BSDF GENERATION AND USE IN ANNUAL, MATRIX-BASED DAYLIGHT SIMULATIONS WITH RADIANCE

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21-23 August 2019

„I love BSDFs.“

Kristen Garibaldi, Arup, May 2019

BSDF simulation with genBSDF and WINDOW7

BSDF Basics

BSDF, BTDF, BRDF, … ?

BSDF bidirectional scattering distribution function

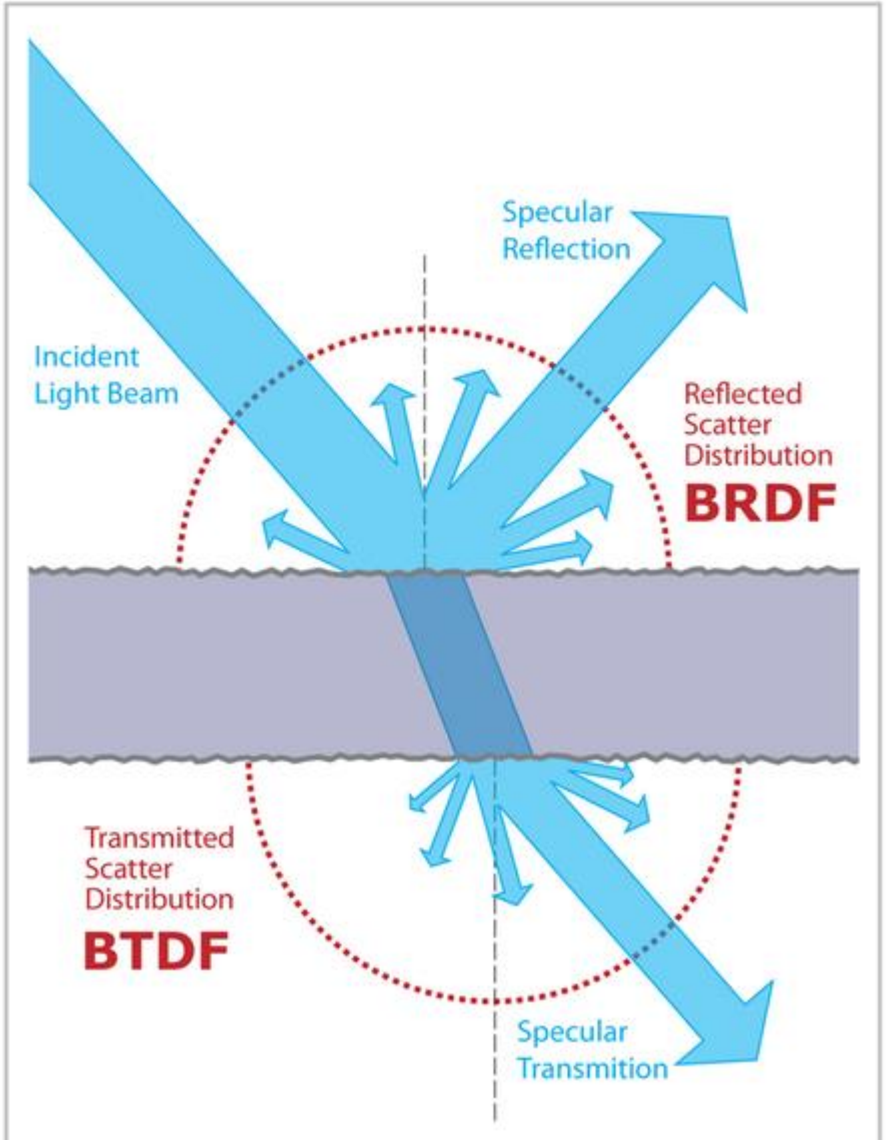
BRDF bidirectional reflection distribution function

BTDF bidirectional transmission distribution function

BSSDF bidirectional (sub)surface scattering distribution function

„BSDF = BRDF + BTDF“

we are talking about data-driven BSDFs!



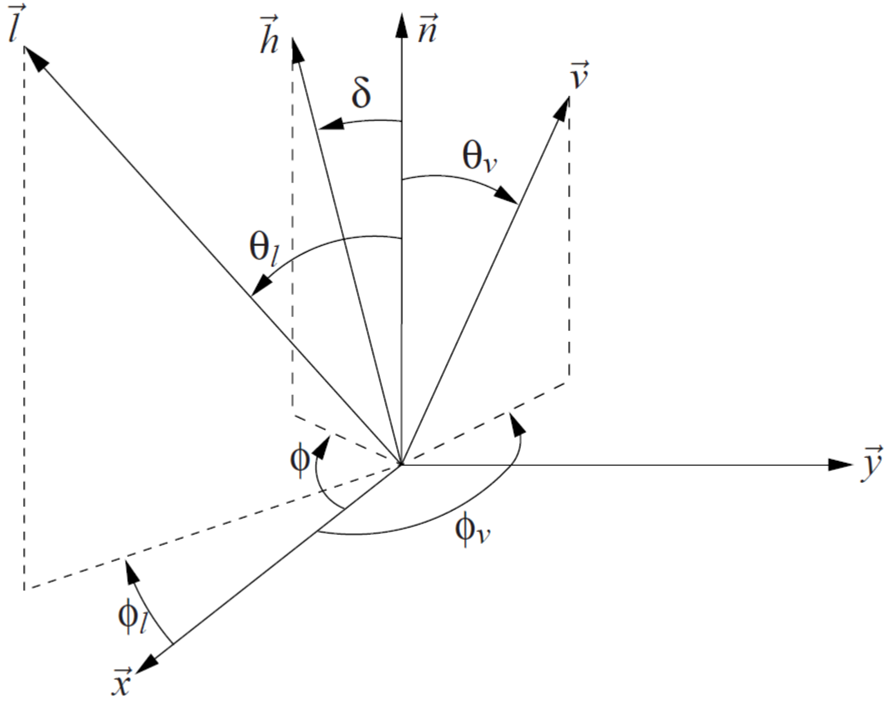
source: wikimedia.org

BSDF Basics

Rendering equation

$$L_v(\theta_v,\phi_v) = \int_0^{2\pi}\int_0^{\pi/2} L_l(\theta_l,\phi_l)\, f(\theta_l,\phi_l;\theta_v,\phi_v)\cos\theta_l \sin\theta_l \, d\theta_l \, d\phi_l$$

