Simulating Dappled Daylight Patterns with Radiance

RADIANCE WORKSHOP 2023

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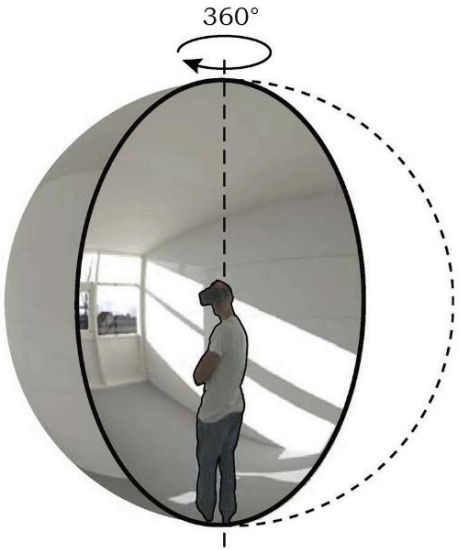
Dr. A. de Vries

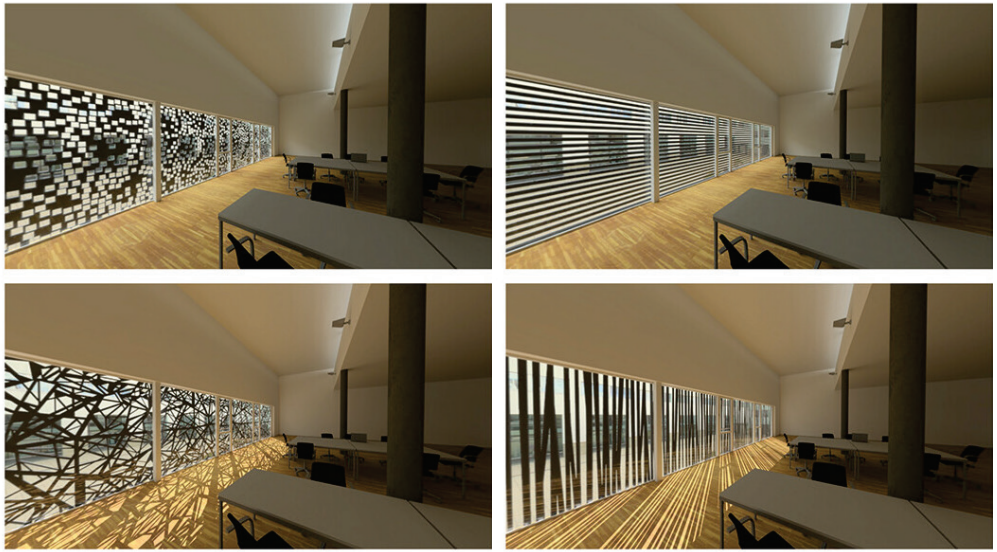
Building Lighting Group

EINDHOVEN ENGINE
signify
TU/e EINDHOVEN UNIVERSITY OF TECHNOLOGY

Immersive virtual reality for perception studies

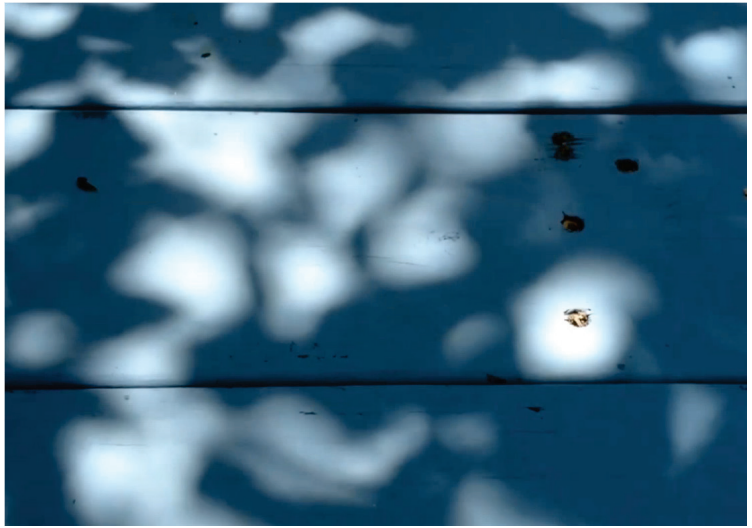


(Chamilothori et al., 2019)



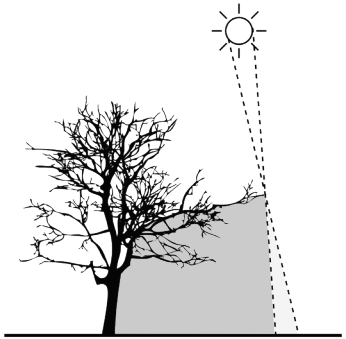
(Chamilothori et al., 2022)

Dappled light

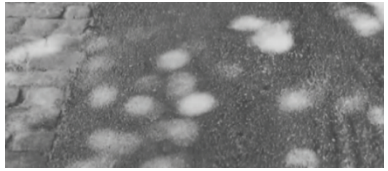


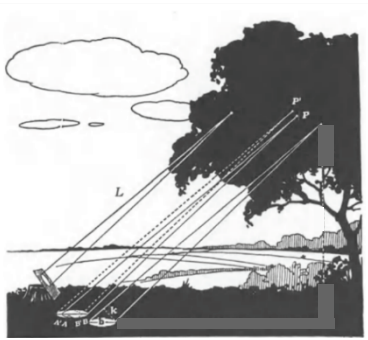
Jodi Verser 2015, Vimeo.com

Solar penumbras



Solar pinhole projections





(Minnaert & Seymour, 1993)

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Can Radiance accurately simulate dappled light?

- Photometrically correct ('matching real-life')
  - Penumbras
  - Pinhole projections

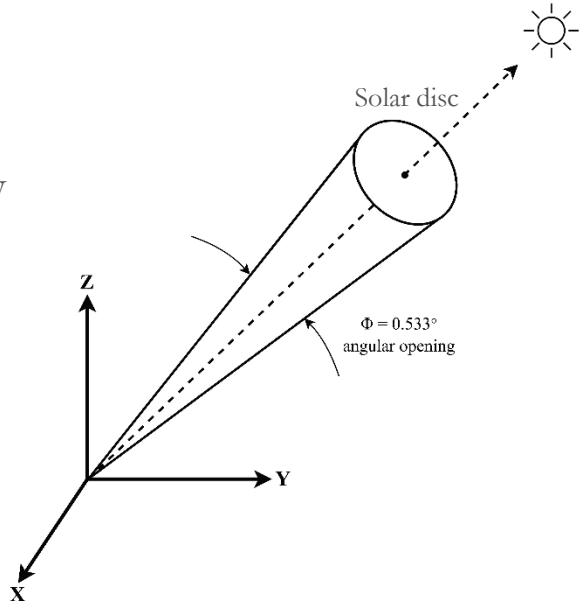
- Investigate dimensions & relative luminances

- **Develop methods to simulate solar penumbras and pinhole projections**
- **Compare simulations to real-life measurement data on solar penumbras and pinhole projections**

