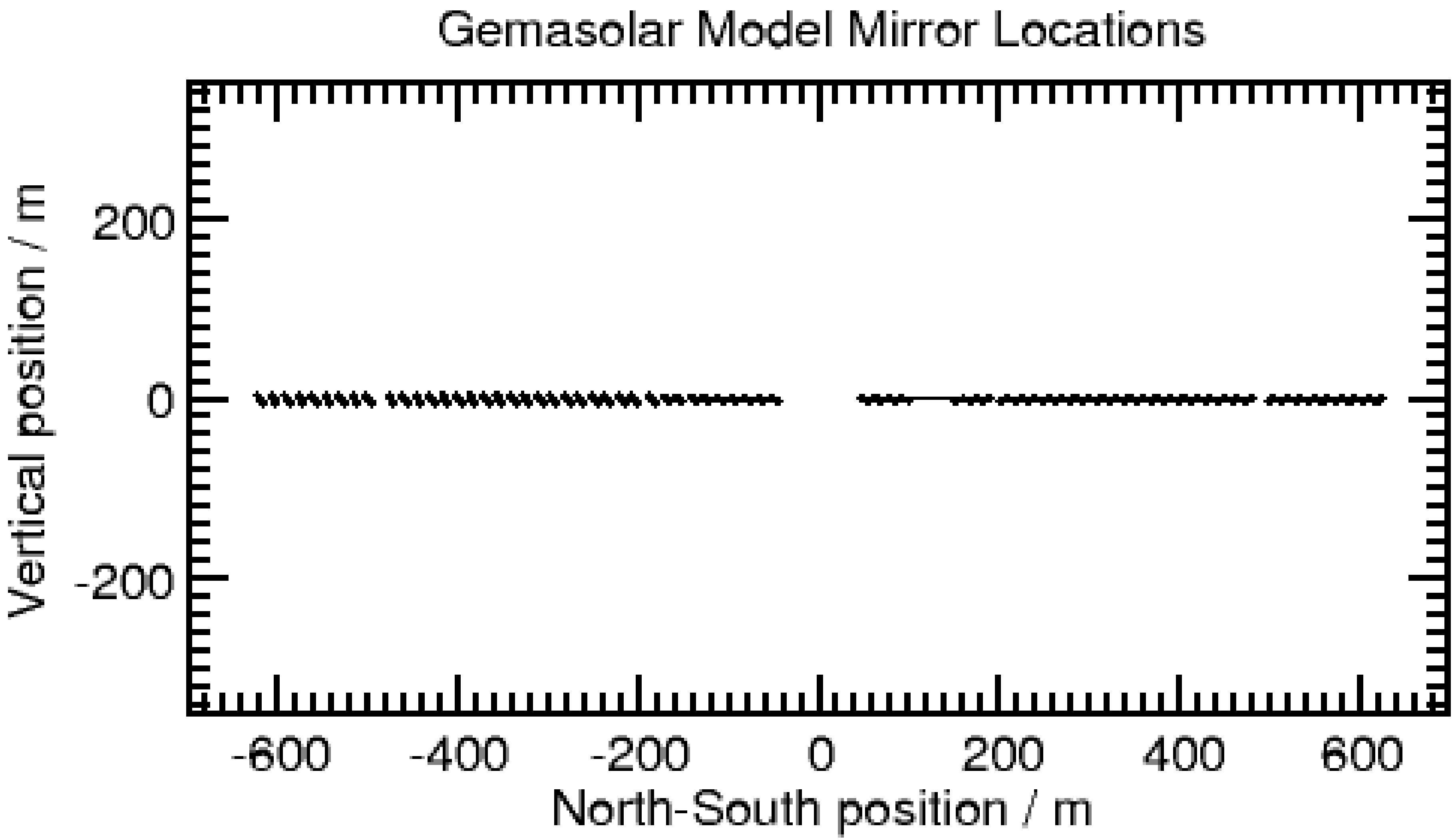
Model Mirror Locations



Model Mirror Locations



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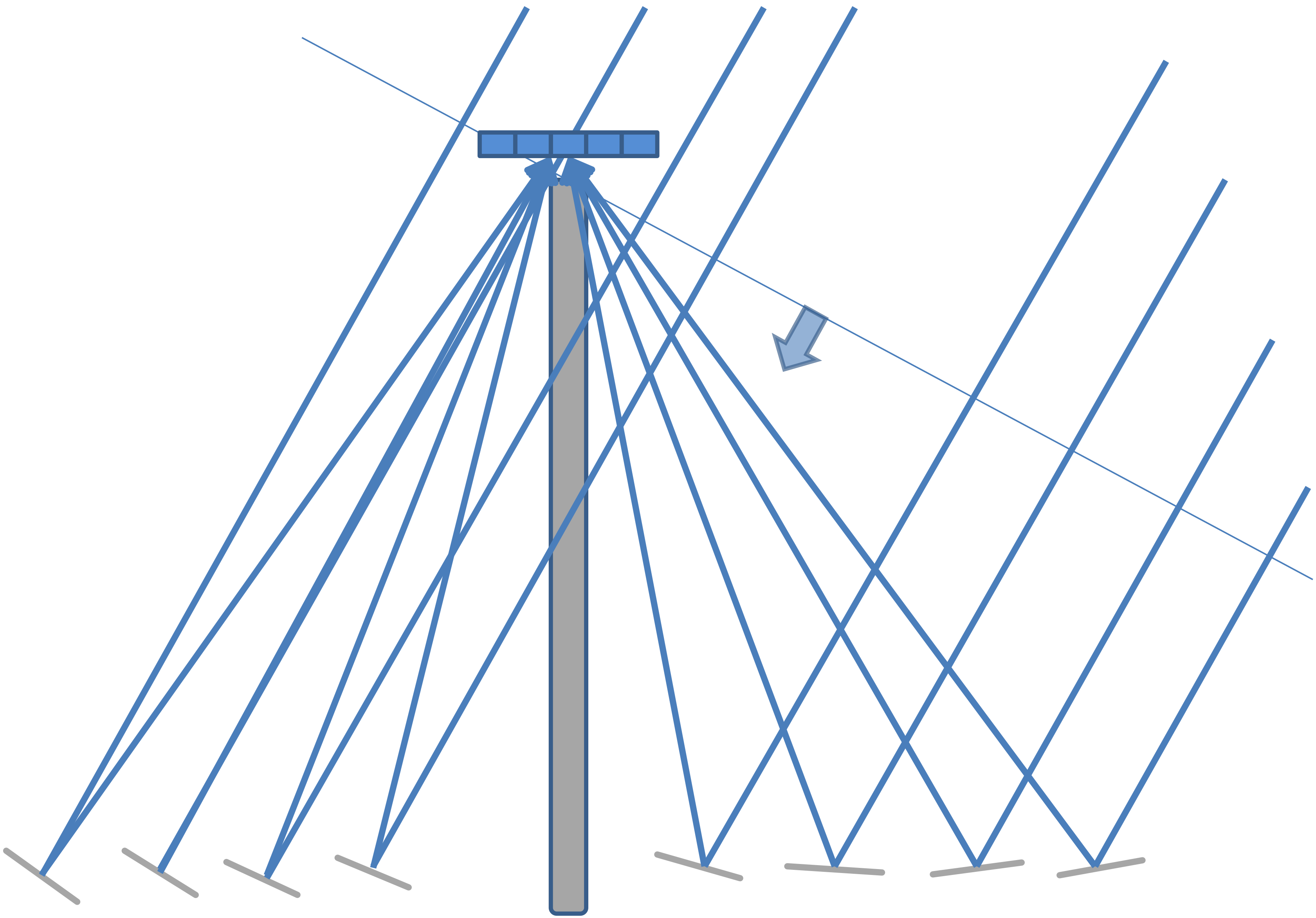
Incoherent Summation: Model Geometry



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Physical Optics Model

1) Calculate Propagation Delays:

For 2650 mirrors and a chosen pointing centre (az = 30°, el = 50°):

$$\tau_i = \tau_{\text{wavefront to mirror } i} + \tau_{\text{mirror } i \text{ to focus}}$$

2) Calculate field at PAF j^th element: Sum signal from each mirror path:

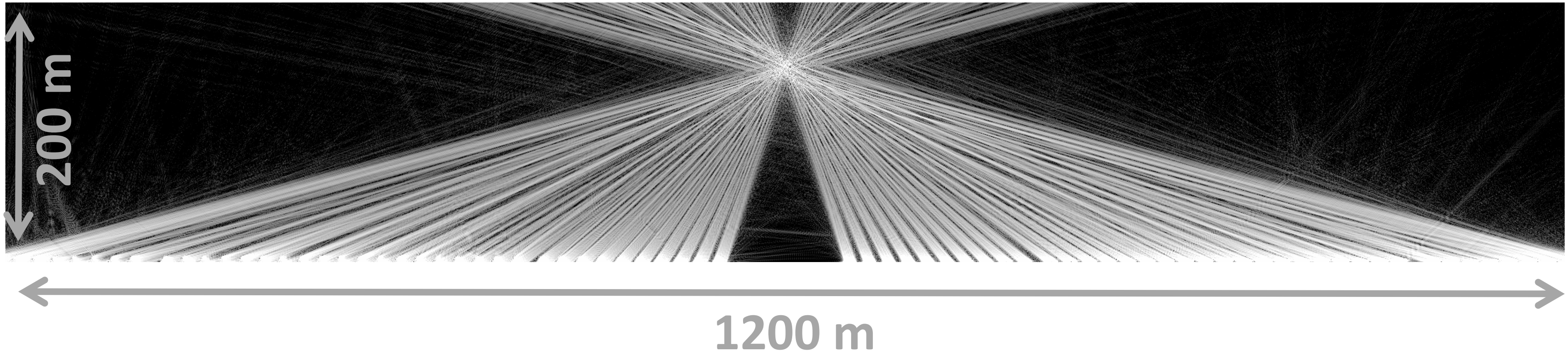
$$\tilde{E}_j = \sum_{i=0}^{2650} e^{-i\omega\tau_i}$$

3) Square the voltage to get power

$$P_j = \tilde{E}_{\mathrm{j}}^{\,2}$$

4) Plot power over focal plane: P_j vs focal plane (x,y)

Physical Optics: Side Profile



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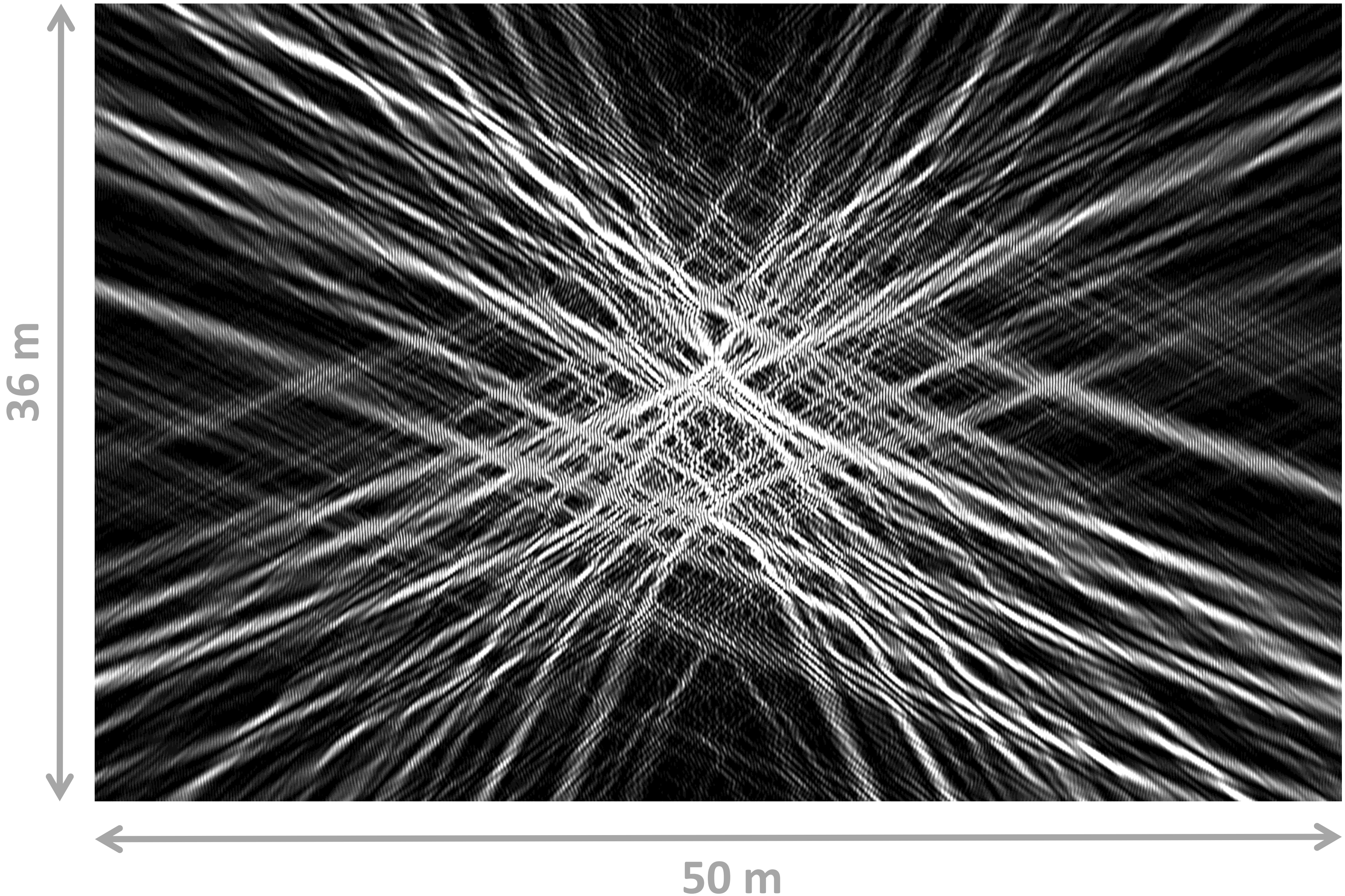
Physical Optics: Side Profile at Focus