(θ_l,φ_l)	light source direction
(θ_v,φ_v)	view point direction
$f(\theta_l,\varphi_l\ ;\theta_v,\varphi_v)$	BSDF
$L_l(\theta_l,\varphi_l)$	radiance in light source direction
$L_v(\theta_v,\varphi_v)$	radiance in view direction



further reading:
Kajiya J. T.: The rendering equation. SIGGRAPH Comput. Graph. 20, 4 (1986), 143–150.
Nicodemus et al.: Geometrical Considerations and Nomenclature for Reflectance. NBS Monograph 160, U. S. Dept. of Commerce, 1977.

Physical plausibility

i. Positivity:

$$f(\theta_l,\varphi_l\,;\theta_v,\varphi_v) \geq 0$$

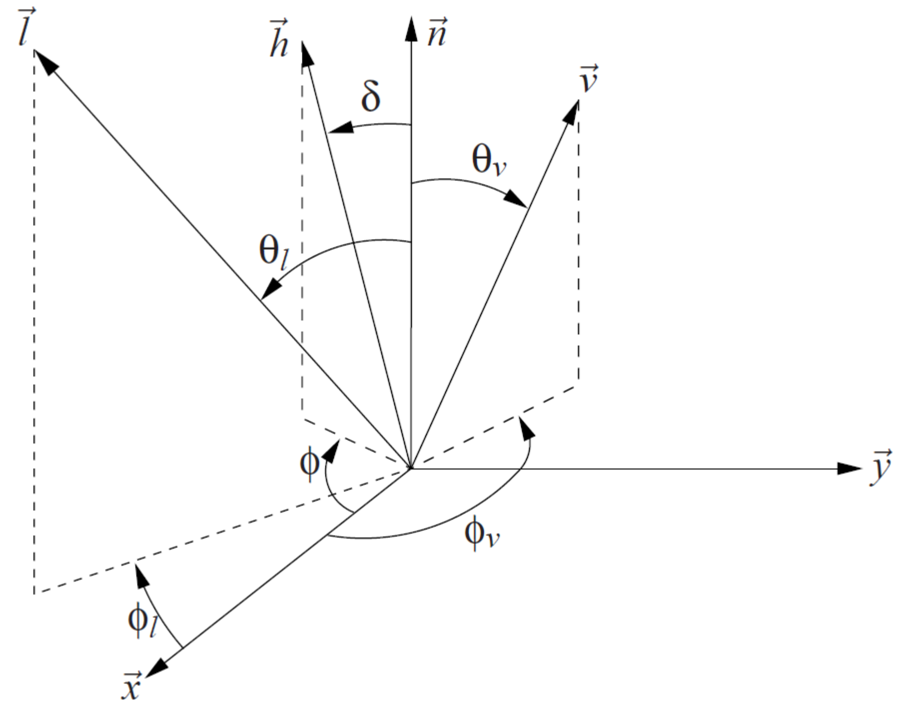
ii. Helmholtz reciprocity:

$$f(\theta_l,\varphi_l\,;\theta_v,\varphi_v) = f(\theta_v,\varphi_v\,;\theta_l,\varphi_l)$$

iii. energy balance:

albedo bounded by 1

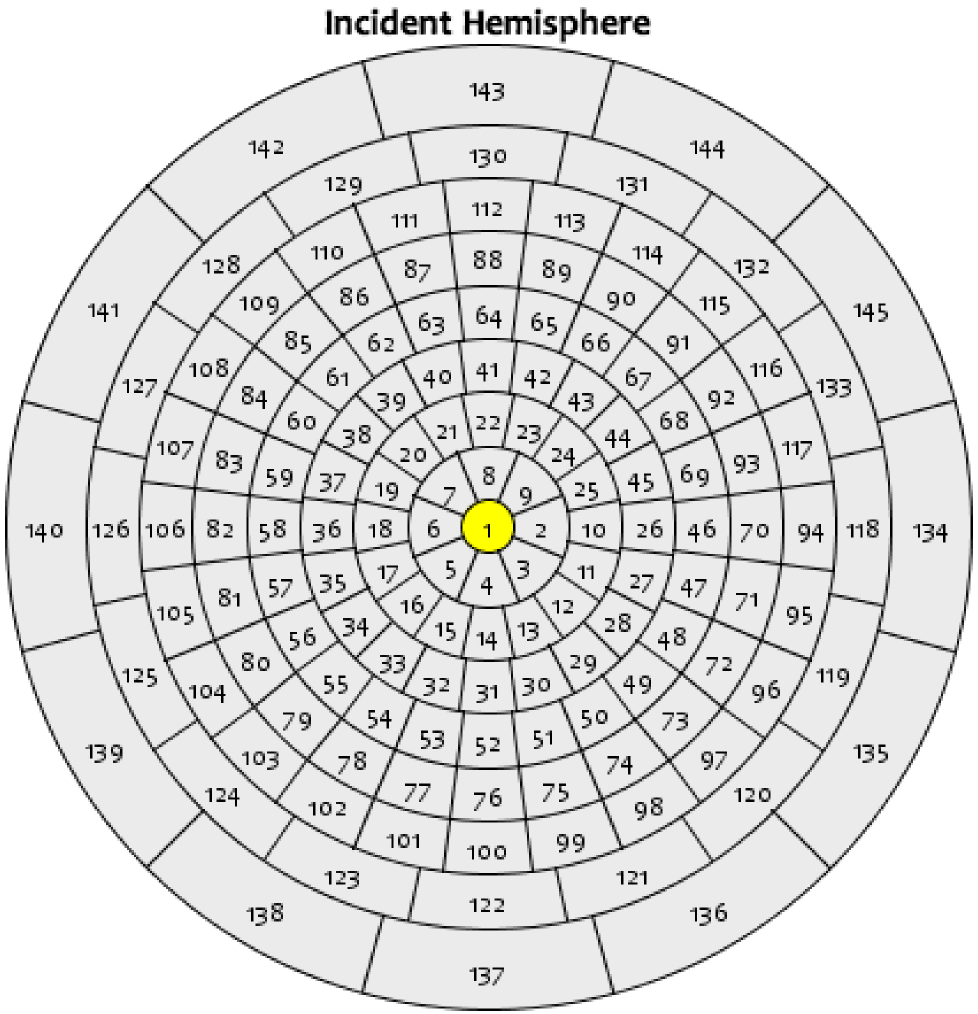
$$a(\theta_l,\phi_l) = \int_0^{2\pi}\int_0^{\pi/2} f(\theta_l,\phi_l;\theta_v,\phi_v)\cos\theta_v\sin\theta_v d\theta_v d\phi_v \leq 1$$



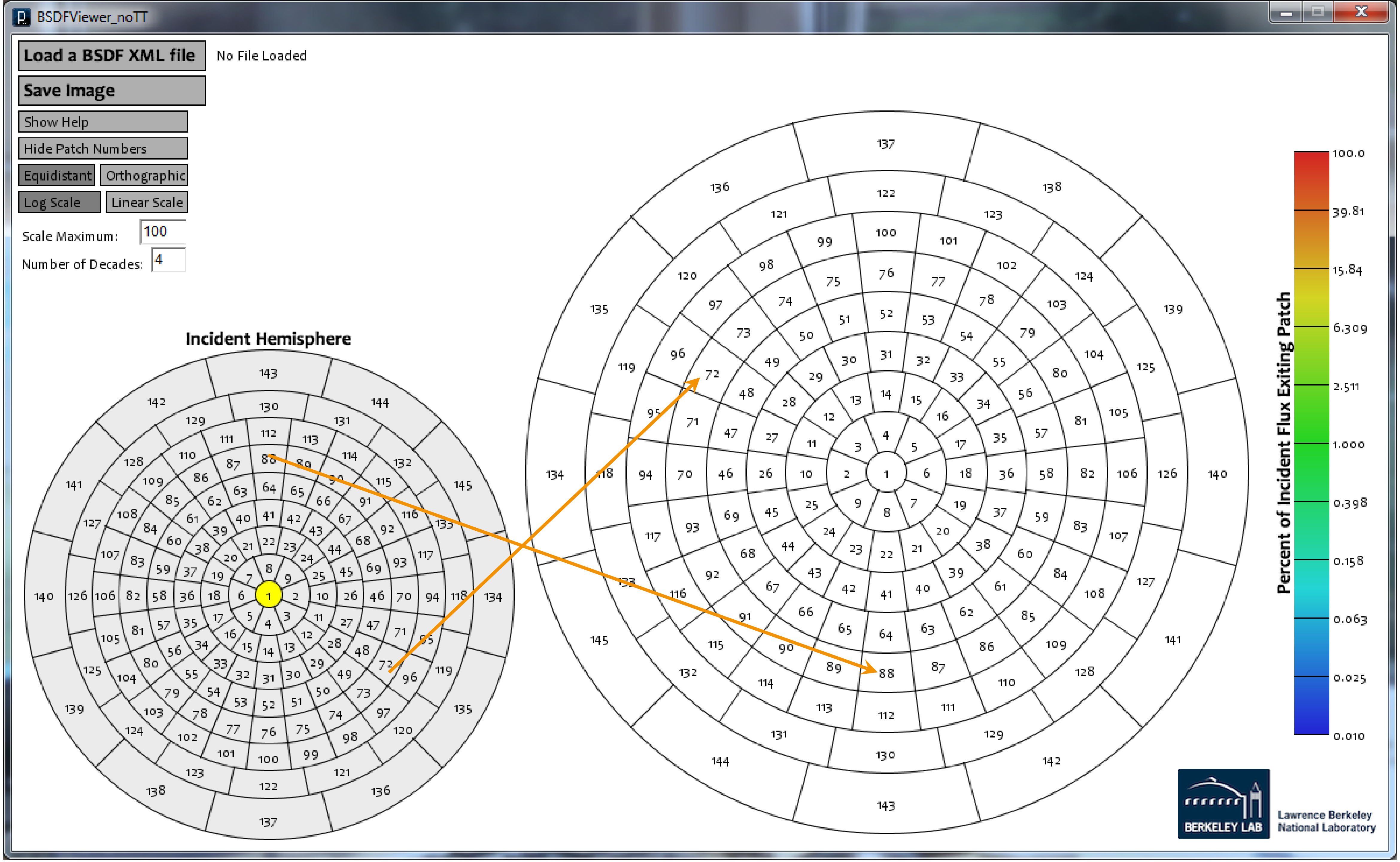
BSDF Basics – Discretizations

Klems‘ discretization

- subdivision of hemisphere into 145 patches
- approx. equal illuminance from each patch if luminance is constant in hemisphere
- 9 θ ranges {0°-5°, 5°-15°, 15°-25°, 25°-35°, 35°-45°, 45°-55°, 55°-65°, 65°-75°, 75°-90°}
- φ subdivisions per θ range {1, 8, 16, 20, 24, 24, 24, 16, 12}
- average solid angle 2π/145 = 0.0433 sr, i.e. cone with 2 x 6.73° apex angle [2π*(1-cos(α/2)) = 2π/145]