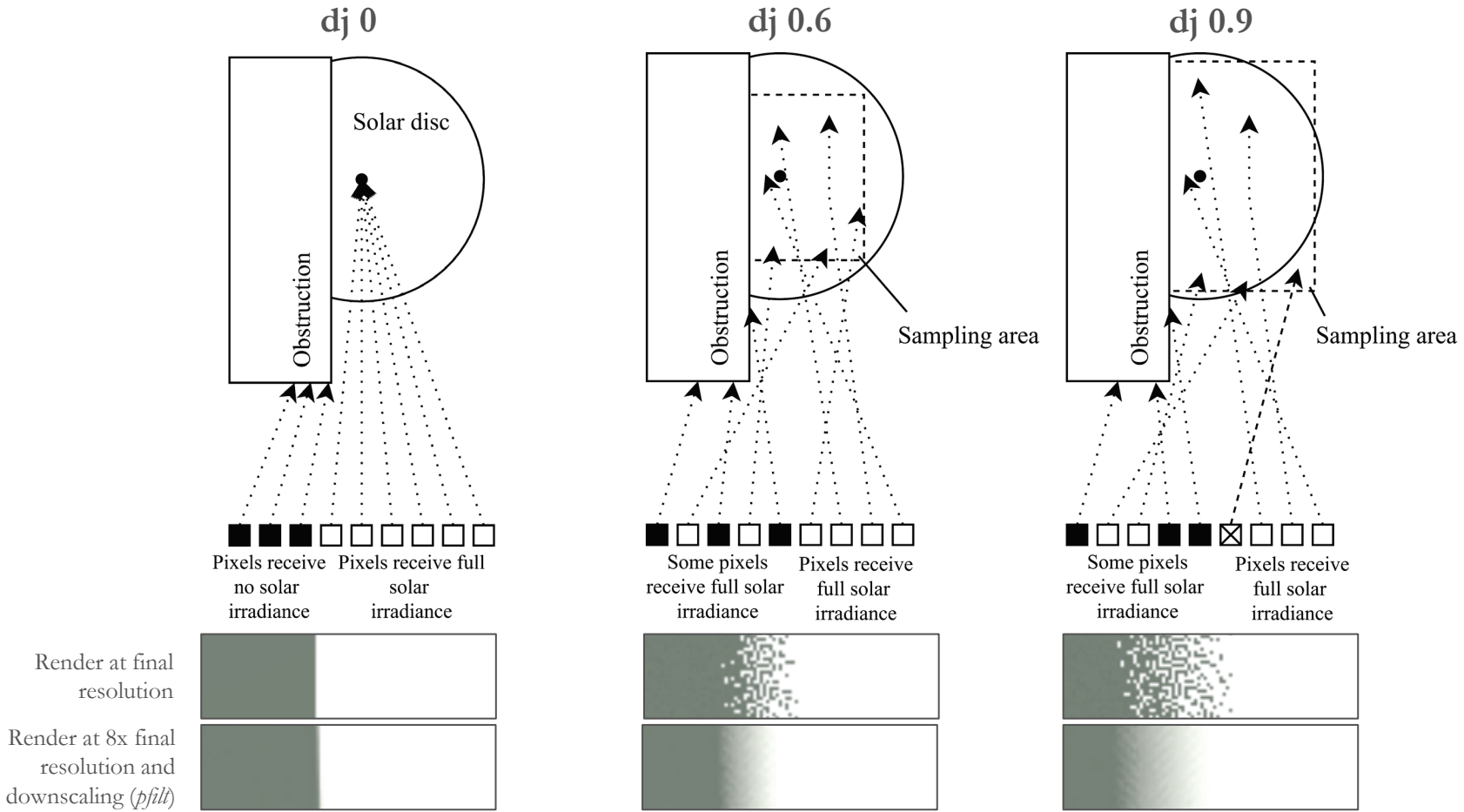
Simulating sunlight

- The sun is modeled as a direction and solid angle
- Angular light sources (*the sun)* are sampled by a single ray

- Smooth penumbras by combining
  - Direct jittering (-dj)
  - Rendering at a much higher resolution and downscaling (*pfilt*)



Adapted from Mardaljevic (2000)



For illustrative purposes only. Since Radiance 4.0, setting dj to 1 does activate sampling over a circle. See 'Radiance 4.0 Improvements' by Greg Ward at Radiance Workshop 2009 Boston for more information.

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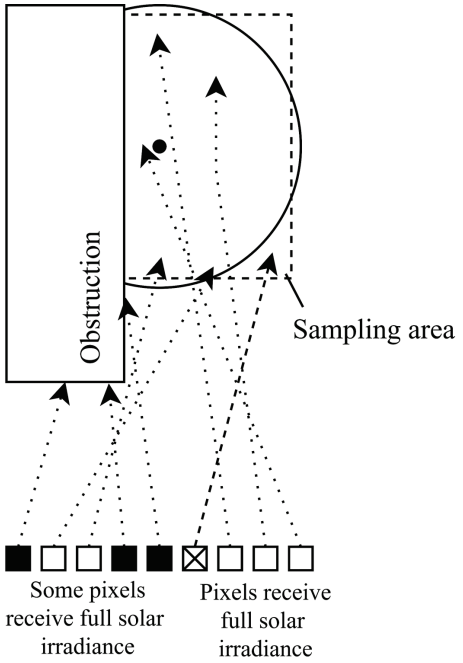
Possible problems of using direct jittering (-dj)

- Rays are jittered randomly
- Renders need to be made at a (very) high resolution

- Rays are jittered over a square, not a circle (solar disc) for dj settings lower than 1



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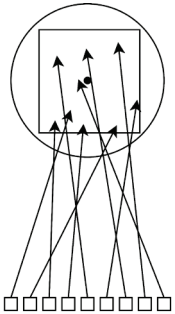
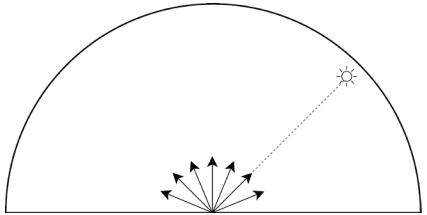
Approaches for simulating penumbras and pinhole projections

Direct jittering and downscaling

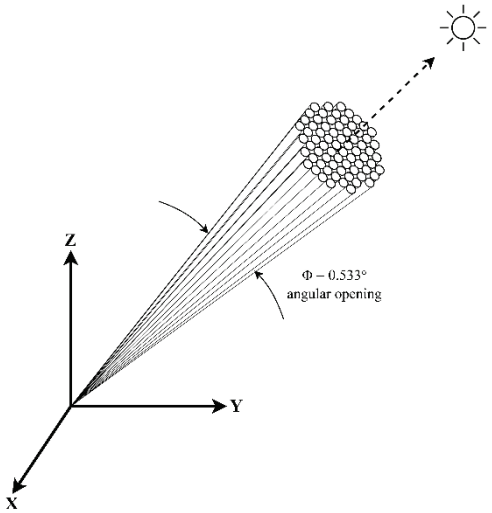


Stochastic calculation

(sun as *glow*)



Many suns



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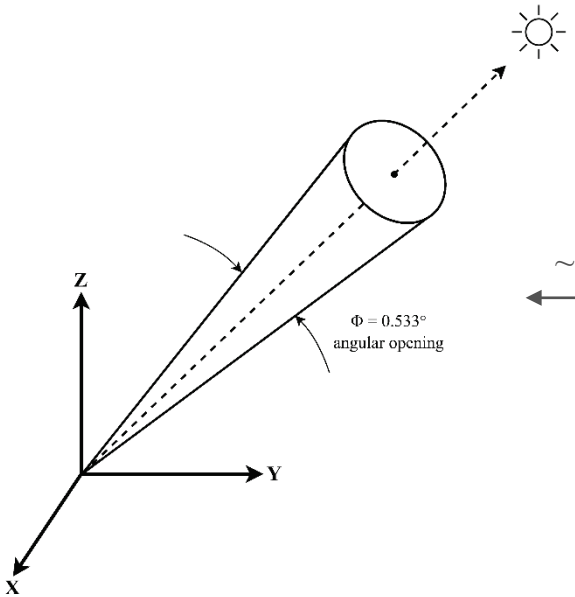
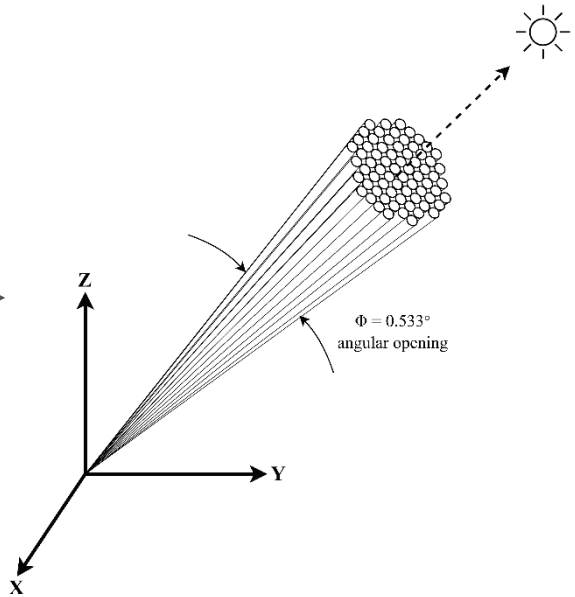
Creating many suns (stencil method)



~ Equal irradiance

(~ Solid angle)



1 light modifier description
1 direction vector + angular opening

1 light modifier description
>500 direction vectors + angular openings

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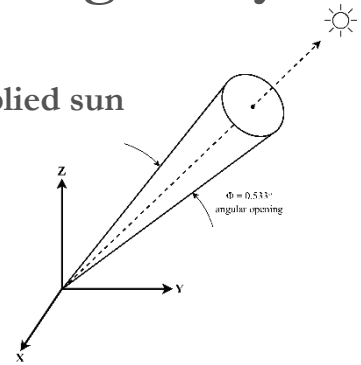
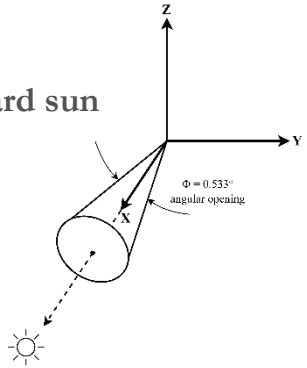
Creating many suns (stencil method)

Supplied sun



Standard sun



typical_sun_description.rad

```
void light solar
0
0
3 5.304e+06 5.304e+06 5.304e+06

solar source sun
0
0
4 0.038123 -0.951374 0.305669 0.533000
```

Radiance (RGB)

Altitude and Azimuth

Direction vector (XYZ)