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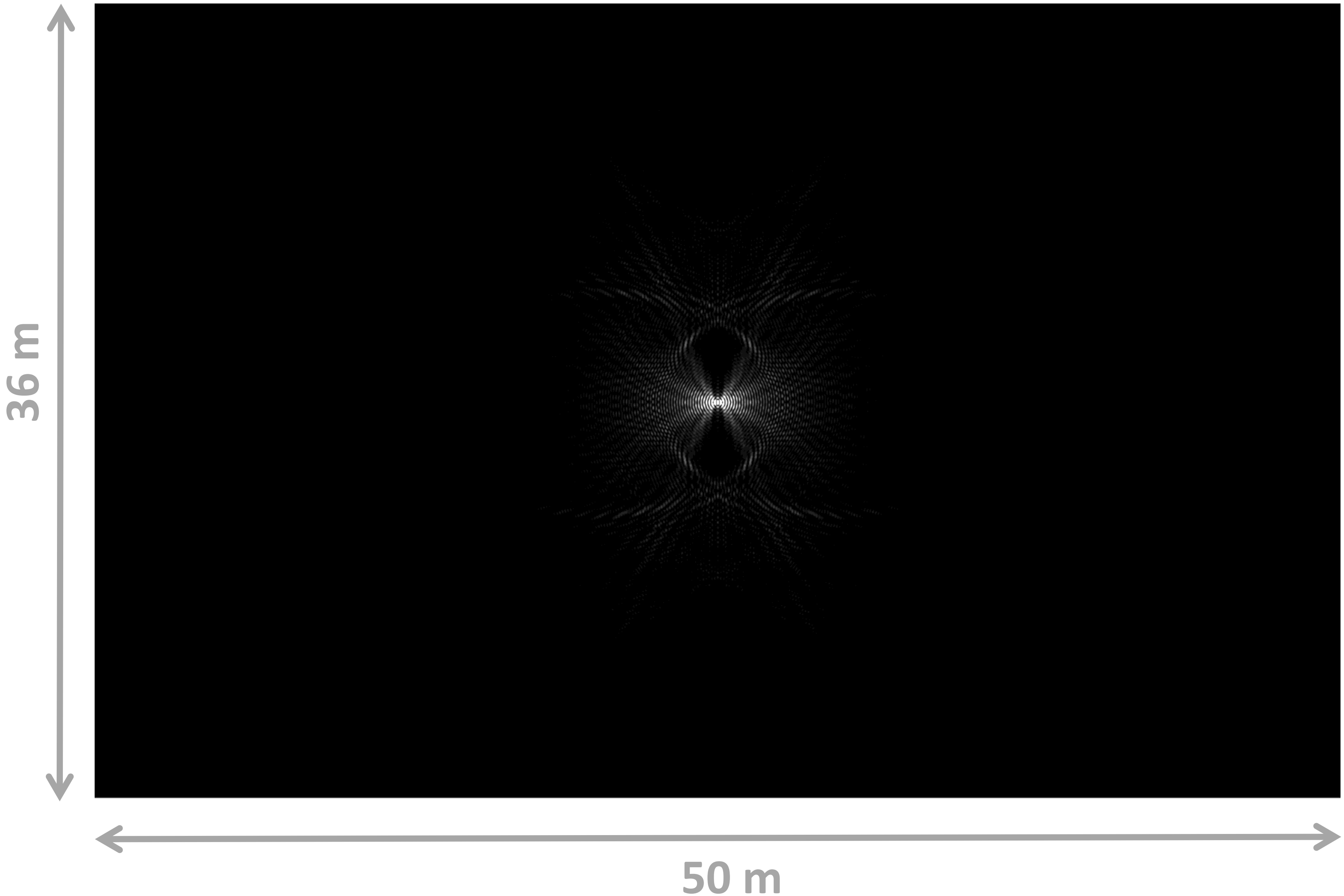
Physical Optics: Side Profile Parabolic Mirror



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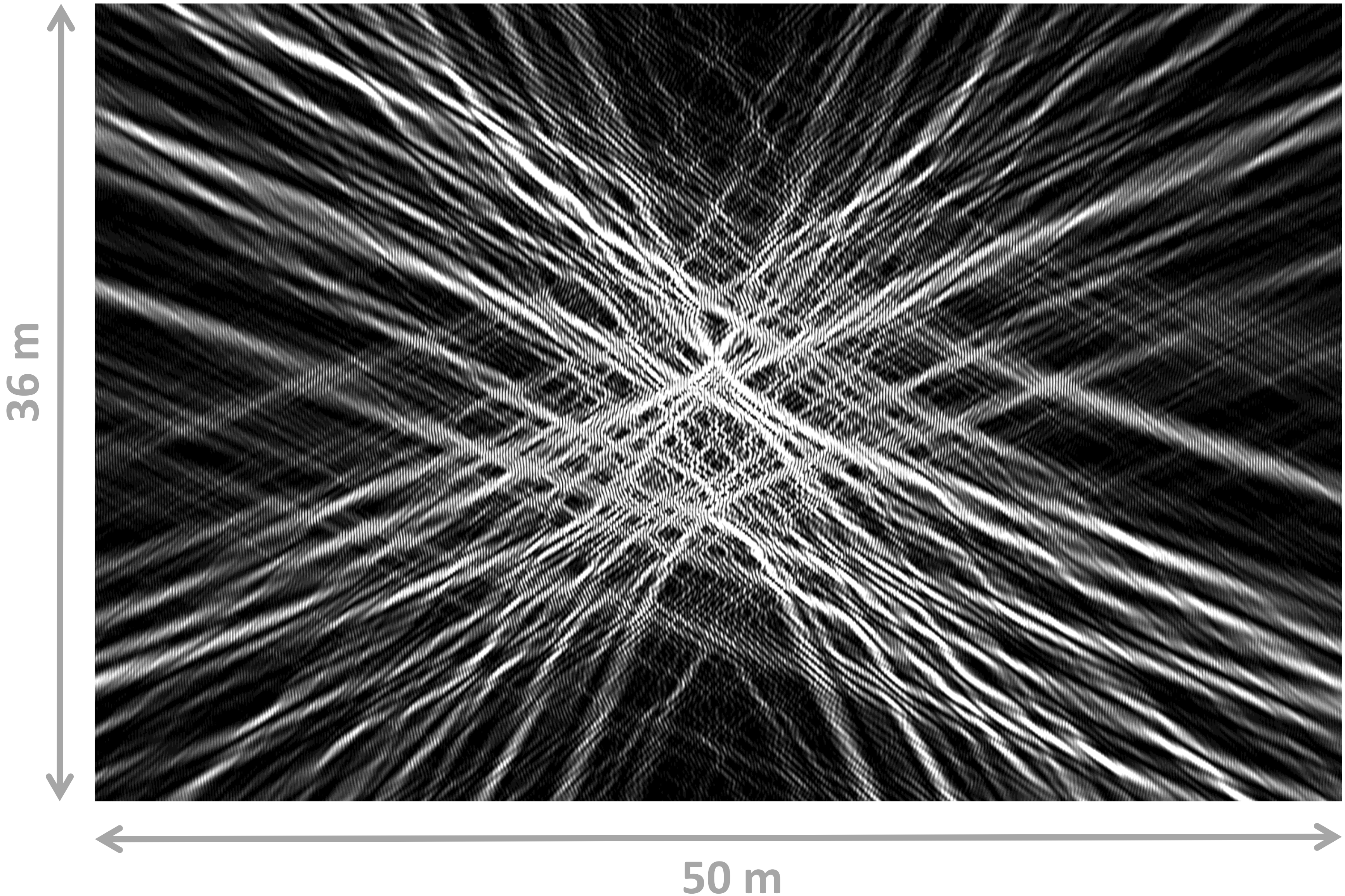
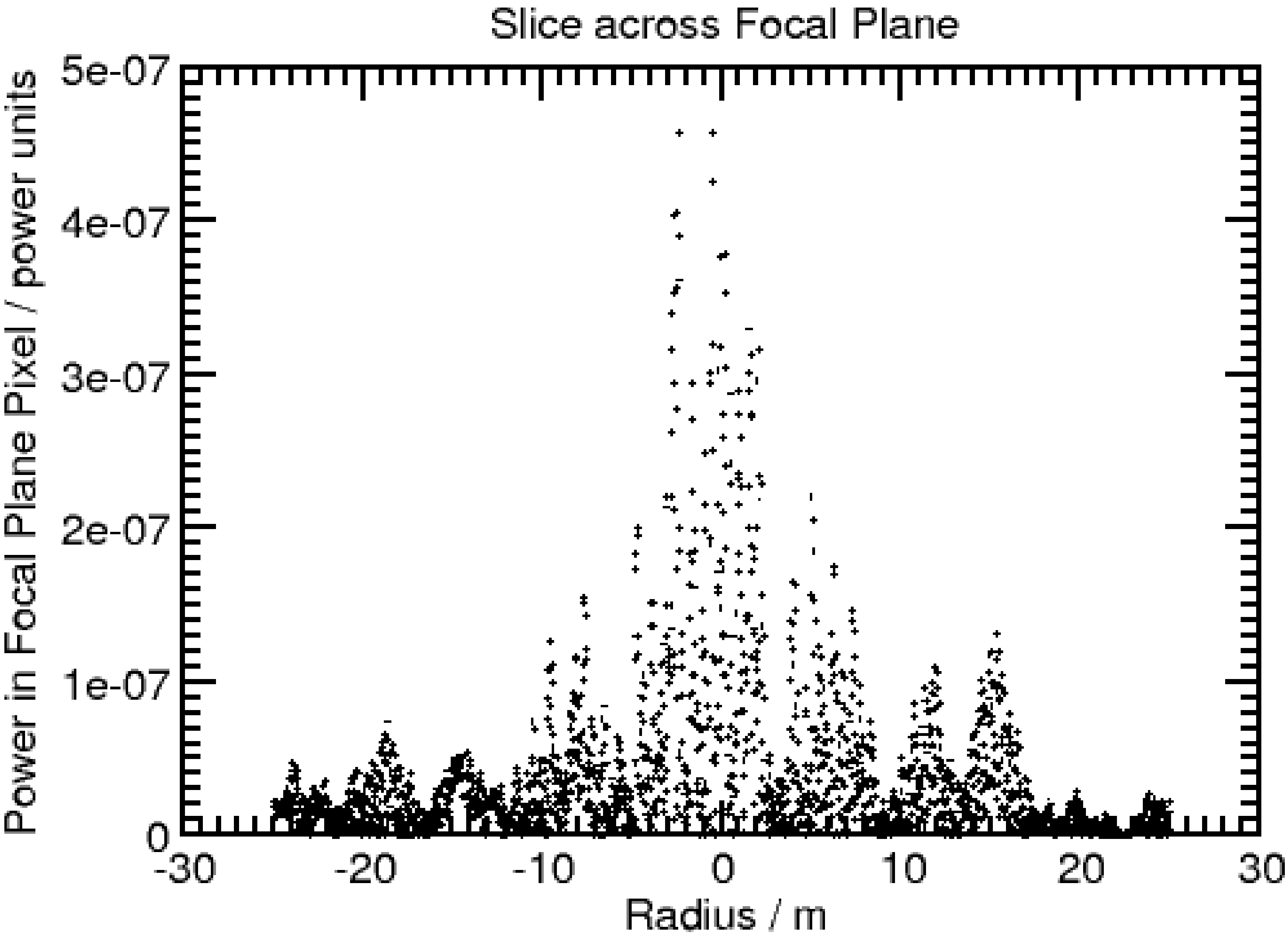
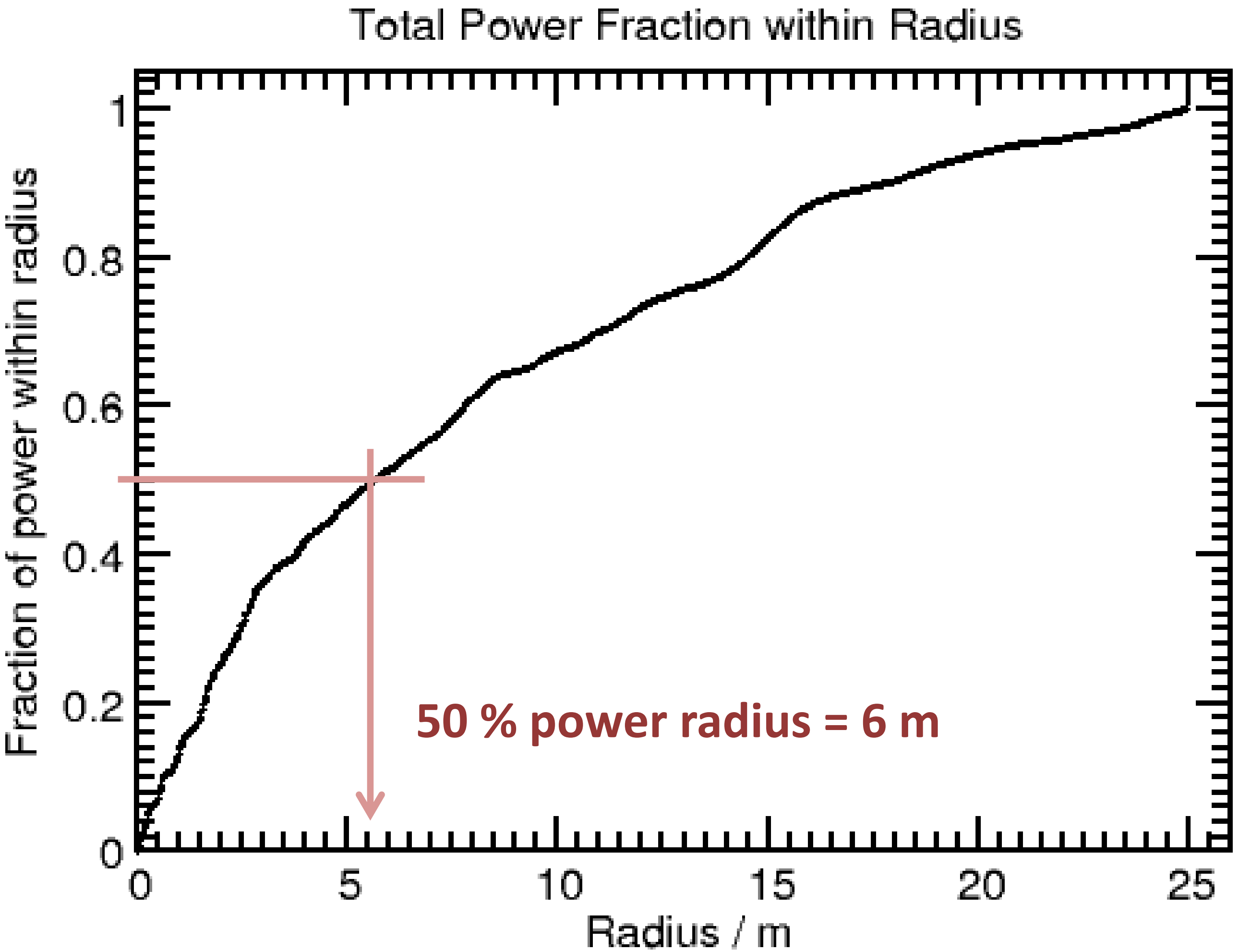
Physical Optics: Side Profile at Focus