further reading:
Klems J.H.: A new method for predicting the solar heat gain of complex fenestration systems; Overview and derivation of the matrix layer calculation. ASHRAE Transactions 100 (1), 1994

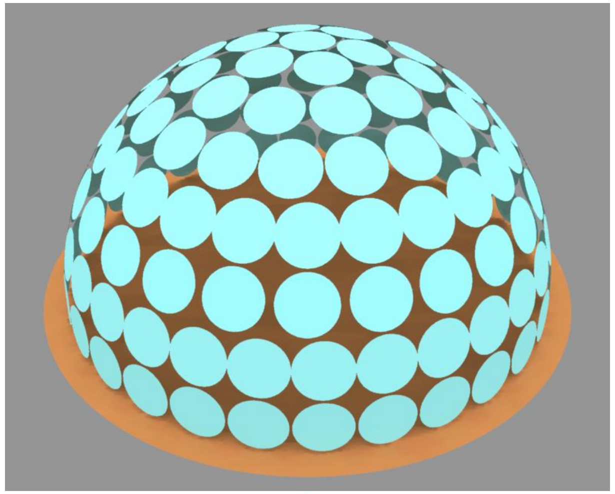


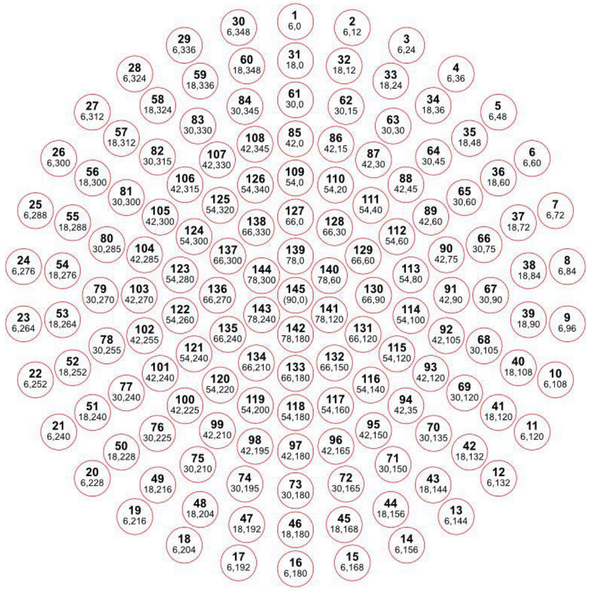
BSDFViewer_noTT
Load a BSDF XML file
No File Loaded
Save Image
Show Help
Hide Patch Numbers
Equidistant
Orthographic
Log Scale
Linear Scale
Scale Maximum: 100
Number of Decades: 4
Incident Hemisphere
Percent of Incident Flux Exiting Patch
100.0
39.81
15.84
6.309
2.511
1.000
0.398
0.158
0.063
0.025
0.010
BERKELEY LAB
Lawrence Berkeley National Laboratory

BSDF Basics – Discretizations

Tregenza scheme (CIE 108-1994)

- subdivision of hemisphere into 145 patches
- approx. equal solid angles foz each patch
- 8 θ ranges {0°-6°, 6°-18°, 18°-30°, 30°-42°, 42°-54°,
  54°-66°, 66°-78°, 78°-90°}
- φ subdivisions per θ range
  {1, 6, 12, 18, 24, 24, 30, 30}
- average solid angle 2π/145 = 0.0433 sr,
  i.e. cone with 2 x 6.73° apex angle [2π*(1-cos(α/2)) = 2π/145]