001-sun.rad

```
void light solar
0
0
3 5.304e+06 5.304e+06 5.304e+06

solar source sun
0
0
4 1 0 0 0.533000
```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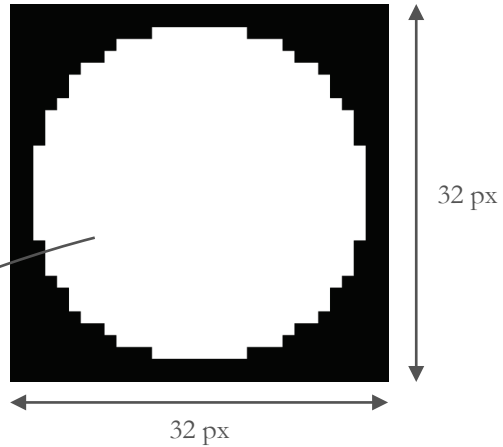
Creating many suns (stencil method)

HDR of standard sun (*pdim =32*)



Generate HDR of standard sun

```
oconv 001-sun.rad > 001-sun.oct

rpict -vf x.vf -x pdim -y pdim -pj 0 -ps 1 001-sun.oct >
standard_sun.hdr
```

Generate direction vectors for every (non-zero brightness) pixel

```
rlam  "!vwrays standard_sun.hdr | rtrace -h -w -od 001-sun.oct"
"!pvalue -h -H -d -b" standard_sun.hdr | rcalc  -e
"$1=$1;$2=$2;$3=$3;cond=$4-1" > 32-sun.vec
```

32-sun.vec

0.9999896	0.00114537	0.004417858
0.9999899	0.00081812	0.004417862
0.9999901	0.00049081	0.004417861
0.9999902	0.00016325	0.004417861
0.9999902	0.00016325	0.004417861

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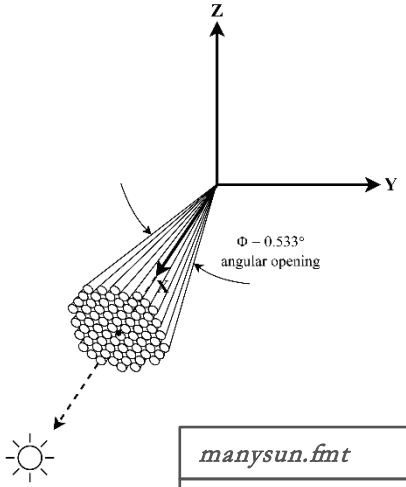
Creating many suns (stencil method)



Arbitrary Radiance value

32-sun.rad

```
void light minisolar
0
0
3 1E4 1E4 1E4

!rcalc -e "x1=$1;y1=$2;z1=$3" -o manysun.fmt 32-sun.vec
```

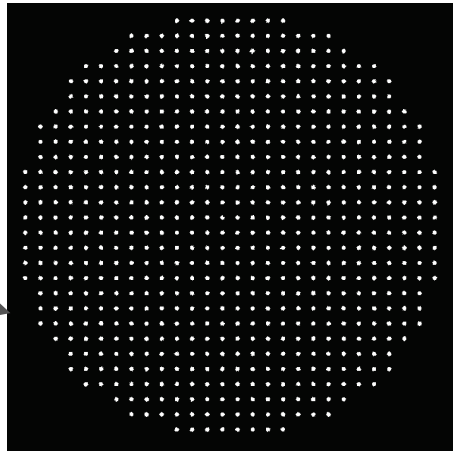
manysun.fmt

```
minisolar source sun.${recno}
0
0
4 ${ x1 } ${ y1 } ${ z1 } 0.00533
```

32-sun.vec

```
0.9999896   0.00114537  0.004417858
0.9999899   0.00081812  0.004417862
0.9999901   0.00049081  0.004417861
0.9999902   0.00016325  0.004417861
0.9999902   0.00016325  0.004417861
```

Rvu 32-sun.rad



Resulting in 632 suns

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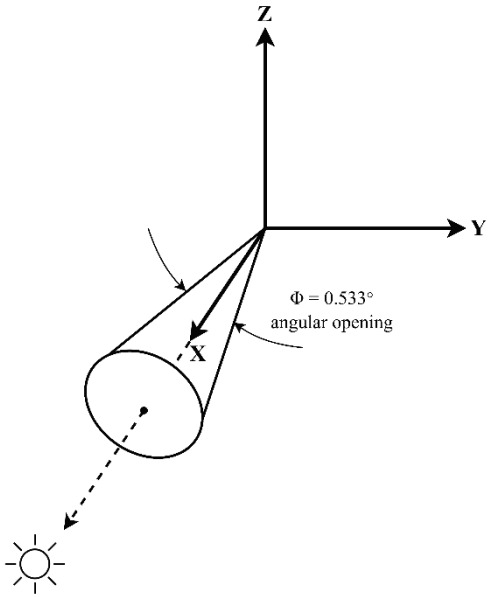
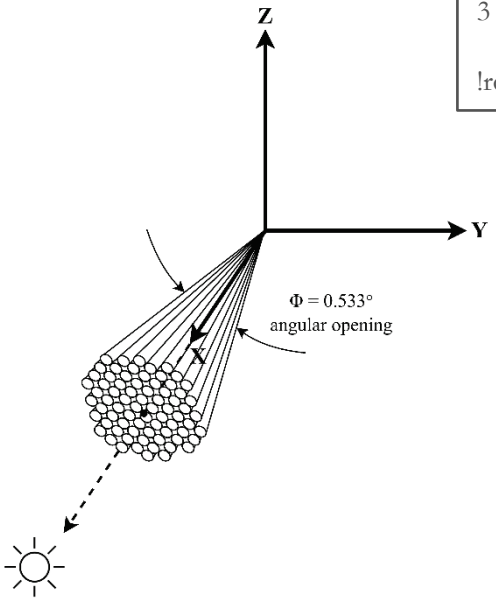
Creating many suns (stencil method)

Set ~ equal irradiance



Irradiance of standard sun
at (0,0,0 1,0,0) = **a**



Irradiance of 632 suns
at (0,0,0 1,0,0) = **b**

32-sun.rad

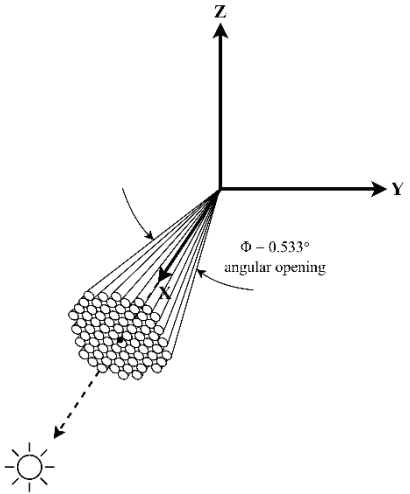
```
void light minisolar
0
0
3 1E4*a/b  1E4 *a/b 1E4 *a/b

!rcalc -e "x1=$1;y1=$2;z1=$3" -o manysun.fmt 32-sun.vec
```


Signify TU/e

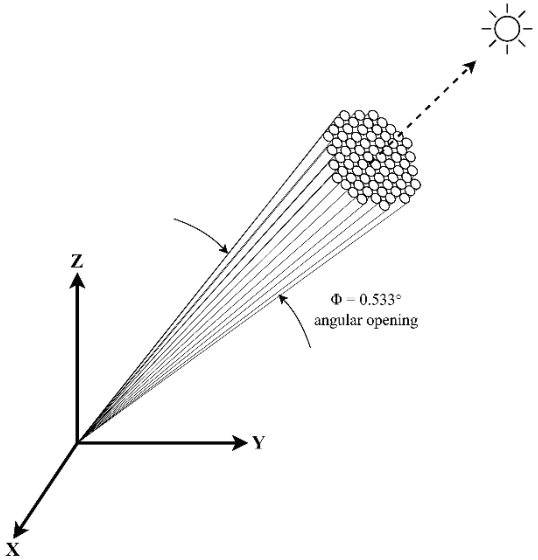
Creating many suns (stencil method)

Set ~ equal solid angle



Altitude and Azimuth

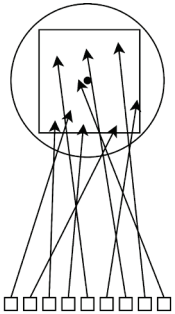
`xform -ry altitude -rz azimuth`



signify TU/e

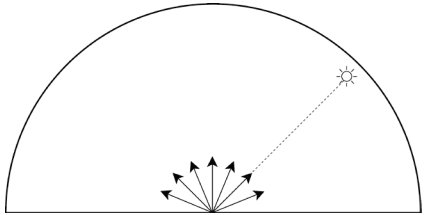
Approaches for simulating penumbras and pinhole projections