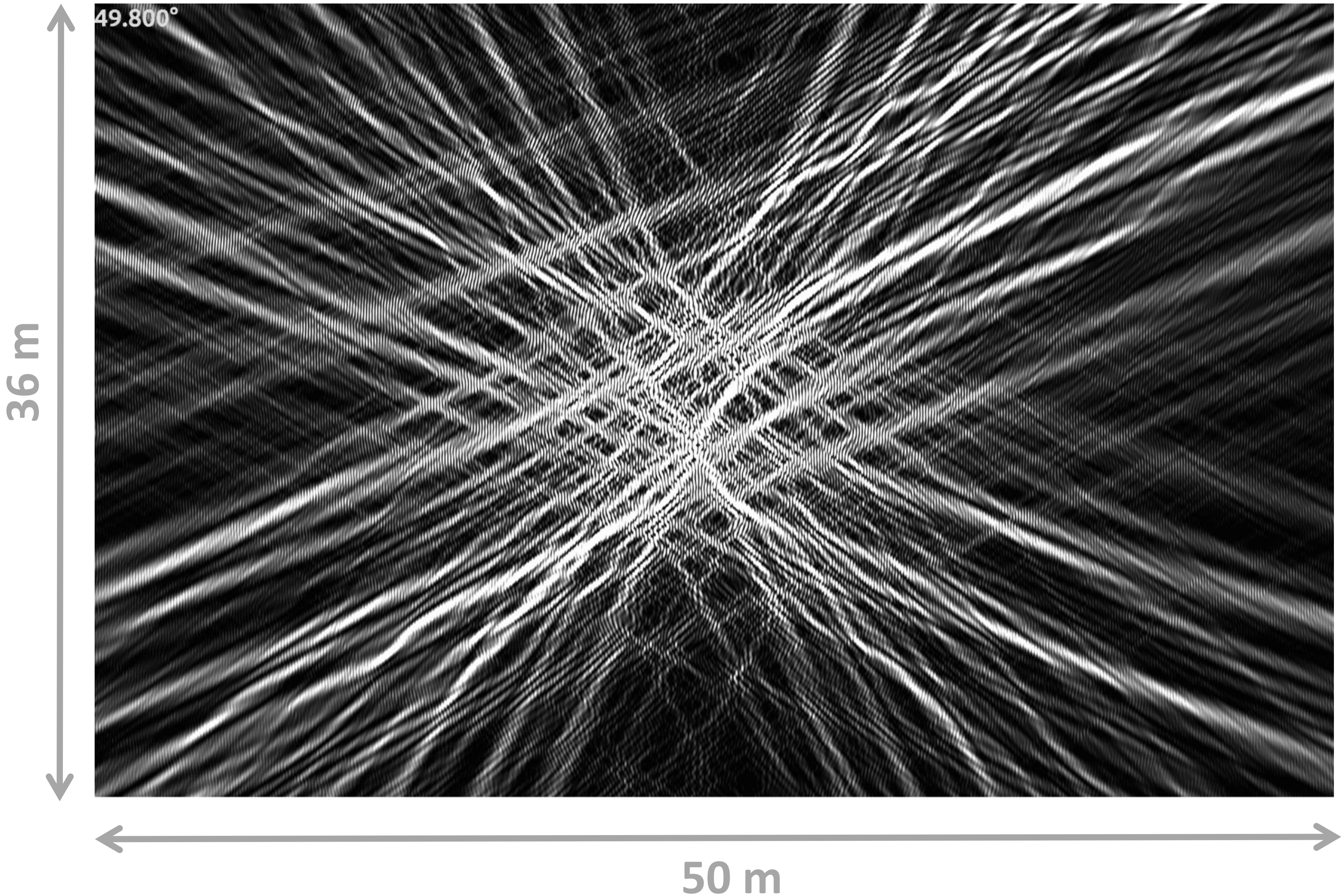
Physical Optics: Side Profile at Focus



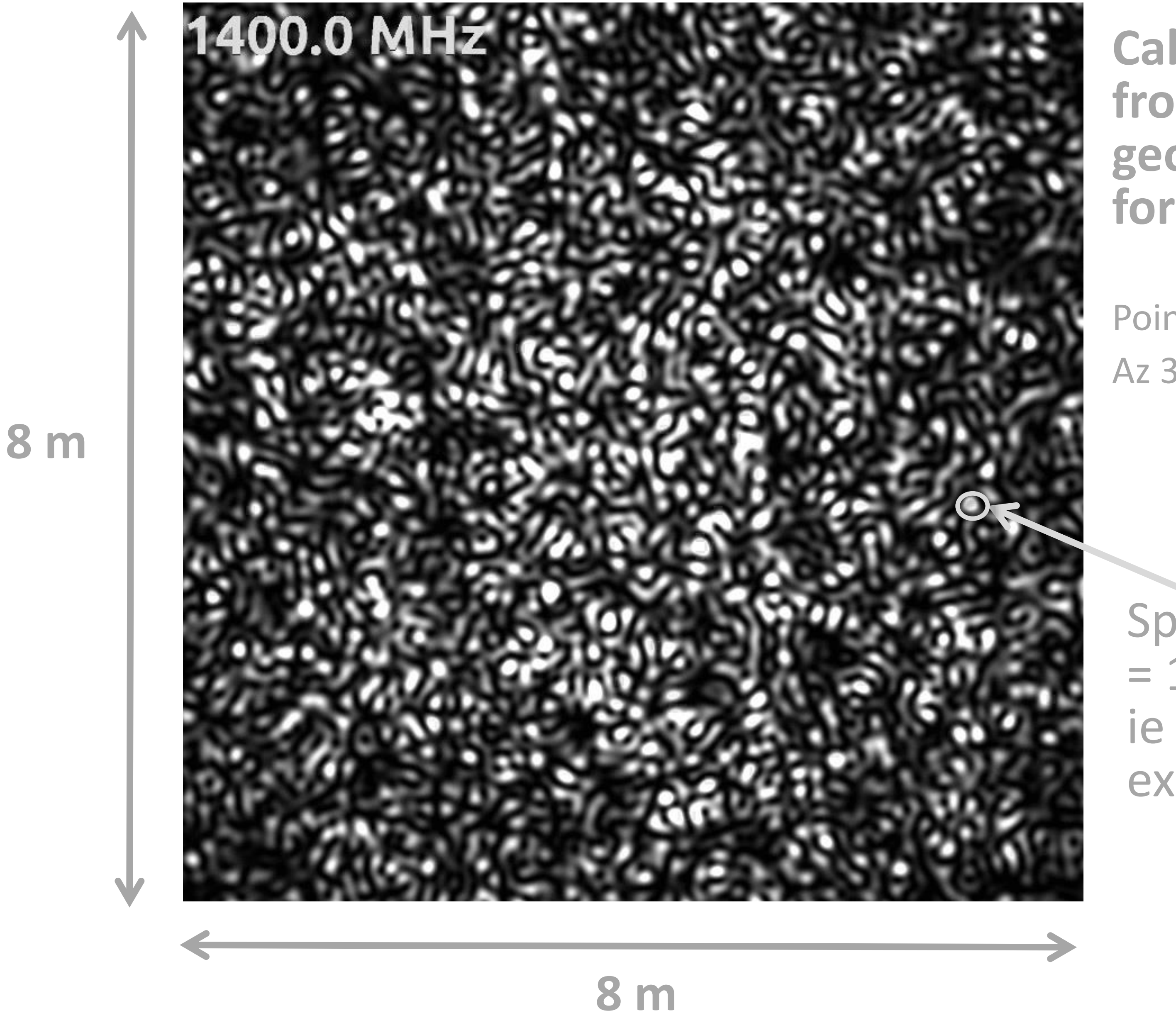
Physical Optics: Side Profile at Focus



Physical Optics: Side Profile at Focus



Focal Plane Speckle



Calculated from array geometry for λ=21 cm

Point source at Az 30° el 50°

Speckle size = 10 cm ie λ/2 as expected

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Coherence Length in Frequency

Movie step size for smooth speckle motion: 0.1 MHz

Delay across 1200 m array: 4 μs
Reciprocal gives channel width: 1 / 4 μs = 0.25 MHz

Monochromatic if channel < 0.25 MHz
Then can correct phases, not delays.