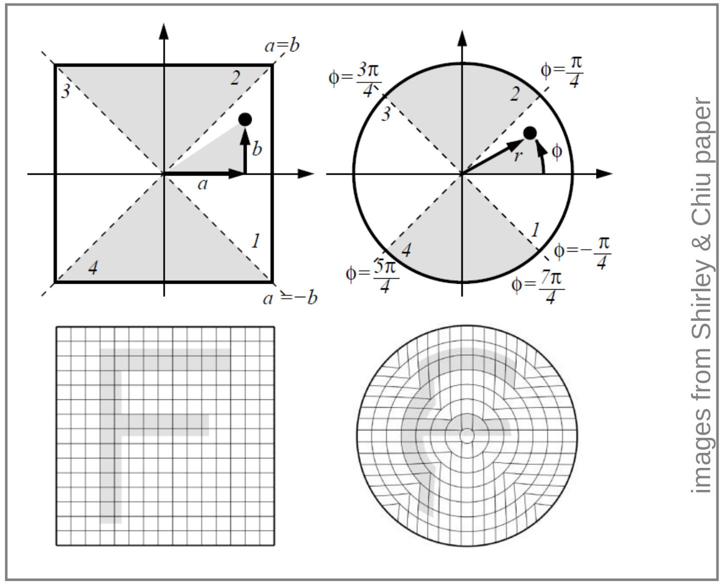


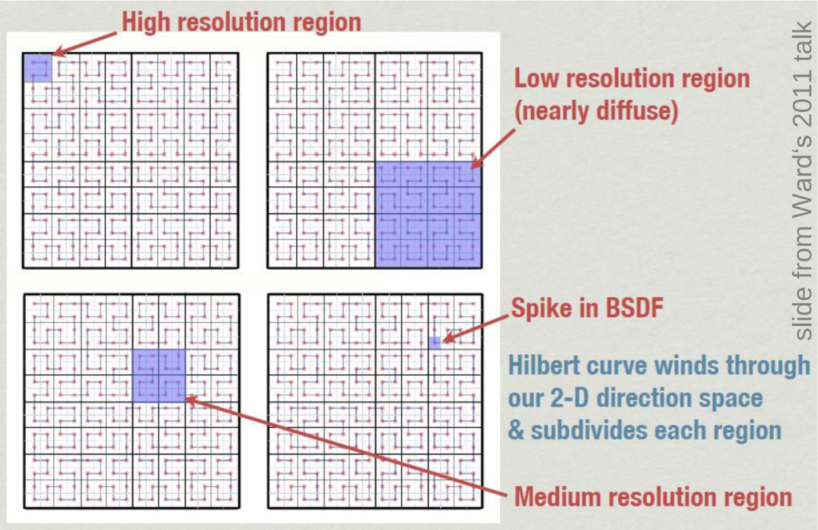
further reading:
CIE 108-1994: Guide to Recommended Practice of Daylight Measurement, 1994

BSDF Basics – Discretizations

Variable resolution („tensor tree“)

- idea: high resolution for spikey regions
  low resolution for smooth regions
- based on Shirley-Chiu-mapping
  (preserves fractional area, i.e. projected solid angle)
- maximum dimensions in 4D 2^{2n} x 2^{2n}
  (n = 4 / 5 / 6: 256^2 / 1024^2 / 4096^2)
- + efficient data structure (ideal diffuse reflector needs 1 value {1/π})
- – no matrix structure (needed for daylight coefficient approach)





further reading:
Shirley P., Chiu K.: A Low Distortion Map between Map and Square, Journal of Graphics Tools 2(3), 1977
Ward G.: Presentations at the 10th Radiance Workshop, radiance-online.org/community/workshops/2011-berkeley-ca
Ward G. et al.: Reducing Anisotropic BSDF Measurement to Common Practice," Workshop on Material Appearance Modeling, 2014

BSDF Basics – Data format

XML file format

- definition of data discretization in header
- data blocks interpreted by software accordingly


```
<?xml version="1.0" encoding="UTF-8"?>
<WindowElement xmlns="http://windows.lbl.gov" xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance"
        <WindowElementType>System</WindowElementType>
        <Optical>
                <Layer>
                <Material>
                        <Name>DALEC_UL_00deg_1u2panes</Name>
                        <Manufacturer>Bartenbach</Manufacturer>
                        <Thickness unit="Meter">0.128</Thickness>
                        <DeviceType>Integral</DeviceType>
                        </Material>
                <DataDefinition>
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                        <AngleBasis>
                        <AngleBasisName>LBNL/Klems Full</AngleBasisName>
                                <AngleBasisBlock>
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                                <nPhis>1</nPhis>
                                <ThetaBounds>
                                <LowerTheta>0</LowerTheta>
                                <UpperTheta>5</UpperTheta>
                                </ThetaBounds>
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                                <AngleBasisBlock>
                                <Theta>10</Theta>
                                <nPhis>8</nPhis>
                                <ThetaBounds>
                                        <LowerTheta>5</LowerTheta>
                                        <UpperTheta>15</UpperTheta>
                                </ThetaBounds>
                                </AngleBasisBlock>
```


Established data formats

name	input resolution	output resolution	currently used by software
WINDOW6 standard basis	Klems (145)	Klems (145)	WINDOW7, Relux, Radiance
IEA 21	Tregenza (145)	5deg full, i.e. 5°x5° (1297)	Relux, Radiance, Dialux*
Shirley-Chiu	variable (limitation through data size)	variable (limitation through data size)	Radiance

BSDF Generation (i) – genBSDF

Workflow

1. **Generate Radiance geometry** → **system.rad**

   Example: Rhino 3D → *.obj, obj2rad

   but can also be: Radiance tools, CAD, text editor, …

2. **Define Radiance material(s) for system** → **system.mat**

   Example: Radiance plastic materials

   but can also be: any Radiance material, e.g. BSDF of base material

3. **Run genBSDF on Radiance scene**

   genBSDF system.mat system.rad > system.xml

Example files: Folder 01_genBSDF in

https://bartenbach-my.sharepoint.com/:f:/p/geisler-moroder_david/EoAgk3OW_6VPnMebT8VJwWIBXs4SSsYwLAyYG6yoyJMoCQ?e=v0KPtT

further reading:
A.McNeil: genBSDF Tutorial, online: https://www.radiance-online.org/learning/tutorials/Tutorial-genBSDF_v1.0.1.pdf