Direct jittering and downscaling

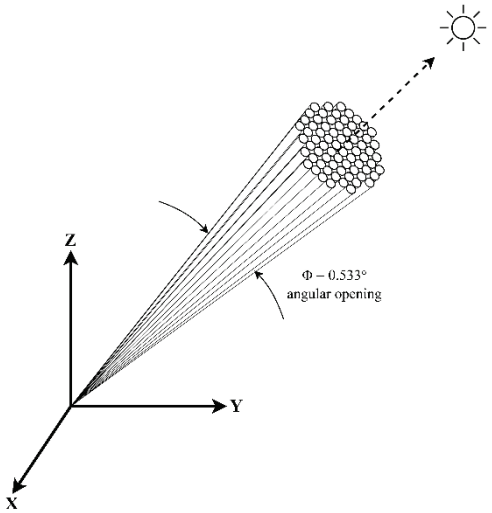


Stochastic calculation

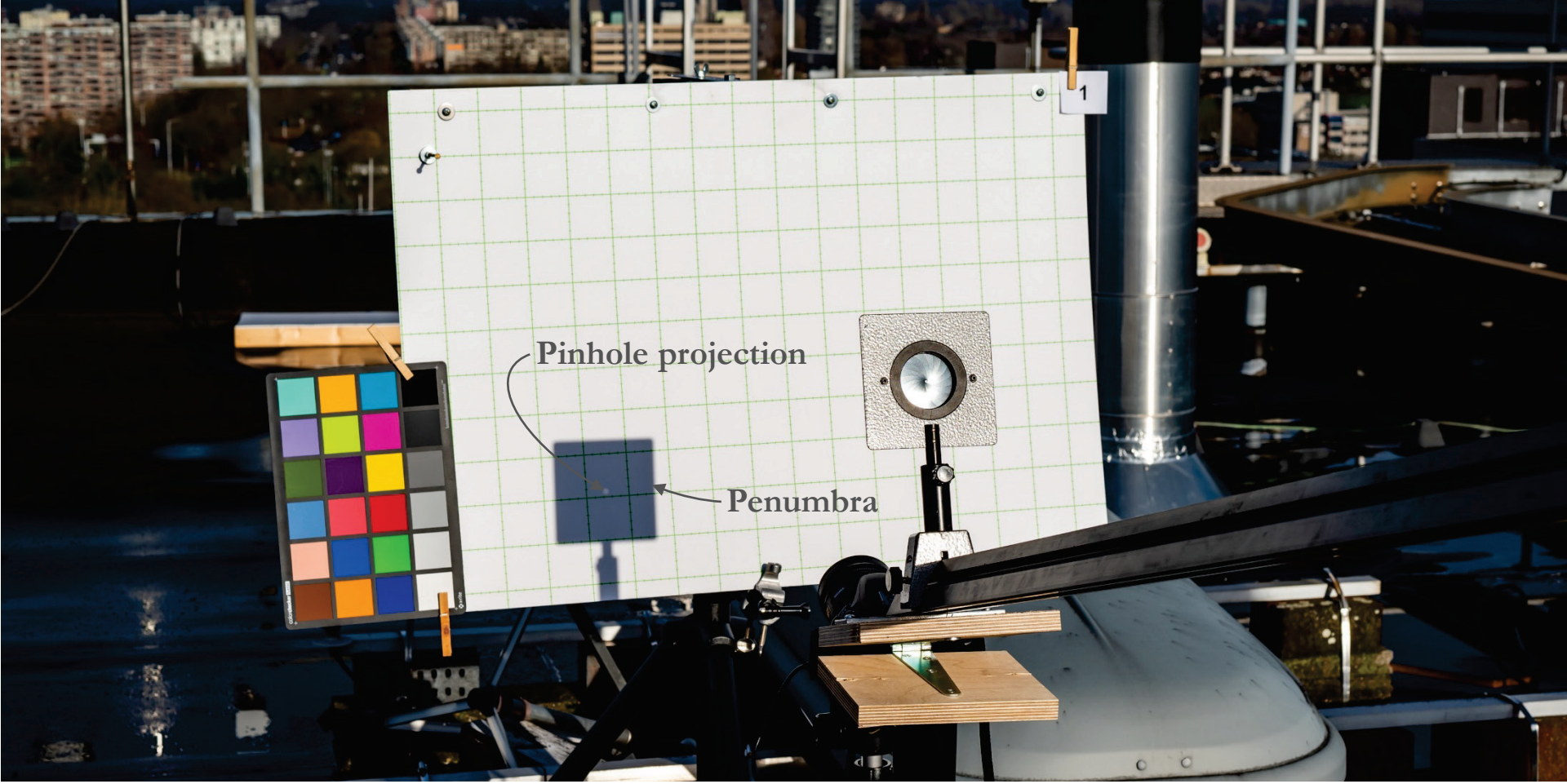
(sun as *glow*)



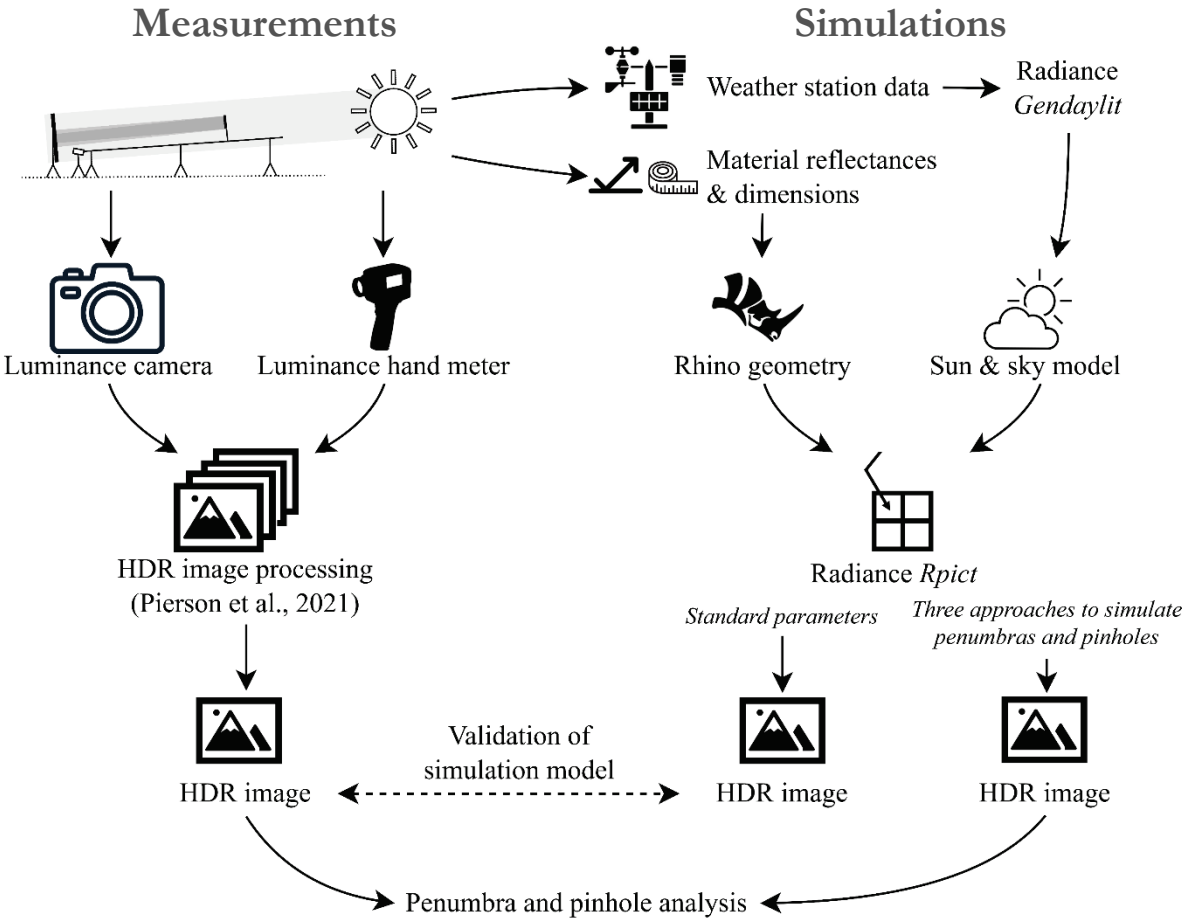
Many suns



signify TU/e


Pinhole projection
Penumbra
1

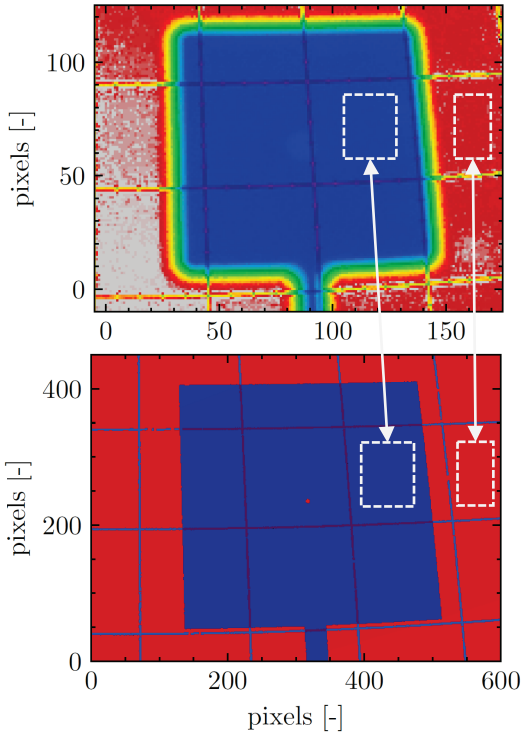

Slidable opaque plate
Luminance meter
Luminance camera
Projection surface

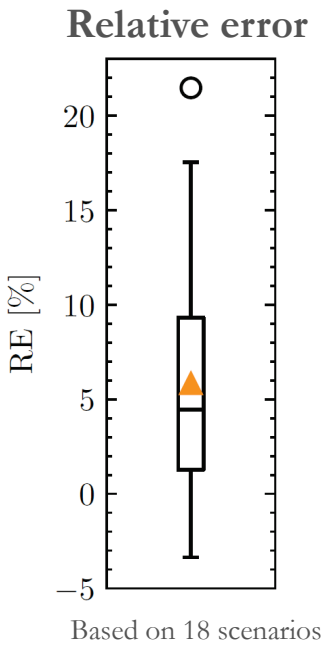

Measurements
Simulations
Weather station data
Radiance
Gendaylit
Material reflectances
& dimensions
Luminance camera
Luminance hand meter
Rhino geometry
Sun & sky model
HDR image processing
(Pierson et al., 2021)
Radiance Rpict
Standard parameters
Three approaches to simulate
penumbras and pinholes
HDR image
Validation of
simulation model
HDR image
HDR image
Penumbra and pinhole analysis