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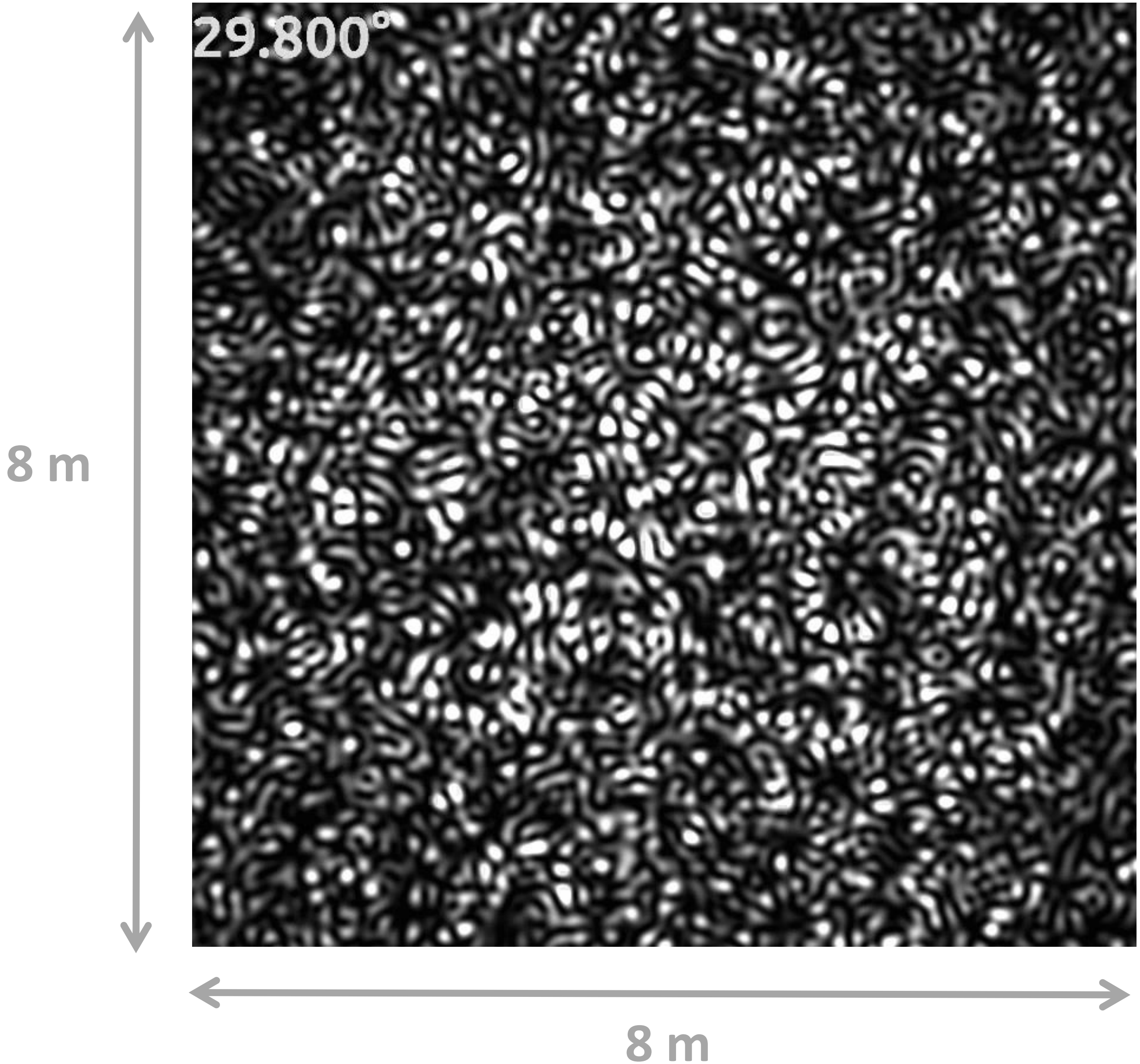
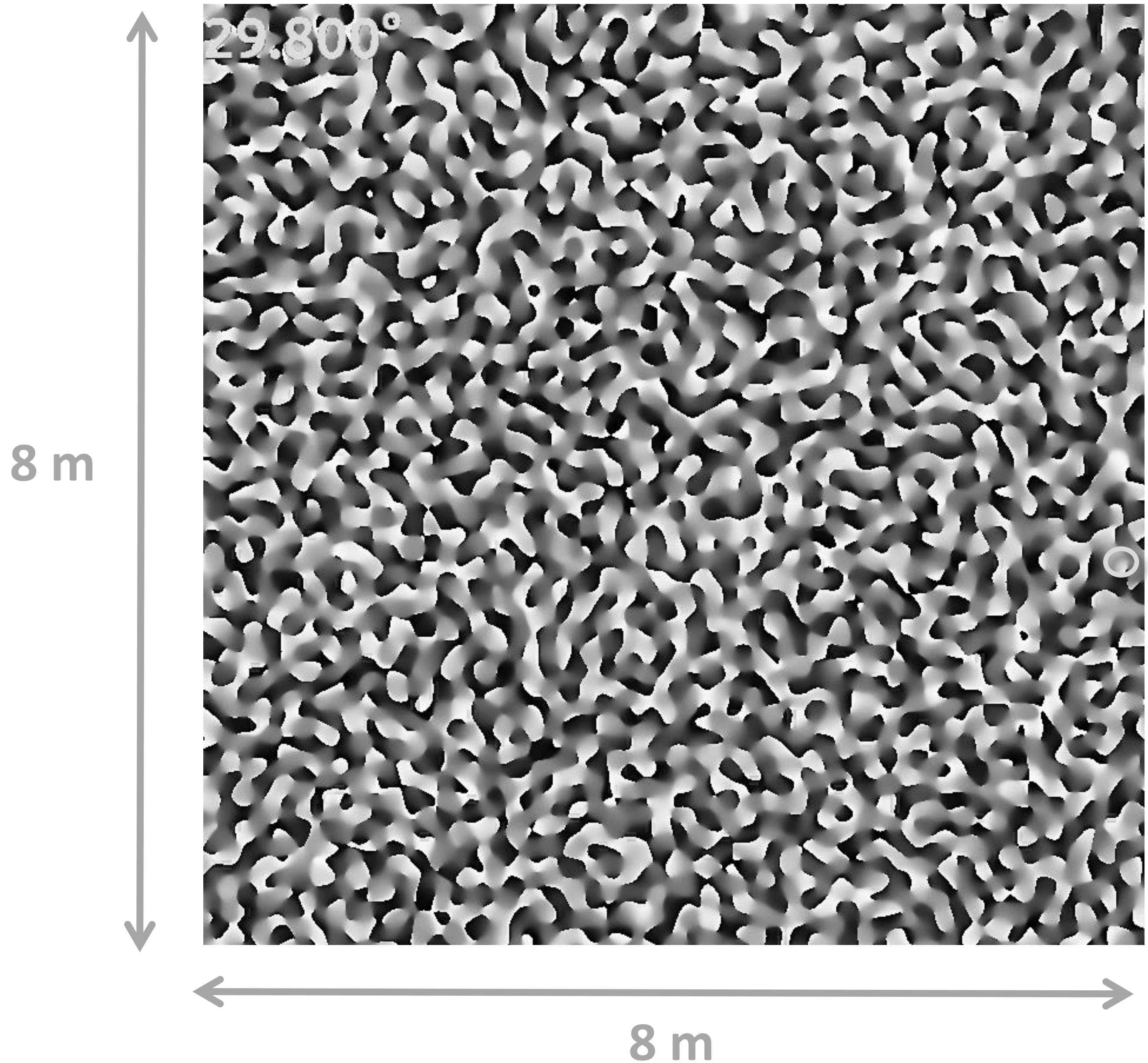
Focal Plane Speckle: Direction Dependence



Calculated from array geometry for λ=21 cm

Point source at Az 30° el 50°

Focal Plane Speckle: phase screen



Calculated from array geometry for λ=21 cm

Point source at Az 30° el 50°

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Beam Reconstruction

1. Calibration Map: *For the desired pointing direction:*

Take the model speckle map in that direction, will be used as calibration map

2. Beamform: Apply calibration and sum over PAF elements:

For each focal plane element:

1. Unwind phase:
   Rotate phase backward using angle from model phase screen
2. Apply weight to amplitude,
   Use gain from model speckle map
3. Add this weighted element into sum

3. Map the resulting beam:

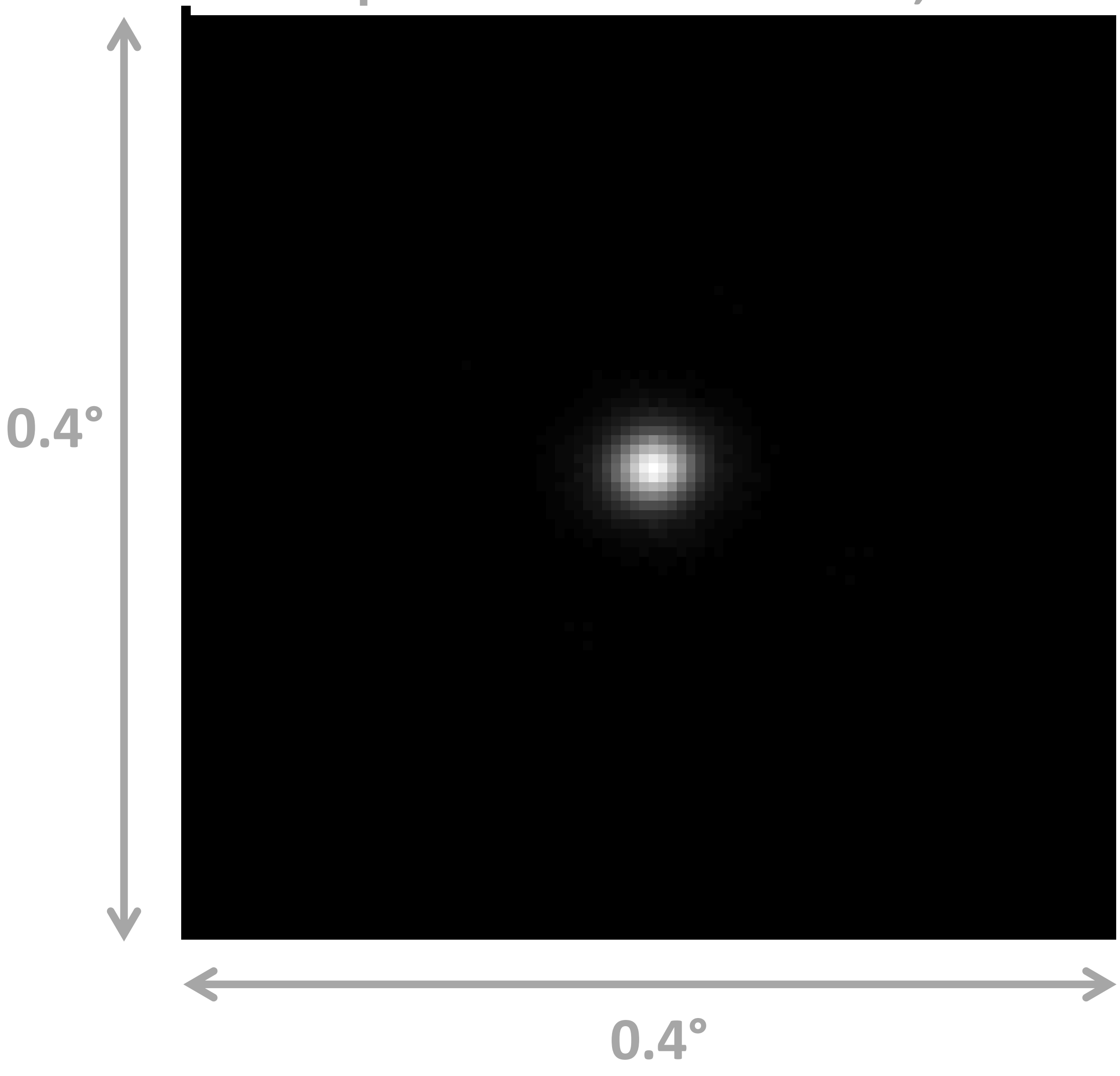
Beam-form the speckle maps from all directions using one cal map

4. Multi-Beaming:

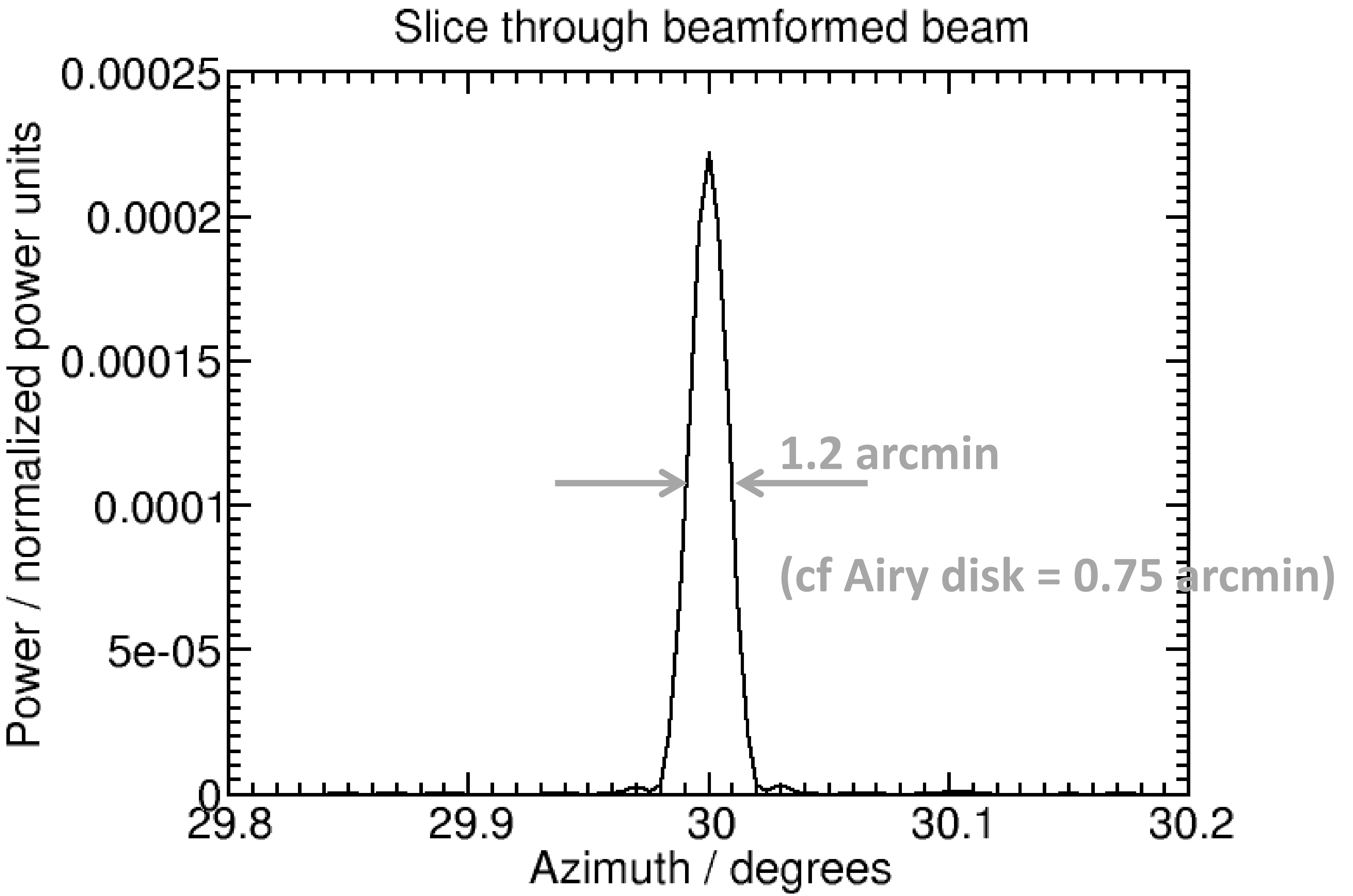
Repeat 1. and 2. for all directions within FoV of 10 m element:

Beam Reconstruction

Cal map direction: az = 30.0°, el =50.0°



Beam Reconstruction



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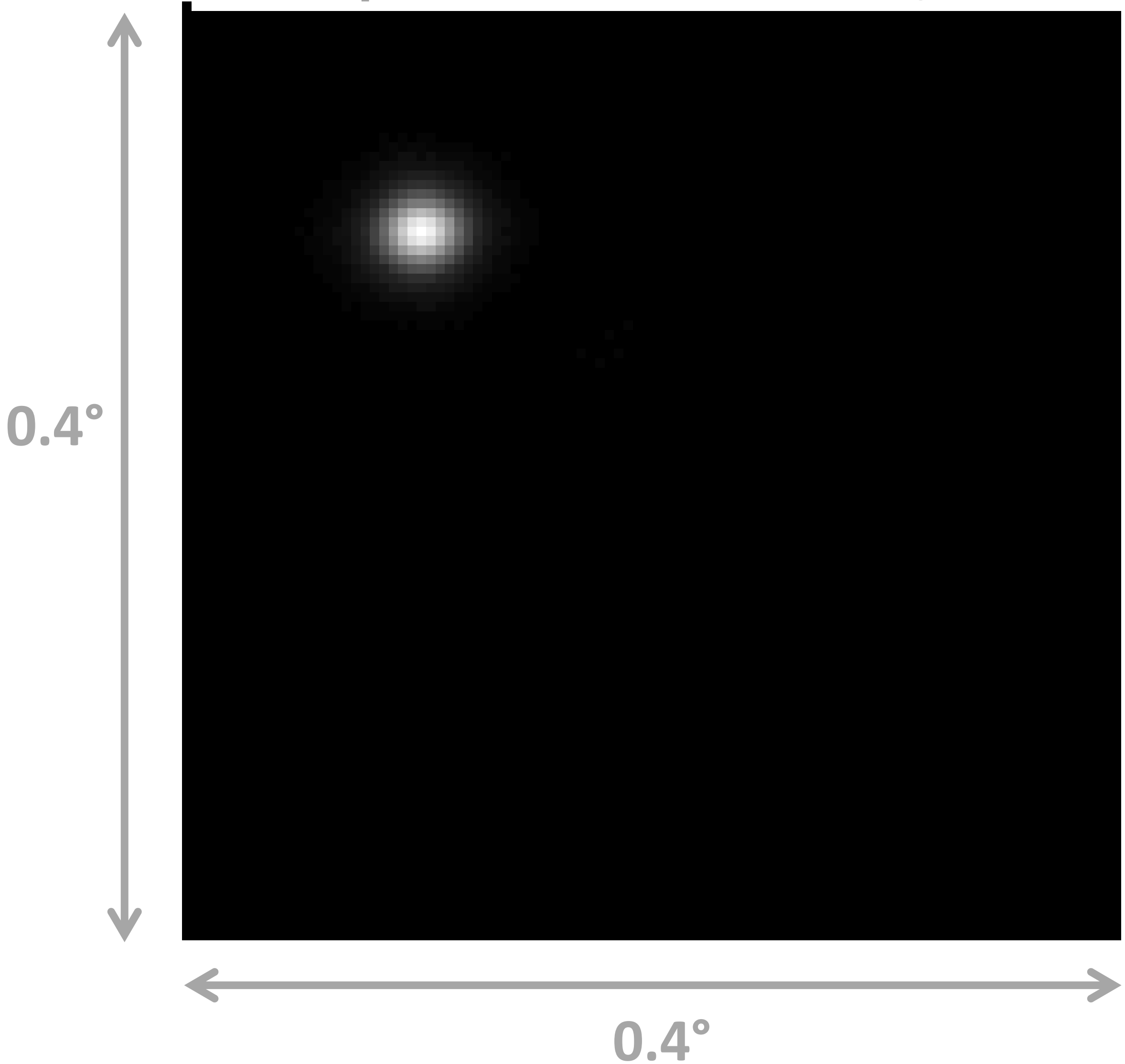
Beam Steering:

Cal map direction: az = 29.9°, el =50.1°



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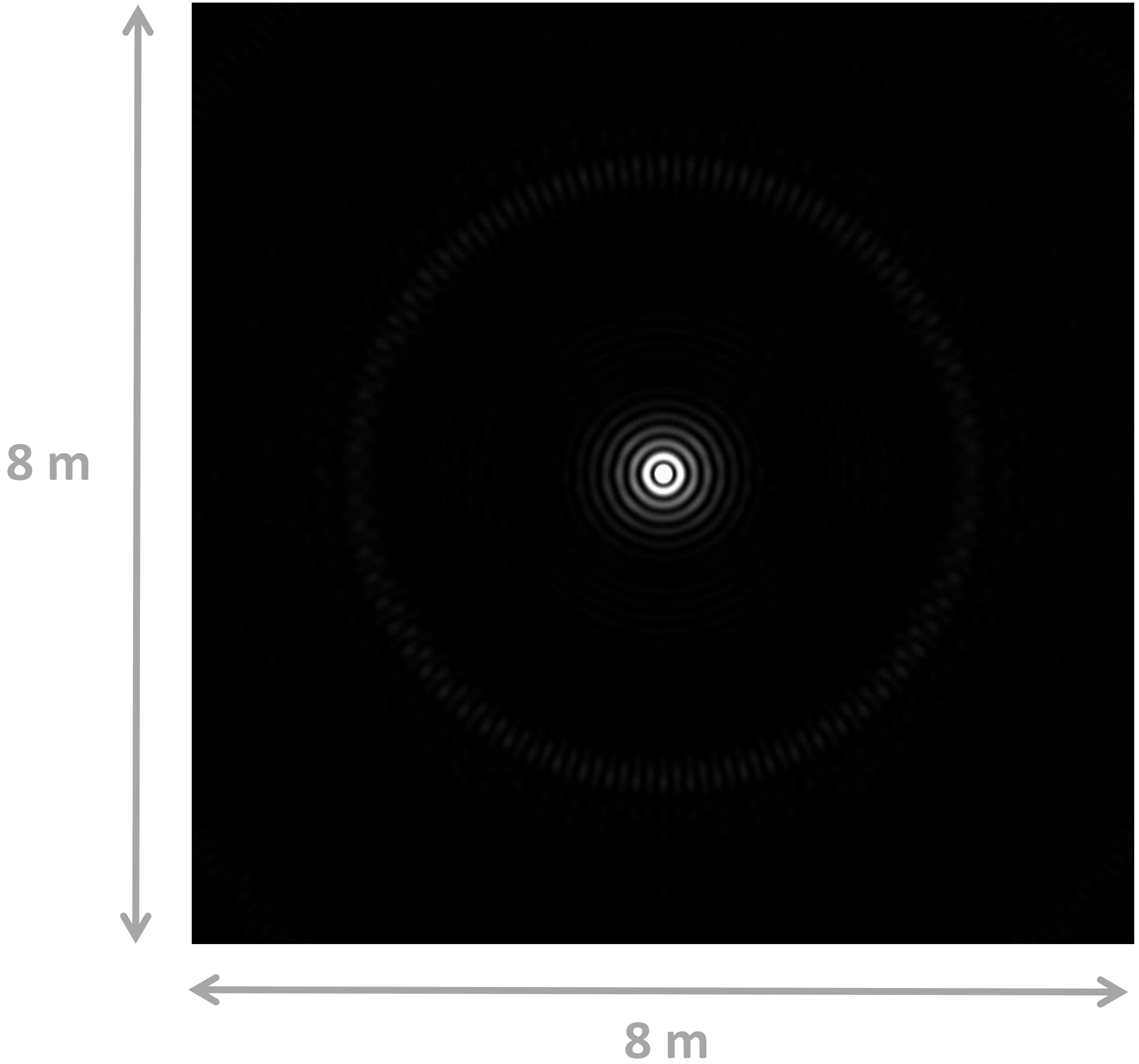
Beamforming: Compare Parabolic Mirror Field



Point source in zenith,

Mirrors lifted onto parabola.

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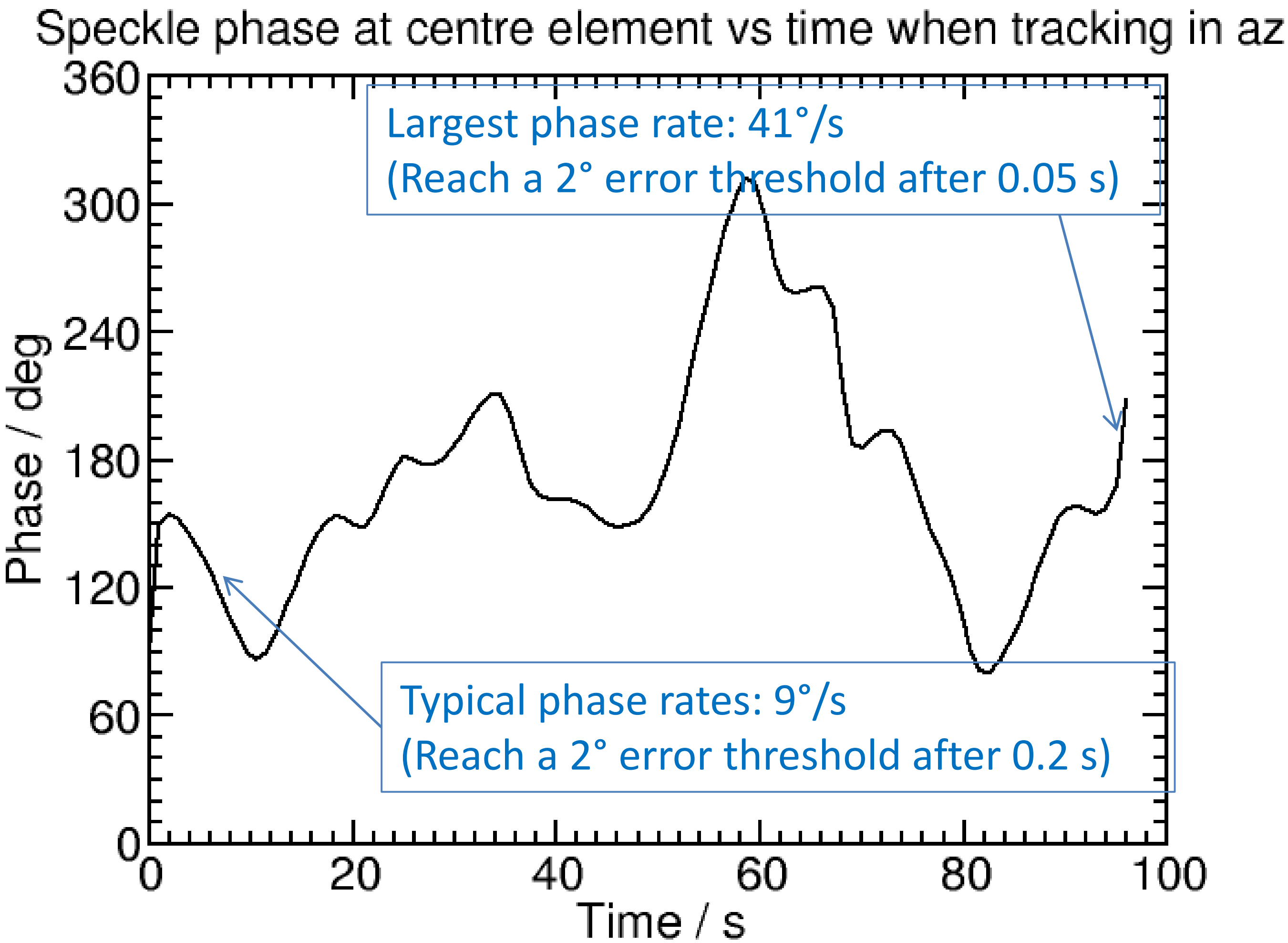
PAF Weight Update Rate:



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Focal Plane Array?