BSDF Generation (i) – genBSDF

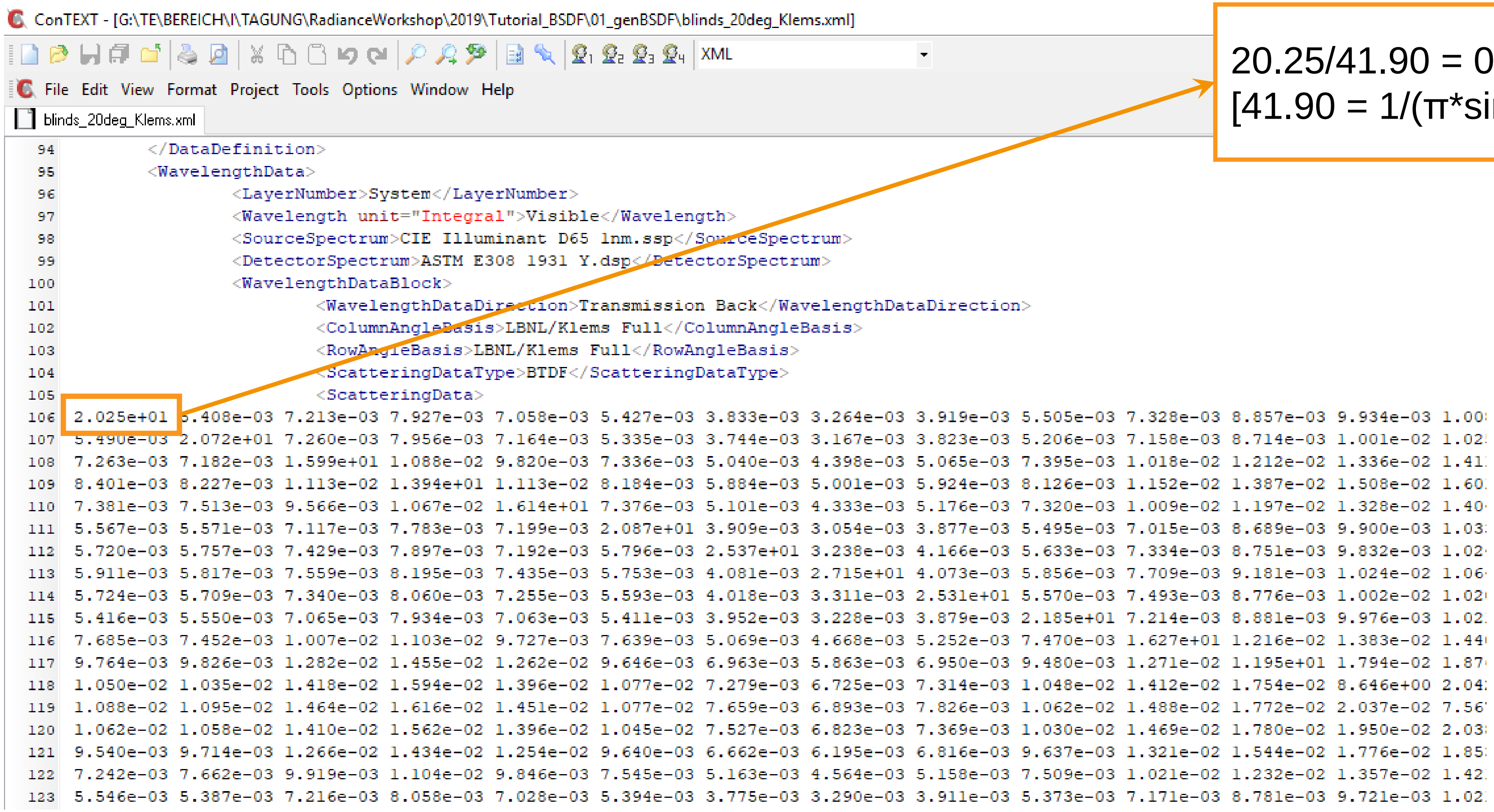
```
geisler-moroder@ws313:BSDF>
geisler-moroder@ws313:BSDF>./00_run_genBSDF.sh
Mon Aug 12 16:27:45 CEST 2019
Running genBSDF on blinds_20deg for Klems...
Recover using: /usr/local/bin/genBSDF -recover /tmp/genBSDF.9riY2H
```

Some important options

- -c: samples per incident patch
- -r: rcontrib options
- -dim: system dimensions
- -t3/4: tensor tree BSDFs
- -t: reduce data in tensor tree BSDF (hidden option)