Validation of the simulation model

Measured HDR image

Simulated HDR image





Based on 18 scenarios

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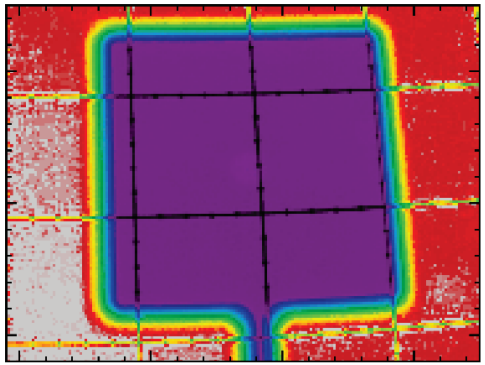
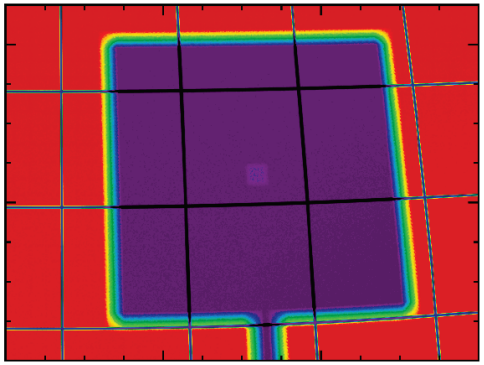
Penumbras

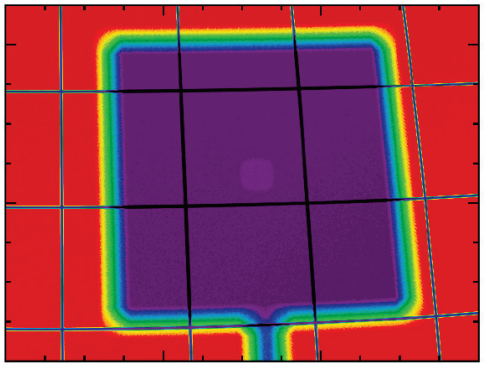
Measurement

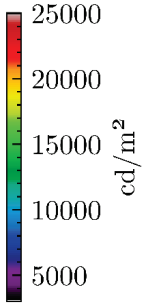


dj 0.6 and 8x downscaling

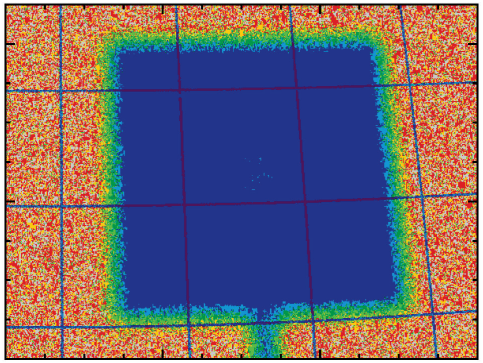


dj 0.9 and 8x downscaling

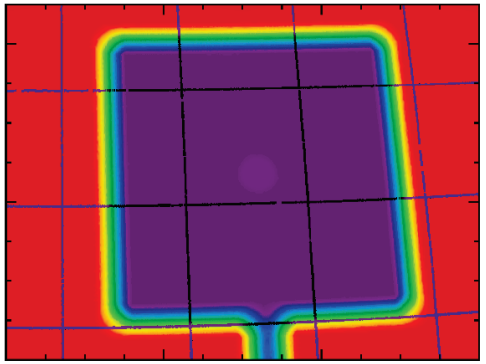




Stochastic calculation



Many (632) suns



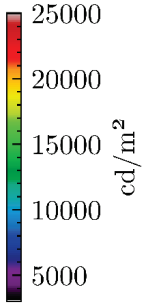


Plate at 160 centimeter from projection surface

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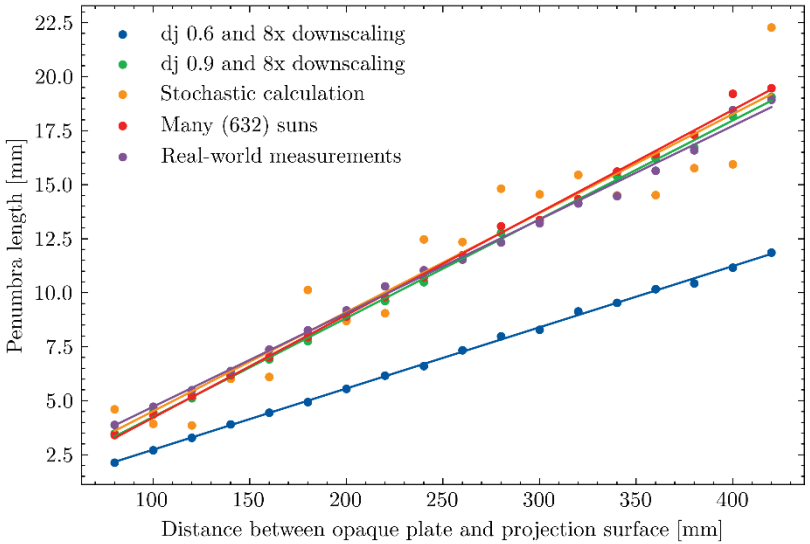
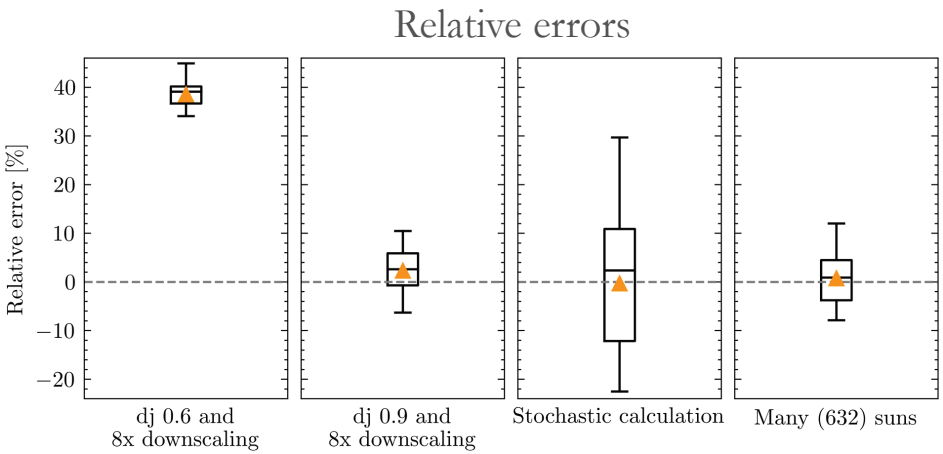
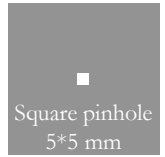
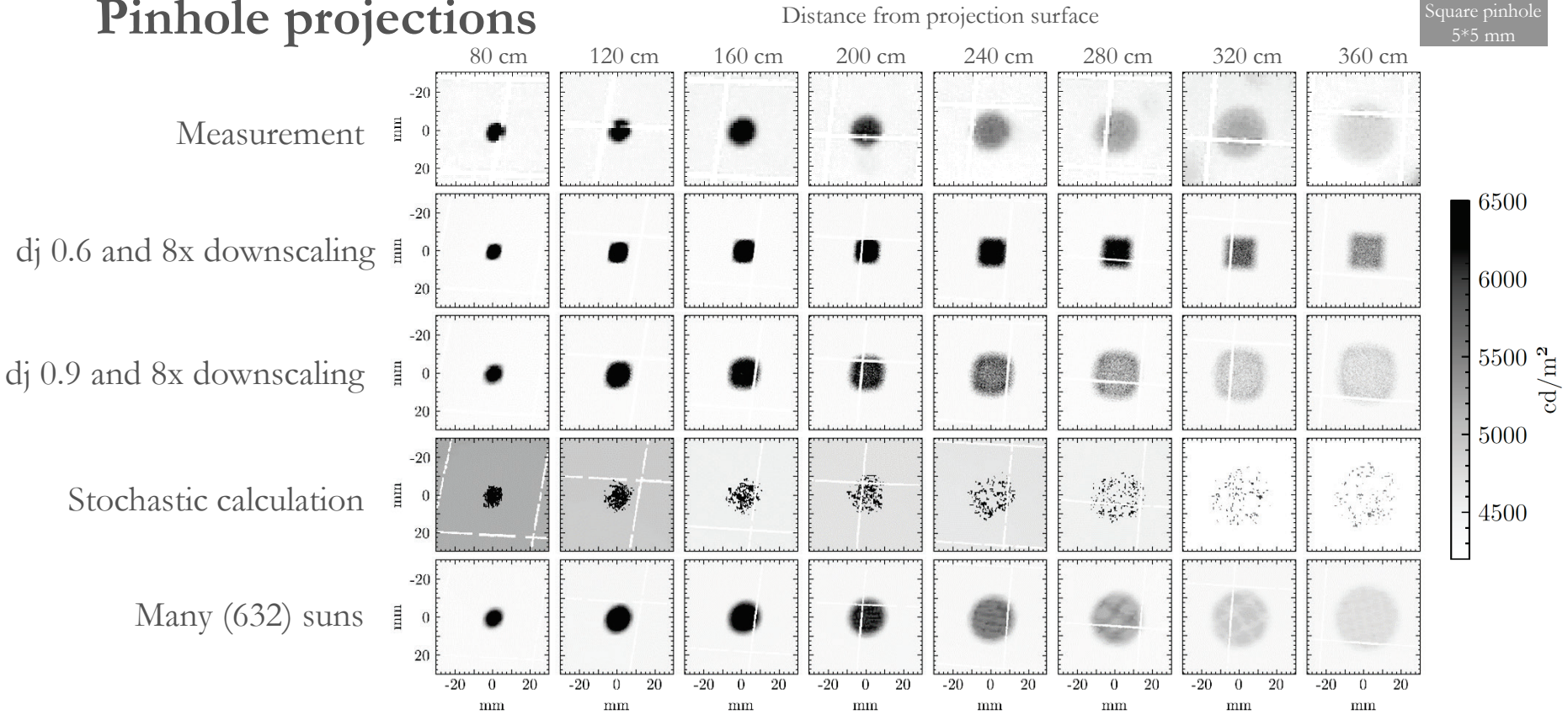
Penumbras