EMBRACE@Nancay
4608 Vivaldi antennas, 12.5 cm spacing
8.42 m x 8.42 m
Torchinsky et al. 2016, A&A

Multi-Beaming:

FoV: 10 m mirror @ $\lambda = 21$ cm -> 1.2°

Synthesized beam: 1200 m aperture -> 1.2’

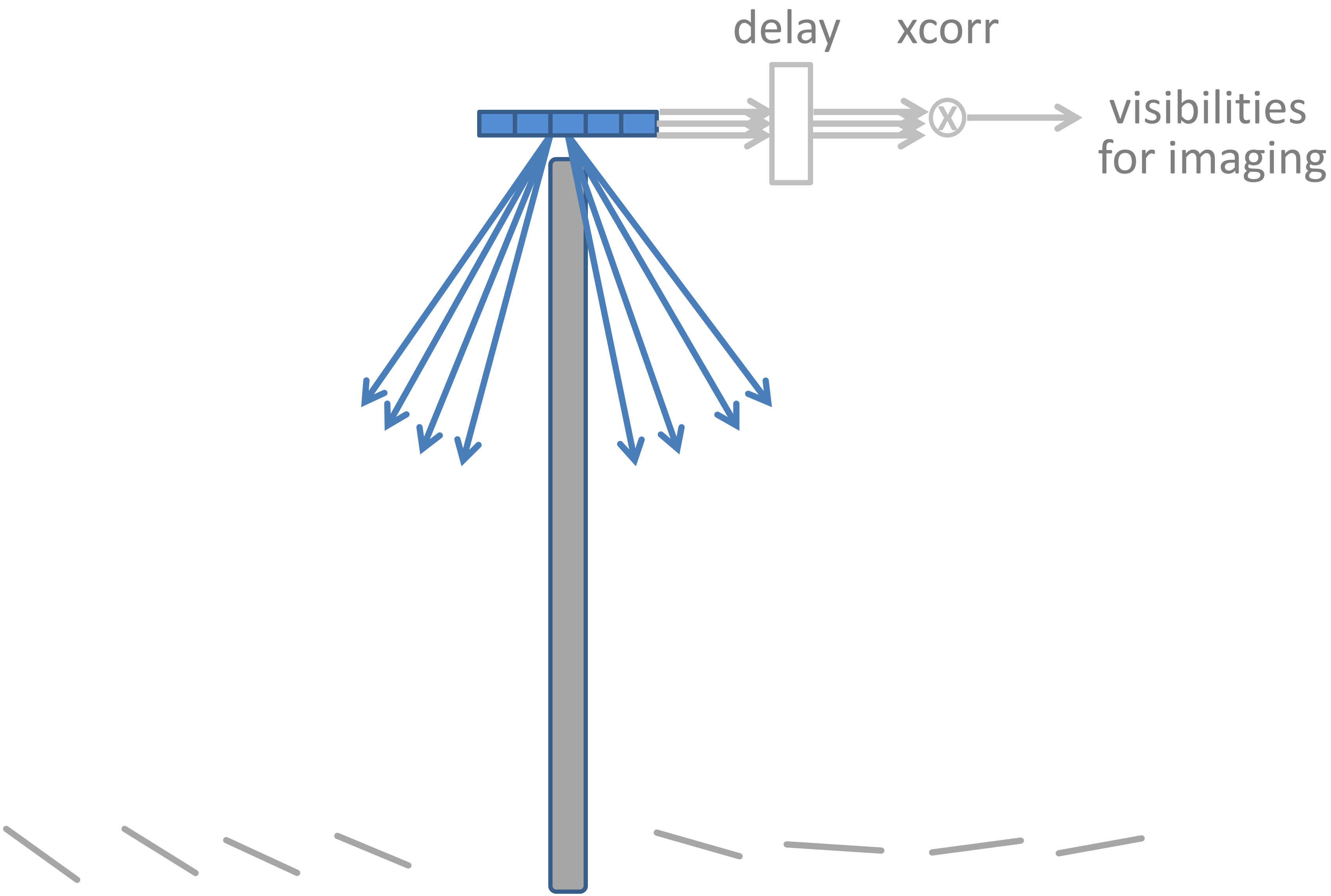
Synthesized beams across FoV: 120

Synthesized beams tiling the FoV: ~ 120 x 120
~ 14000

PAF cost scaled from APERTIF:

Area = 12 m x 12 m = 110 m^2
APERTIF: 250 kEUR for 1 m^2
-> 25 MEUR (upper limit since DSP costs dropping)

Beamform Towards Mirrors, Digital Delay?



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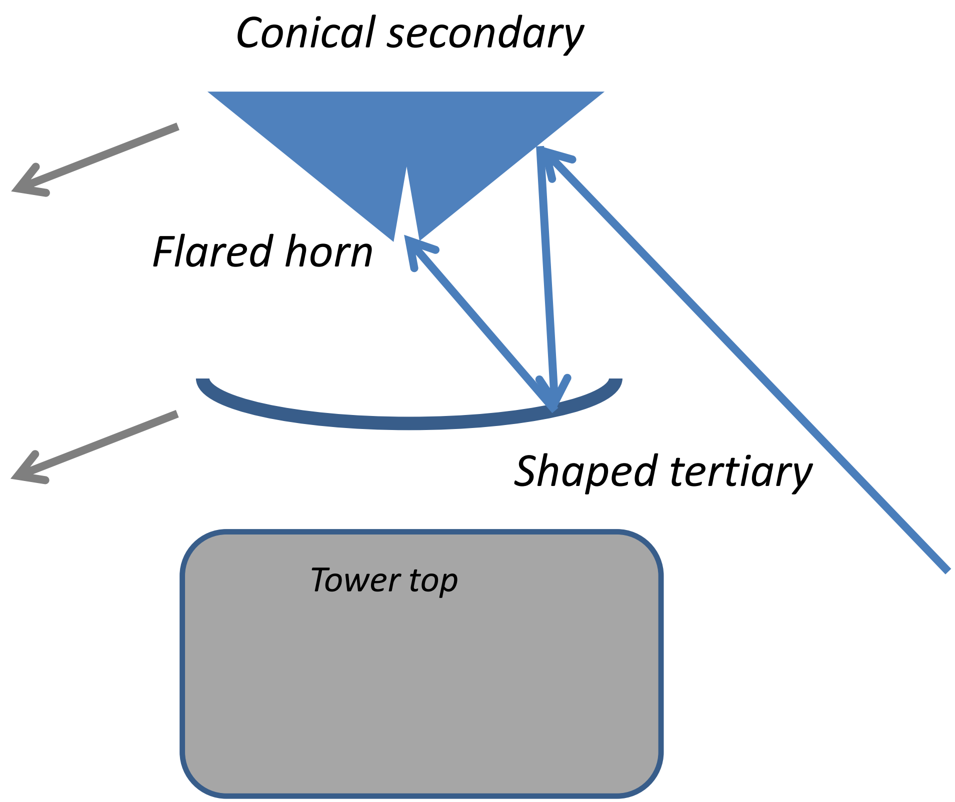
Single Element? Concentrating Optics like RATAN 600

RATAN 600 secondary
www.sao.ru



(Pointed out by Dave Graham)

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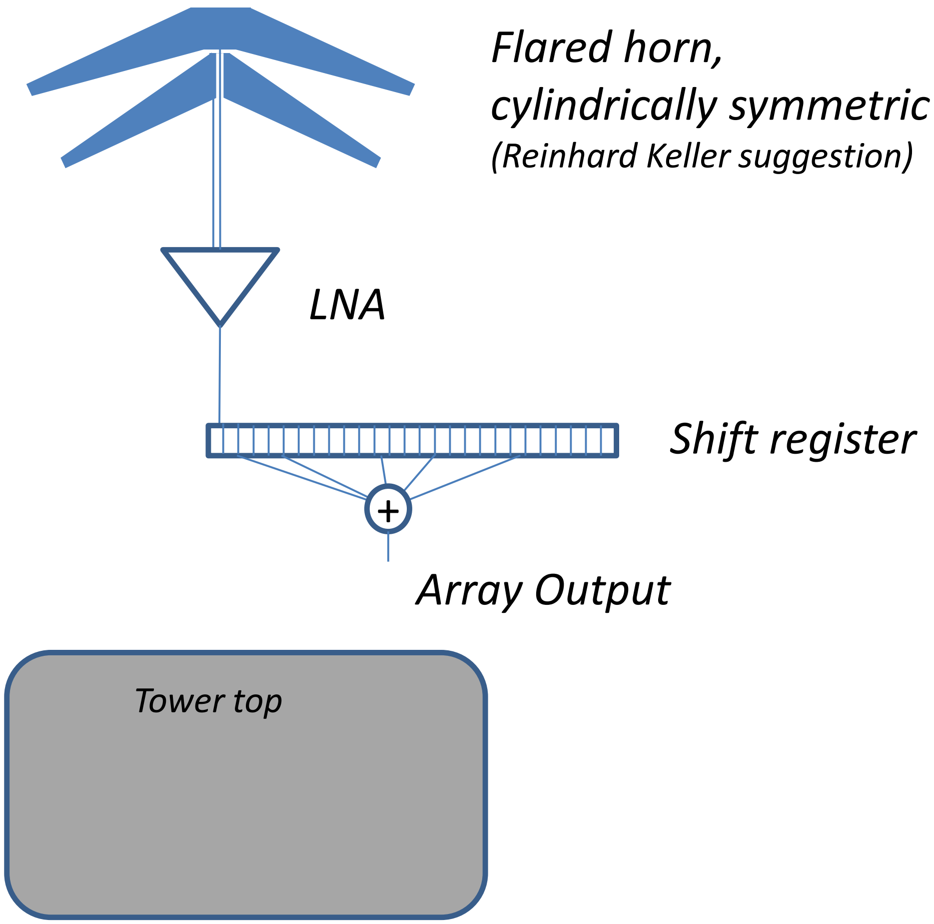
RAKE Receiver: Horn, Receiver, Processing



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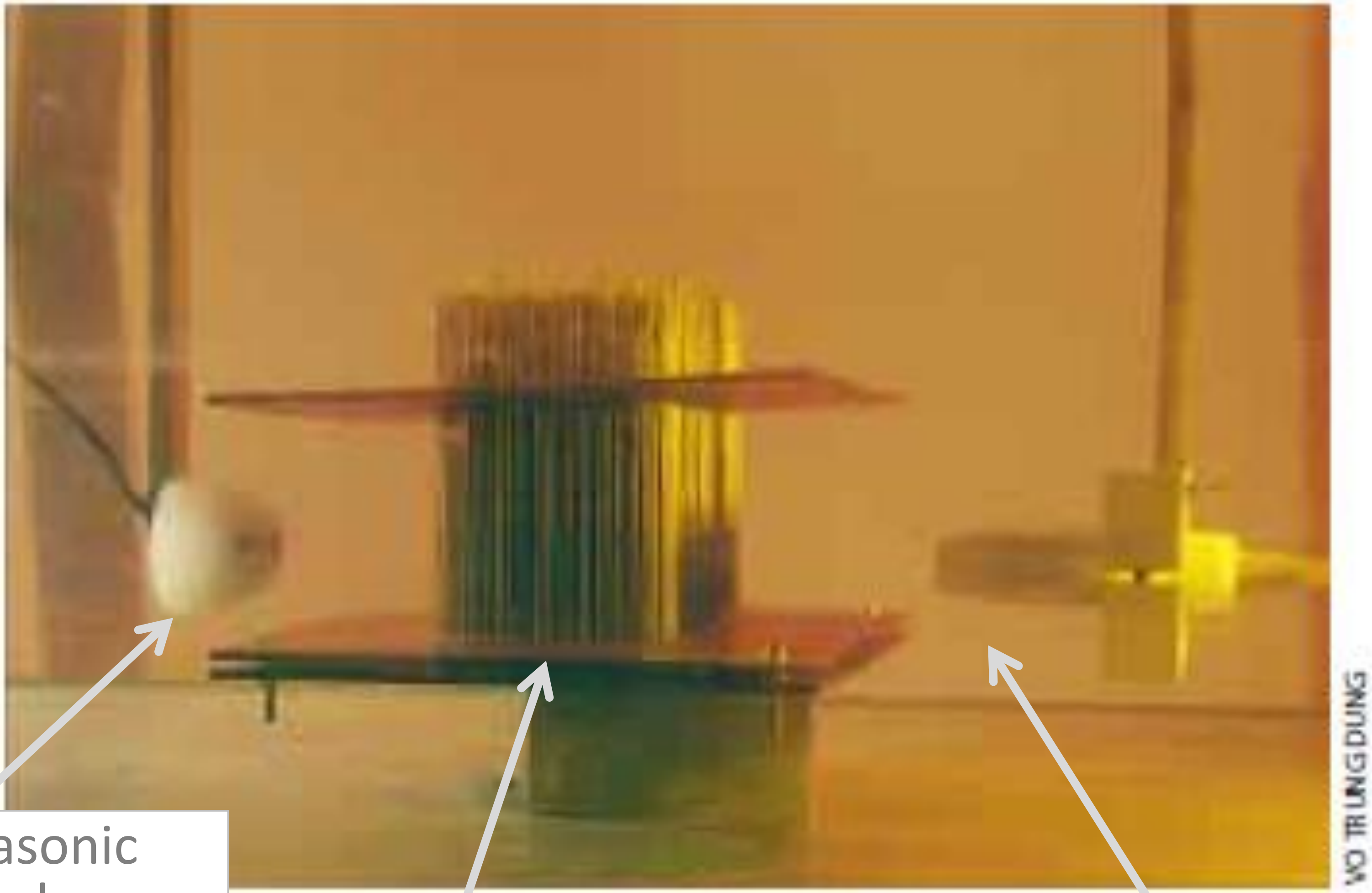
Time-Domain Reconstruction: Acoustic Chaotic Pinball