Viewing BSDFs

Text editor

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			<Wavelength unit="Integral">Visible</Wavelength>
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			<DetectorSpectrum>ASTM E308 1931 Y.dsp</DetectorSpectrum>
			<WavelengthDataBlock>
				<WavelengthDataDirection>Transmission Back</WavelengthDataDirection>
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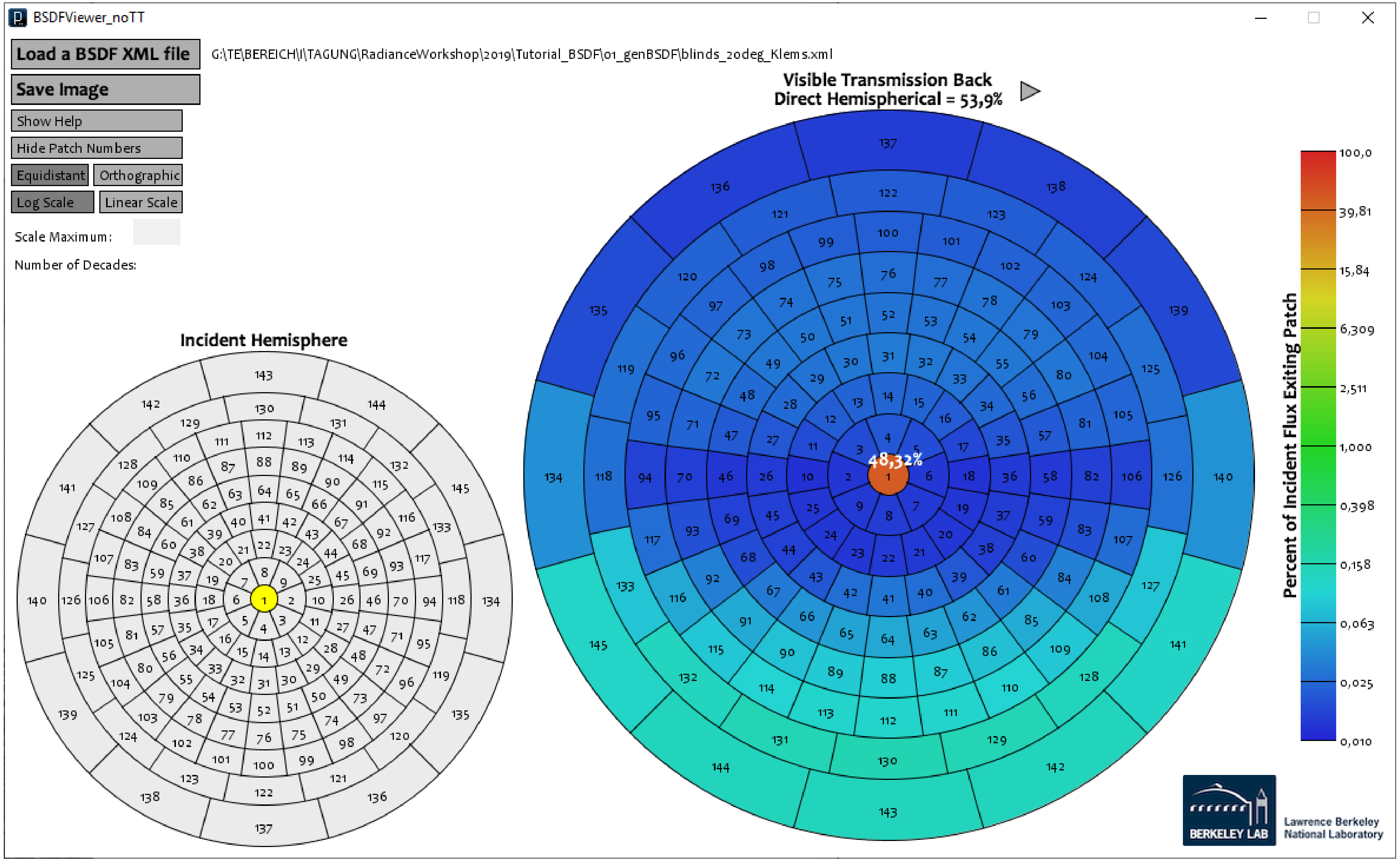
				<RowAngleBasis>LBNL/Klems Full</RowAngleBasis>
				<ScatteringDataType>BTDF</ScatteringDataType>
				<ScatteringData>
2.025e+01 5.408e-03 7.213e-03 7.927e-03 7.058e-03 5.427e-03 3.833e-03 3.264e-03 3.919e-03 5.505e-03 7.328e-03 8.857e-03 9.934e-03 1.00
5.490e-03 2.072e+01 7.260e-03 7.956e-03 7.164e-03 5.335e-03 3.744e-03 3.167e-03 3.823e-03 5.206e-03 7.158e-03 8.714e-03 1.001e-02 1.02
7.263e-03 7.182e-03 1.599e+01 1.088e-02 9.820e-03 7.336e-03 5.040e-03 4.398e-03 5.065e-03 7.395e-03 1.018e-02 1.212e-02 1.336e-02 1.41
8.401e-03 8.227e-03 1.113e-02 1.394e+01 1.113e-02 8.184e-03 5.884e-03 5.001e-03 5.924e-03 8.126e-03 1.152e-02 1.387e-02 1.508e-02 1.60
7.381e-03 7.513e-03 9.566e-03 1.067e-02 1.614e+01 7.376e-03 5.101e-03 4.333e-03 5.176e-03 7.320e-03 1.009e-02 1.197e-02 1.328e-02 1.40
5.567e-03 5.571e-03 7.117e-03 7.783e-03 7.199e-03 2.087e+01 3.909e-03 3.054e-03 3.877e-03 5.495e-03 7.015e-03 8.689e-03 9.900e-03 1.03
5.720e-03 5.757e-03 7.429e-03 7.897e-03 7.192e-03 5.796e-03 2.537e+01 3.238e-03 4.166e-03 5.633e-03 7.334e-03 8.751e-03 9.832e-03 1.02