dj 0.6 and 8x downscaling
dj 0.9 and 8x downscaling
Stochastic calculation
Many (632) suns
Real-world measurements
Penumbra length [mm]
Distance between opaque plate and projection surface [mm]
22.5
20.0
17.5
15.0
12.5
10.0
7.5
5.0
2.5
100
150
200
250
300
350
400


Relative errors
Relative error [%]
40
30
20
10
0
−10
−20
dj 0.6 and
8x downscaling
dj 0.9 and
8x downscaling
Stochastic calculation
Many (632) suns

Pinhole projections





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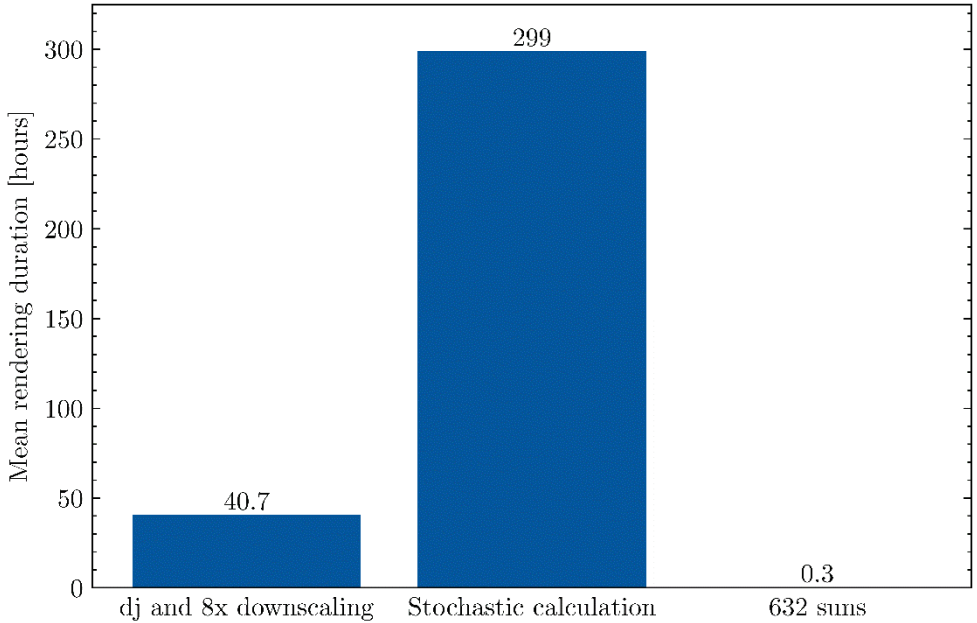
Rpict parameters dj and 8x downscaling: -ps 1 -ds 0 -dj 0.6 *and* 0.9 -ab 2 -aa 0 -ad 256 -as 0 -x 32768 -y 32768
Rpict parameters Stochastic calculation: -ab 2 -aa 0 -ar 0 -ad 524.288 -as 262.144 -x 4096 -y 4096
Rpict parameters 632 suns: -ds 0 -dt 0 -ab 4 -aa 0.1 -ad 4096 -ar 128 -as 2048 -x 4096 -y 4096

Render durations



Single core renders: AMD EPYC 7452 (2.35 GHz) with 8 GB RAM/core

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Conclusion

- With the right workflow, Radiance can accurately simulate dappled light
- Recommendations for rendering penumbras:
  - Direct jittering (dj 0.9) and downscaling
  - Create many suns
- Recommendation for rendering pinhole projections:
  - Create many suns

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Script for generating many suns available at:
https://github.com/SietsedeVriesTUe/gen_many_suns

https://www.linkedin.com/in/sietse-de-vries/

Special thanks to John Mardaljevic for his valuable contributions in developing the stencil method for generating many suns

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References

Chamilothori, K., Wienold, J., Moscoso, C., Matusiak, B., & Andersen, M. (2022). Regional Differences in the Perception of Daylit Scenes across Europe Using Virtual Reality. Part II: Effects of Façade and Daylight Pattern Geometry. *LEUKOS*, 1–25. https://doi.org/10.1080/15502724.2021.1999257

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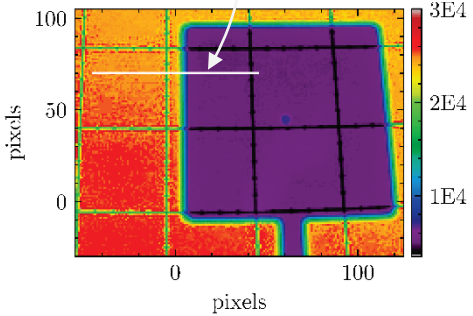
Experiment photographs by Maud Staassen Fotografie