Fink 1999 Scientific American

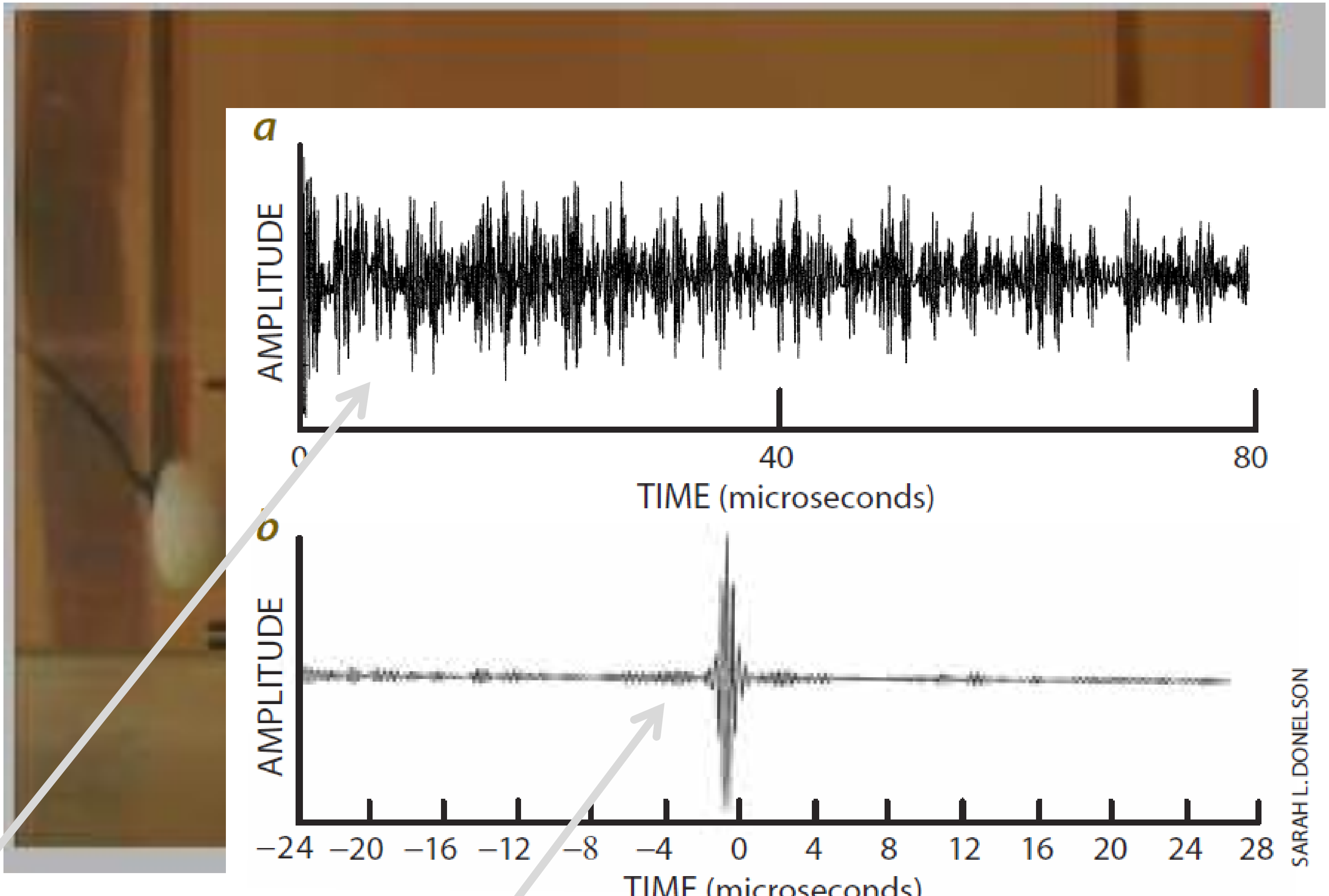


Ultrasonic transducer emits 1 μs pulse
(eg pulsar)

2000 randomly placed steel rods cause scattering
(eg Gemasolar mirror field)

96 element transducer array
(eg focal plane array)

Time-Domain Reconstruction: Acoustic Chaotic Pinball



Fink 1999 Scientific American

Signal received on one array element >> 1 µs

Pulse arriving back at transmitter after time-reversed play-back from array

The RAKE Receiver in Mobile Phones (2G upward)

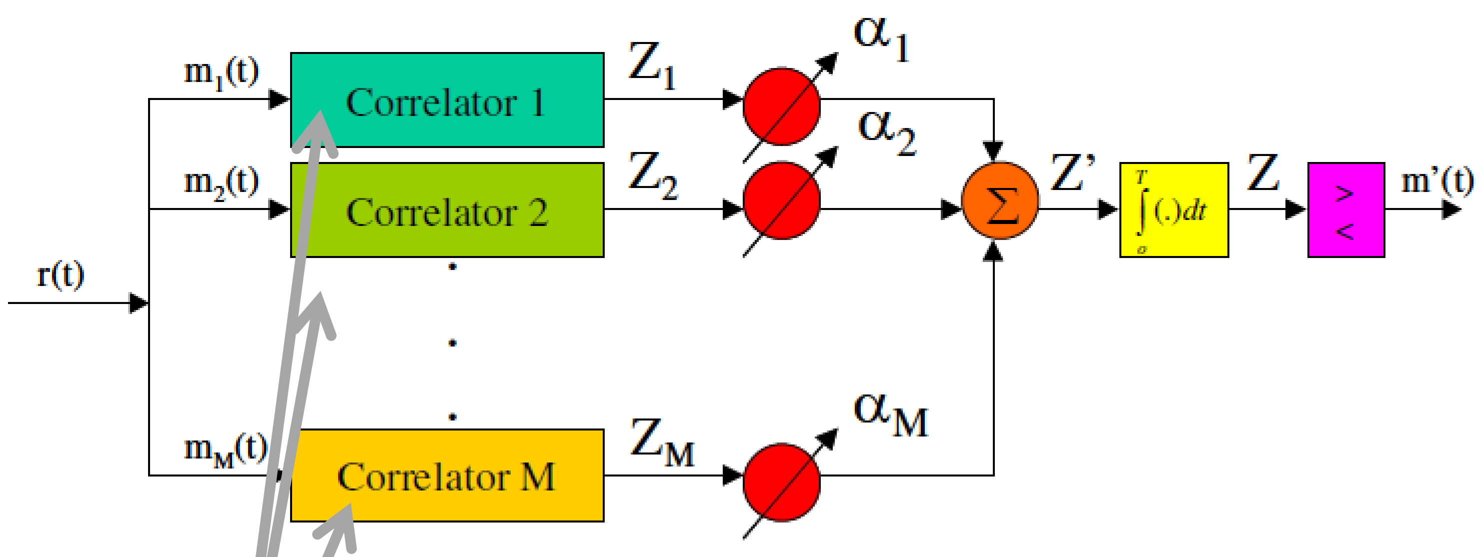


Figure 3. An M-branch RAKE receiver implementation

Each correlator detects a time-shifted version of the signal by shifting the code in each correlator

Source: Tommi Heikkilä (TeliaSonera AB) 2004 “RAKE Receiver” from “Postgraduate Course in Radio Communications, Autum 2004”, Aalto University

The RAKE Receiver in Mobile Phones (2G upward)

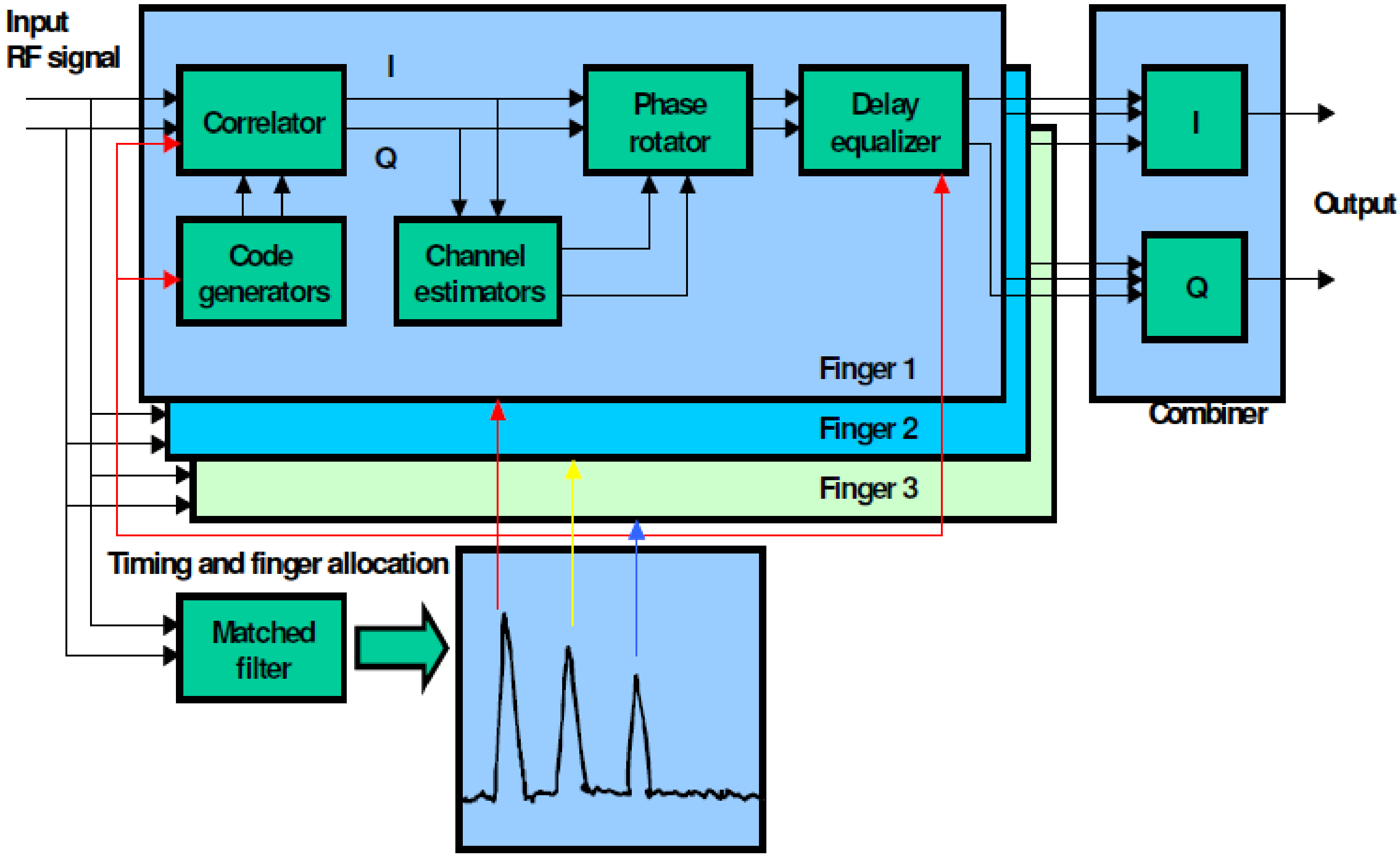


Figure 4. Block diagram of a RAKE receiver

Source: Tommi Heikkilä (TeliaSonera AB) 2004 "RAKE Receiver"
from "Postgraduate Course in Radio Communications, Autum 2004", Aalto University

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The RAKE Receiver Patent

Price & Green 1956 (MIT Lincoln Lab),

Anti-Multipath Receiving System

US Patent 2982853 A

<snip>

the signal arriving over each path is detected individually. All detected signals are then added after weighting by a factor maximizing the signal to noise ratio of the sum.

<snip>

multipath produces at different frequencies regions of signal reinforcement and cancellation. The wide band technique described here has the effect of making greater use of the frequencies having greater response while attenuating the receiver response at others.

<snip>

if the signals detected from each path are individually delayed by the proper amount, all signals can be made to arrive at the addition point at the same time. Then the propagation from transmitter to receiver output consists effectively of a single strong path rather than a succession of weaker paths.

<snip>

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Sensitivity Comparison with SKA

	Area	Frequency	Tsys	Aeff / Tsys
SKA1-survey	14 674 m^2	350 to 4000 MHz	30 K	391 m^2/K
SKA1-mid	42 737 m^2	580 to 1670 MHz (8000 to 13800 MHz)	25 K	1 390 m^2/K
SKA2	350 000 m^2	200 to 2000 MHz	25 K (?)	10 000 m^2/K
Gemasolar	305 000 m^2	800 to 14000 MHz (?)	100 K (?)	3 050 m^2/K

SKA Data: “SKA1 System Baseline Design” P Dewdney 2013

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Existing Solar Power Towers: PS10, PS20

Location:	Seville, Spain
Capacity:	10 MW (PS10) / 20 MW (PS20)
Area:	**305 m** (PS10) / **440 m** (PS20) diameter single dish
Heliostats:	610 (PS10) / 1255 (PS20) each 120 m^2
Tower height:	165 m
Construction:	2005-2007 (PS10) / 2006-2009 (PS20)

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Existing Solar Power Towers: Crescent Dunes

Location:	Nevada, USA (310 km NW from Las Vegas)
Capacity:	110 MW
Area:	1 092 000 m^2 = **1180 m** diameter single dish
Heliostats:	17 500 each 62.4 m^2

Future Solar Power Towers: Khi Solar One

www.abengoasolar.com

Location:	Northern Cape area, South Africa
Capacity:	50 MW
Area:	576 800 m^2 = **850 m** diameter single dish
Heliostats:	4120 each 140 m^2
Tower height:	205 m
Construction:	Nov 2012 – Sep 2015
Project:	Abengoa (Spain), development on PS10 and PS20 in Spain
Note by Abengoa:	SA Govt plans 20 % energy from renewables by 2032