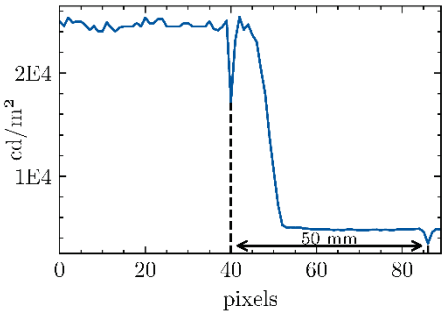
Supplementary information

Calculating penumbra lengths

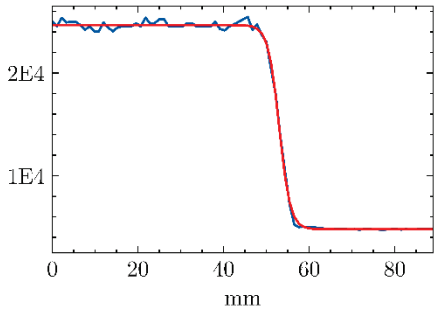
1. Extract line luminances



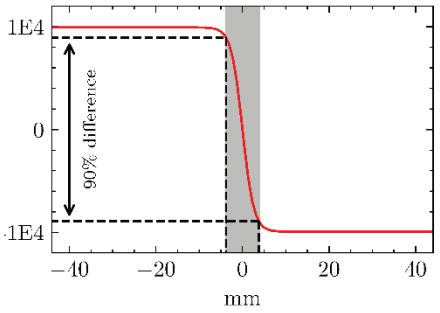
2. Extract grid points



3. Fit *tanh* formula



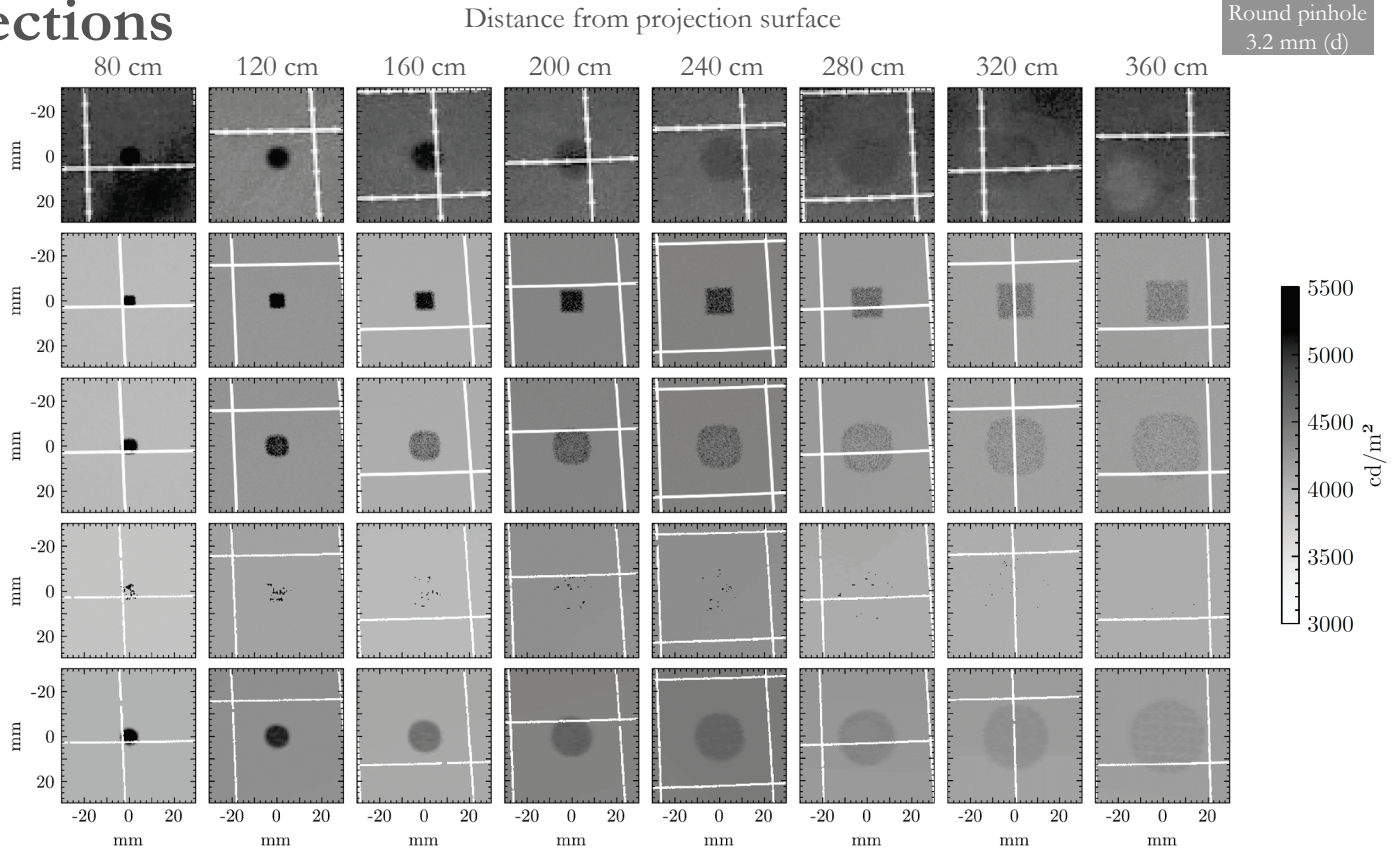
4. Compute penumbra length



signify TU/e

Pinhole projections

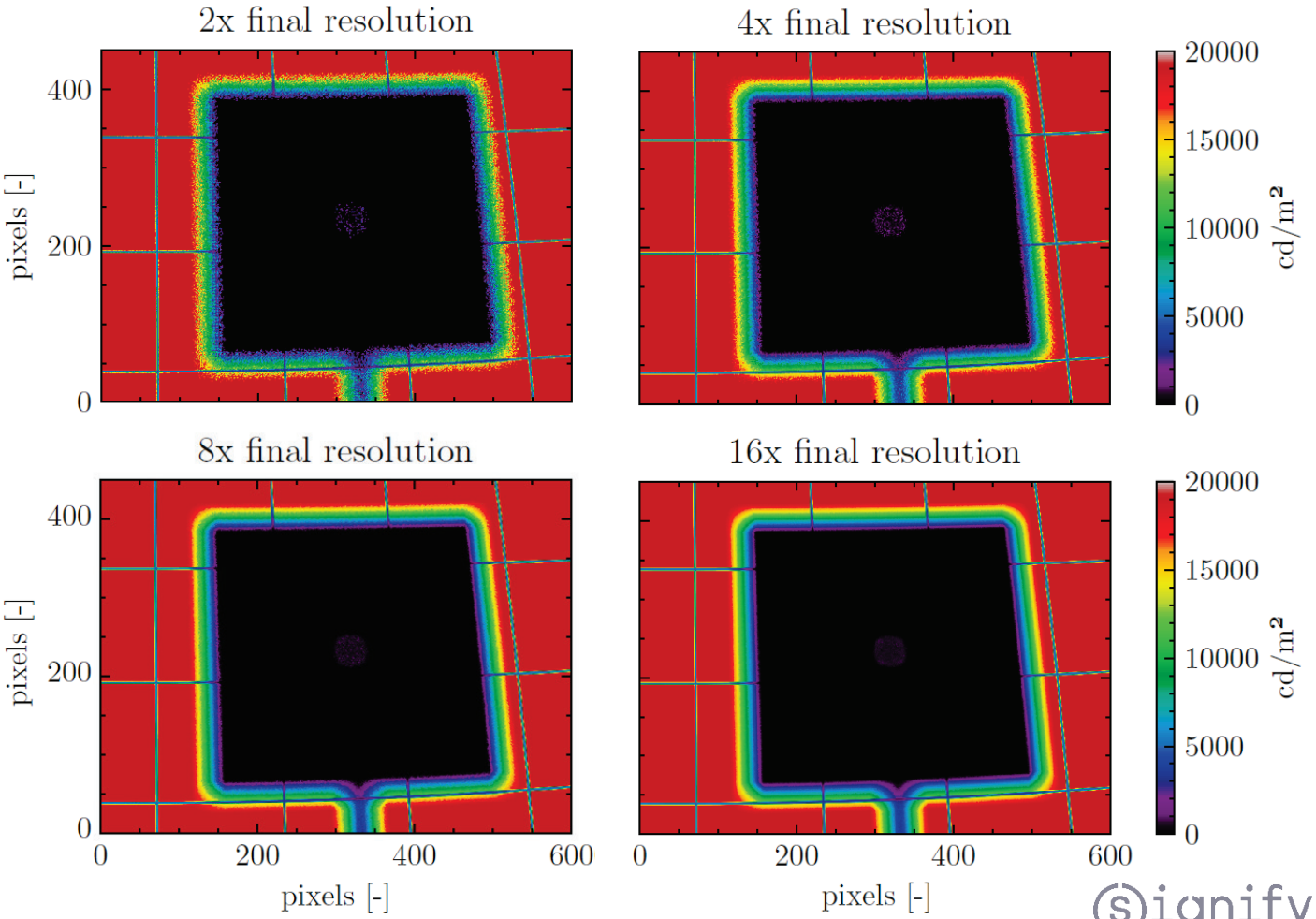
Round pinhole
3.2 mm (d)



signify TU/e

Rpict parameters: -ps 1 -ds 0 -dj 0.9 -ab 0 -x 4096 (final resolution) -y 4096 (final resolution)

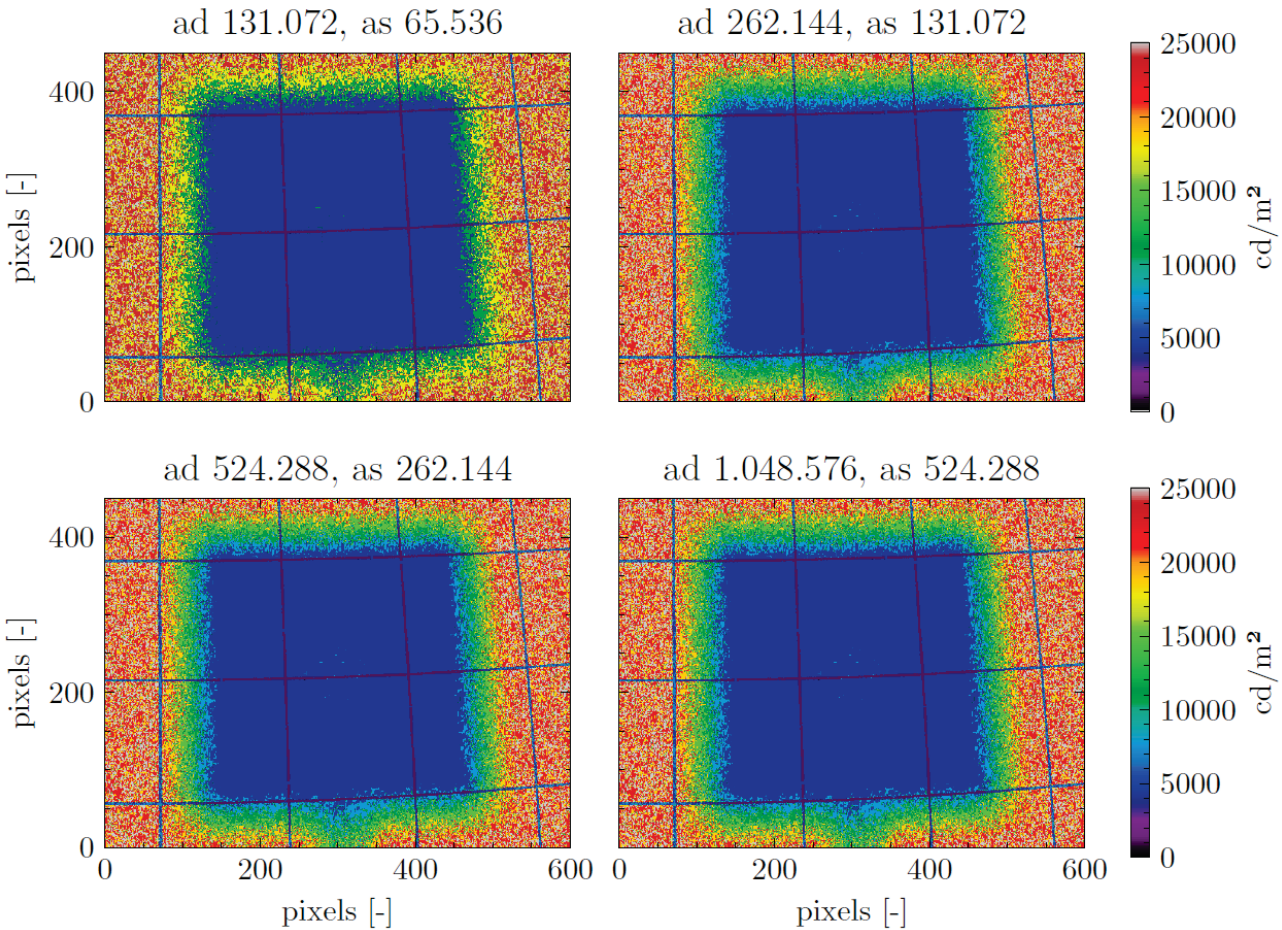
Dj and downscaling parameters



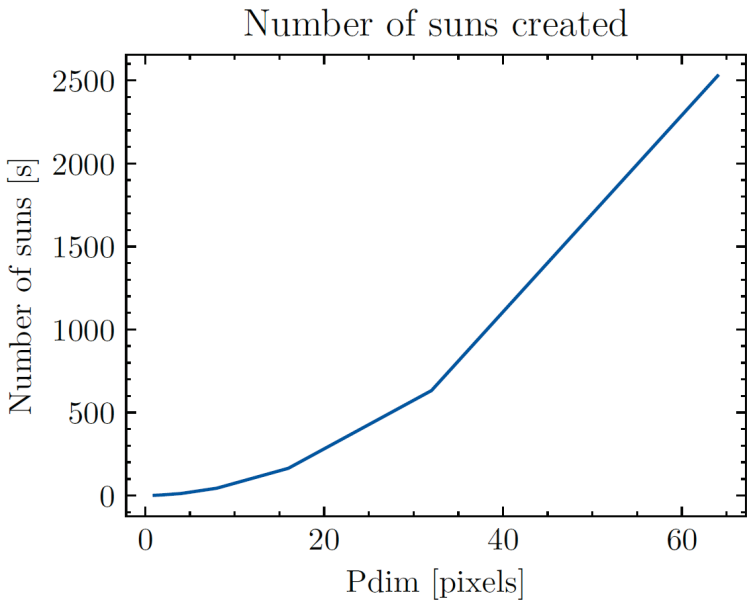
signify TU/e

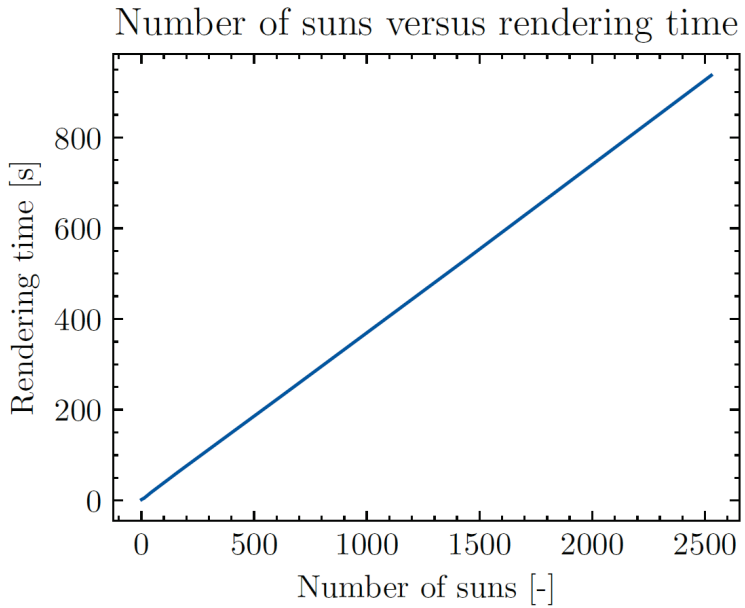
Rpict parameters: -ab 2 -aa 0 -ar 0 -ad *see below* -as *see below* -x 4096 -y 4096

Stochastic calculation parameters



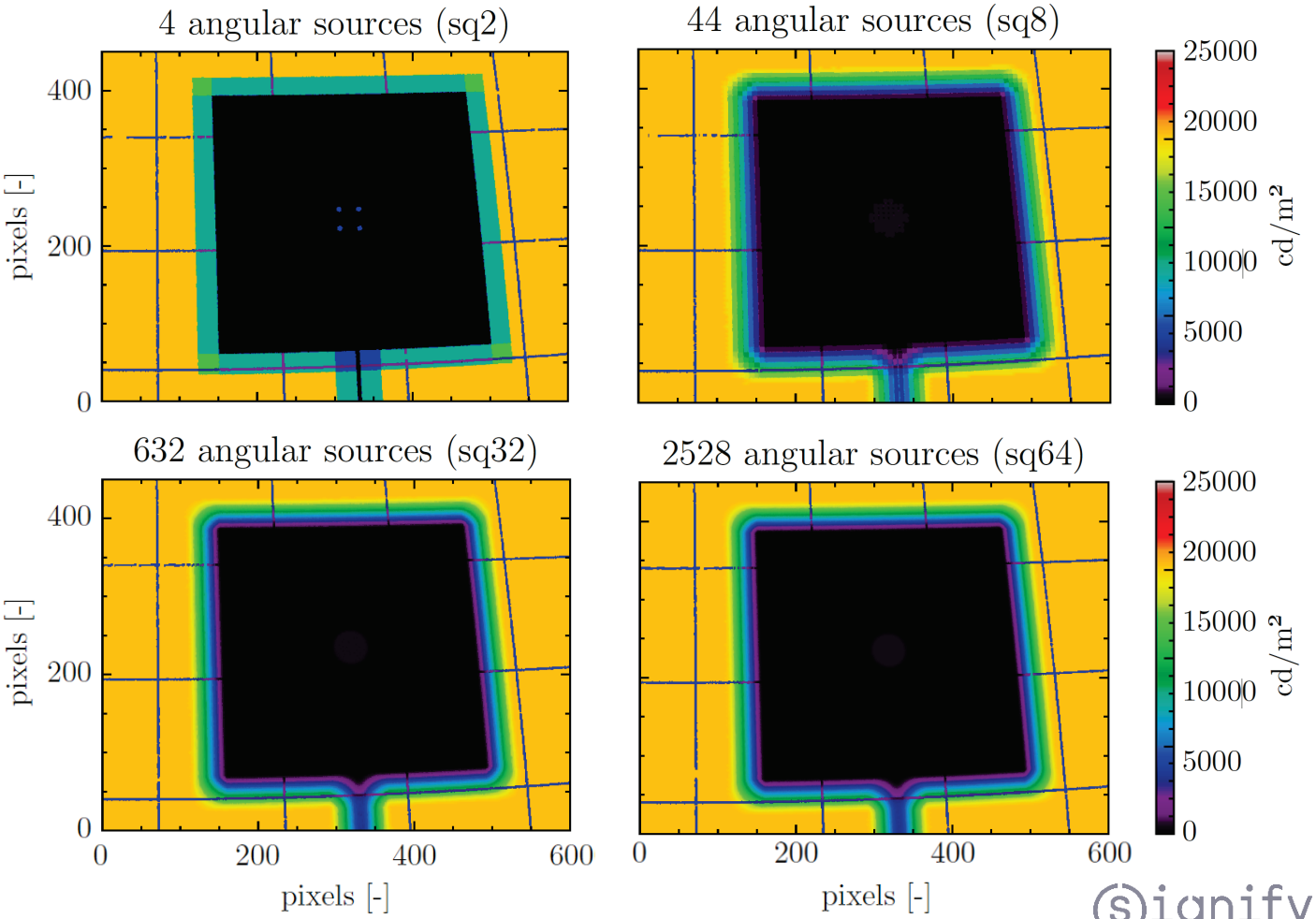
Creating many suns





signify TU/e

Creating many suns



signify TU/e