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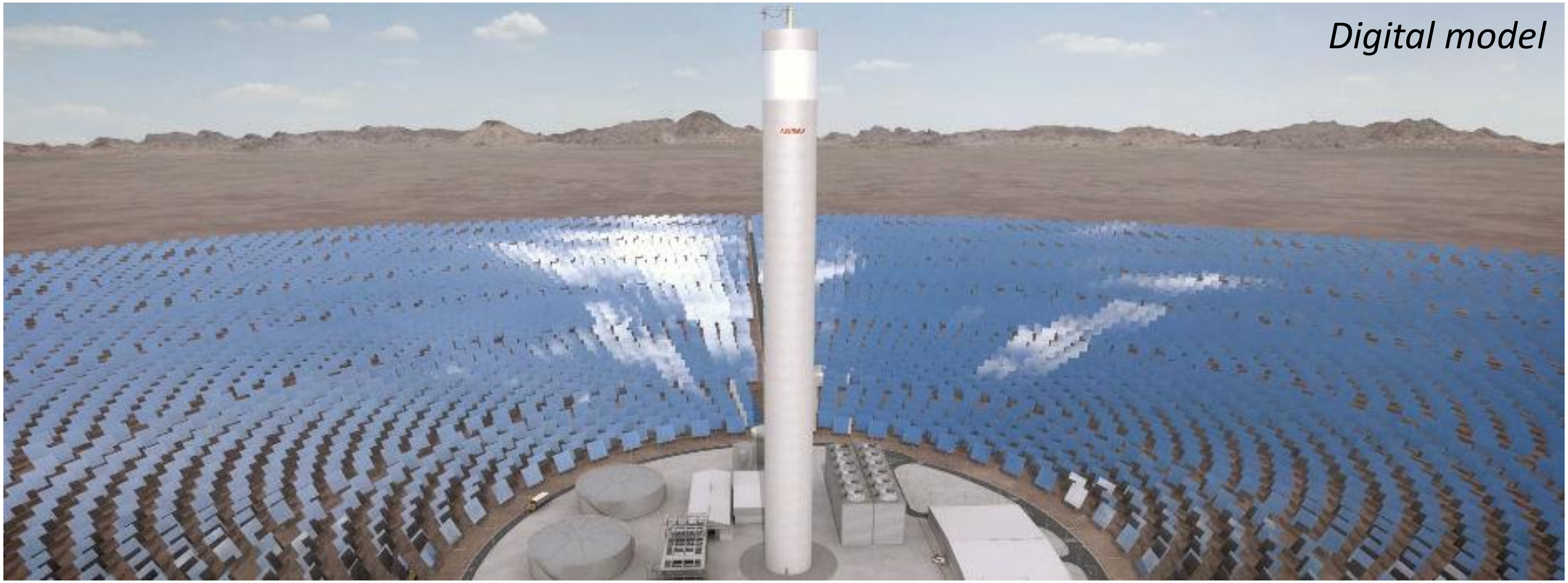
Future Solar Power Towers: Atacama-1(?)



Location:	Comune de María Elena, Antofagasta Region, Chile
Capacity:	110 MW
Area:	1 484 000 m^2 = **1375 m** diameter single dish
Heliostats:	10 600 each 140 m^2
Tower height:	250 m
Construction:	Q3 2014 – 2017 (2015 Oct: on hold due to fall in copper demand)
Project:	Abengoa (Spain)

www.abengoasolar.com

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Existing Solar Power Towers: Ivanpah

Location:	Nevada, USA (75 km SW from Las Vegas)
Capacity:	392 MW
Area:	2 602 500 m^2 = **1820 m** diameter single dish
Heliostats:	173 500 each 15 m^2
Tower height:	140 m
Construction:	Oct 2010 - Feb 2014 complete online, cost 2.2 billion USD

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Solar Power Towers

Power Tower Projects

Concentrating solar power (CSP) projects that use power tower systems are listed below—alphabetically by project name. You can browse a project profile by clicking on the project name. You can also find related information on power tower principles and research and development.

- ACME Solar Tower
- Ashalim Plot B (Megalim)
- Atacama-1
- Crescent Dunes Solar Energy Project (Tonopah)
- Dahan Power Plant
- Gemasolar Thermosolar Plant (Gemasolar)
- Greenway CSP Mersin Tower Plant
- Ivanpah Solar Electric Generating System (ISEGS)
- Jemalong Solar Thermal Station
- Jülich Solar Tower
- Khi Solar One
- Lake Cargelligo
- NOOR III
- Palen Solar Electric Generating System
- Planta Solar 10 (PS10)
- Planta Solar 20 (PS20)
- Qinghai Delingha Solar Thermal Generation Project
- Redstone Solar Thermal Power Plant
- Rice Solar Energy Project (RSEP)
- Sierra SunTower (Sierra)
- Supcon Solar Project

2015: 11 stations operating
area = **4.3 km²**

2018: 21 stations operating
area = **11.7 km²**

2032: South Africa + Chile: 20 % energy from renewables.

http://www.nrel.gov/csp/solarpaces/power_tower.cfm

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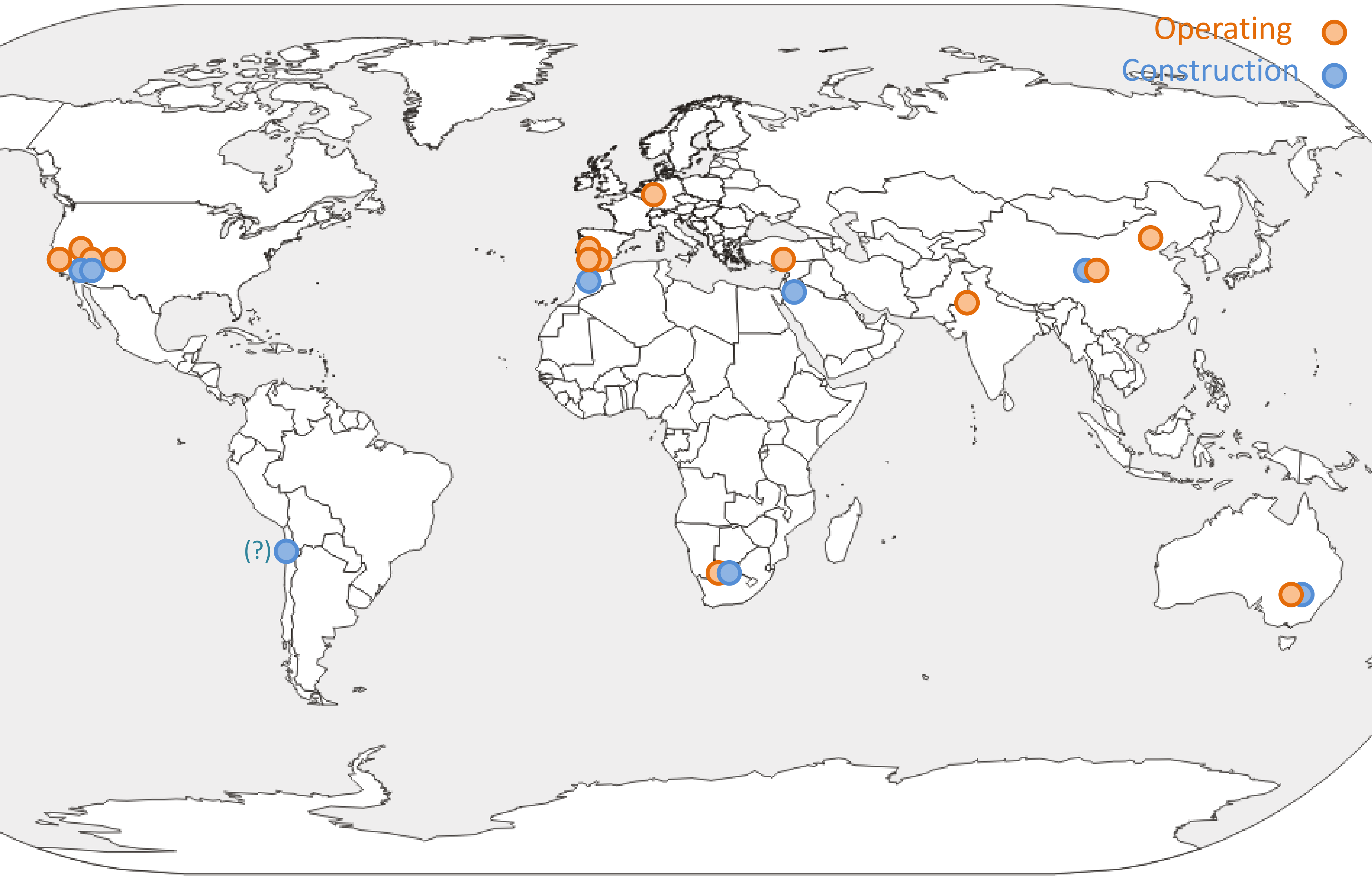
Solar Power Towers



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Research Facility: National Solar Thermal Test Facility

Location:	Albuquerque, NM (Kirtland AFB)
Area:	7850 m^2 = **100 m** diameter single dish
Heliostats:	218 each 36 m^2
Owners:	Dept of Energy, operated by Sandia Labs
Purpose:	Research (solar, astronomy, etc)
User fees:	500 USD/8 h day for solar field use

http://energy.sandia.gov/energy/renewable-energy/solar-energy/csp2/nsttf

Research Facility: National Solar Thermal Test Facility

STACEE

Air Cherenkov detector

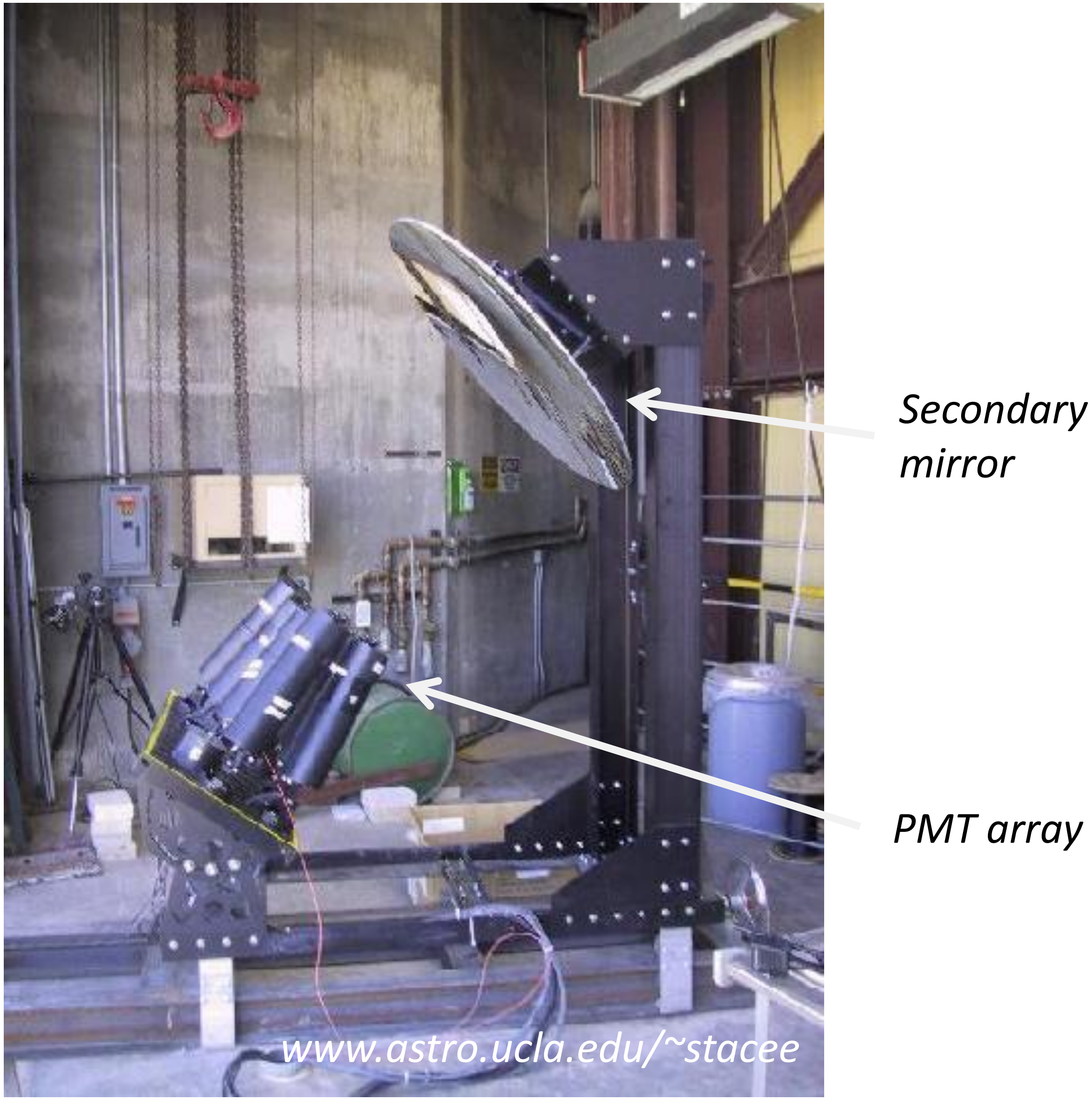
γ-rays 130 – 2000 GeV

U. Alberta, UCLA, UC Santa Cruz, Case Western, Columbia U., McGill U.

2001-2007 observations

Detected Crab, Mrk 421, Light curves, spectra

Replaced by VERITAS, MAGIC



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Research Facility: Jülich Solar Tower

Capacity:	1.5 MW
Area:	17 650 m^2 = **150 m** diameter single dish
Heliostats:	2153 each 8.2 m^2
Tower height:	60 m
Construction:	2007-2008
Owners:	DLR, Uni Aachen

Research Facility: Jülich Solar Tower

1.5 MW heat exchanger for power production

Mispointed mirrors show focal area of a mirror

Experiment platform 500 kW

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Research Facility: Jülich Solar Tower

View from experiment platform shows high mirror covering factor and subtended angle – good for illumination with conventional feed horn.