5.911e-03 5.817e-03 7.559e-03 8.195e-03 7.435e-03 5.753e-03 4.081e-03 2.715e+01 4.073e-03 5.856e-03 7.709e-03 9.181e-03 1.024e-02 1.06
5.724e-03 5.709e-03 7.340e-03 8.060e-03 7.255e-03 5.593e-03 4.018e-03 3.311e-03 2.531e+01 5.570e-03 7.493e-03 8.776e-03 1.002e-02 1.02
5.416e-03 5.550e-03 7.065e-03 7.934e-03 7.063e-03 5.411e-03 3.952e-03 3.228e-03 3.879e-03 2.185e+01 7.214e-03 8.881e-03 9.976e-03 1.02
7.685e-03 7.452e-03 1.007e-02 1.103e-02 9.727e-03 7.639e-03 5.069e-03 4.668e-03 5.252e-03 7.470e-03 1.627e+01 1.216e-02 1.383e-02 1.44
9.764e-03 9.826e-03 1.282e-02 1.455e-02 1.262e-02 9.646e-03 6.963e-03 5.863e-03 6.950e-03 9.480e-03 1.271e-02 1.195e+01 1.794e-02 1.87
1.050e-02 1.035e-02 1.418e-02 1.594e-02 1.396e-02 1.077e-02 7.279e-03 6.725e-03 7.314e-03 1.048e-02 1.412e-02 1.754e-02 8.646e+00 2.04
1.088e-02 1.095e-02 1.464e-02 1.616e-02 1.451e-02 1.077e-02 7.659e-03 6.893e-03 7.826e-03 1.062e-02 1.488e-02 1.772e-02 2.037e-02 7.56
1.062e-02 1.058e-02 1.410e-02 1.562e-02 1.396e-02 1.045e-02 7.527e-03 6.823e-03 7.369e-03 1.030e-02 1.469e-02 1.780e-02 1.950e-02 2.03
9.540e-03 9.714e-03 1.266e-02 1.434e-02 1.254e-02 9.640e-03 6.662e-03 6.195e-03 6.816e-03 9.637e-03 1.321e-02 1.544e-02 1.776e-02 1.85
7.242e-03 7.662e-03 9.919e-03 1.104e-02 9.846e-03 7.545e-03 5.163e-03 4.564e-03 5.158e-03 7.509e-03 1.021e-02 1.232e-02 1.357e-02 1.42
5.546e-03 5.387e-03 7.216e-03 8.058e-03 7.028e-03 5.394e-03 3.775e-03 3.290e-03 3.911e-03 5.373e-03 7.171e-03 8.781e-03 9.721e-03 1.02
```

20.25/41.90 = 0.483
[41.90 = 1/(π*sin²(5°))]

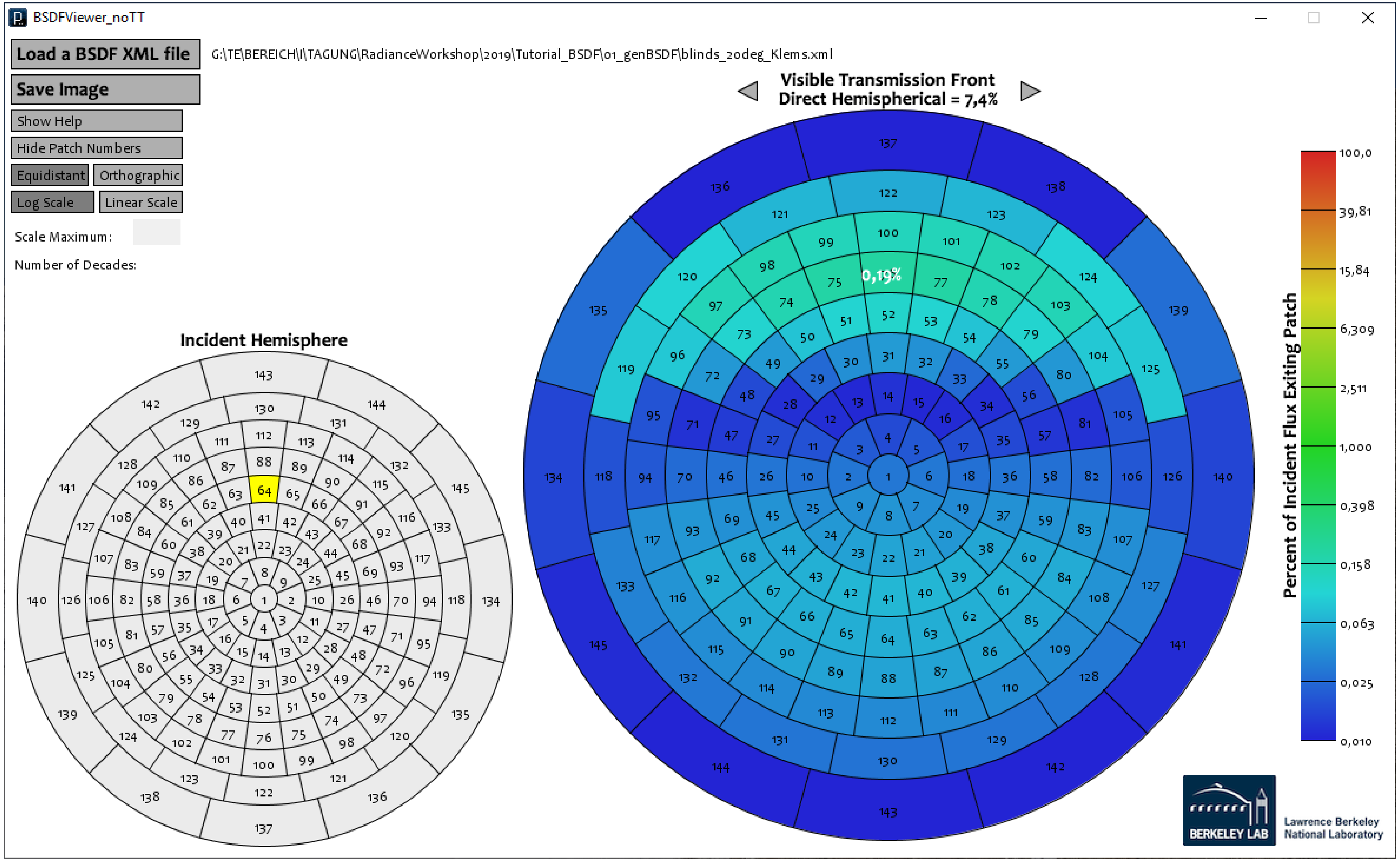
Viewing BSDFs

BSDFViewer



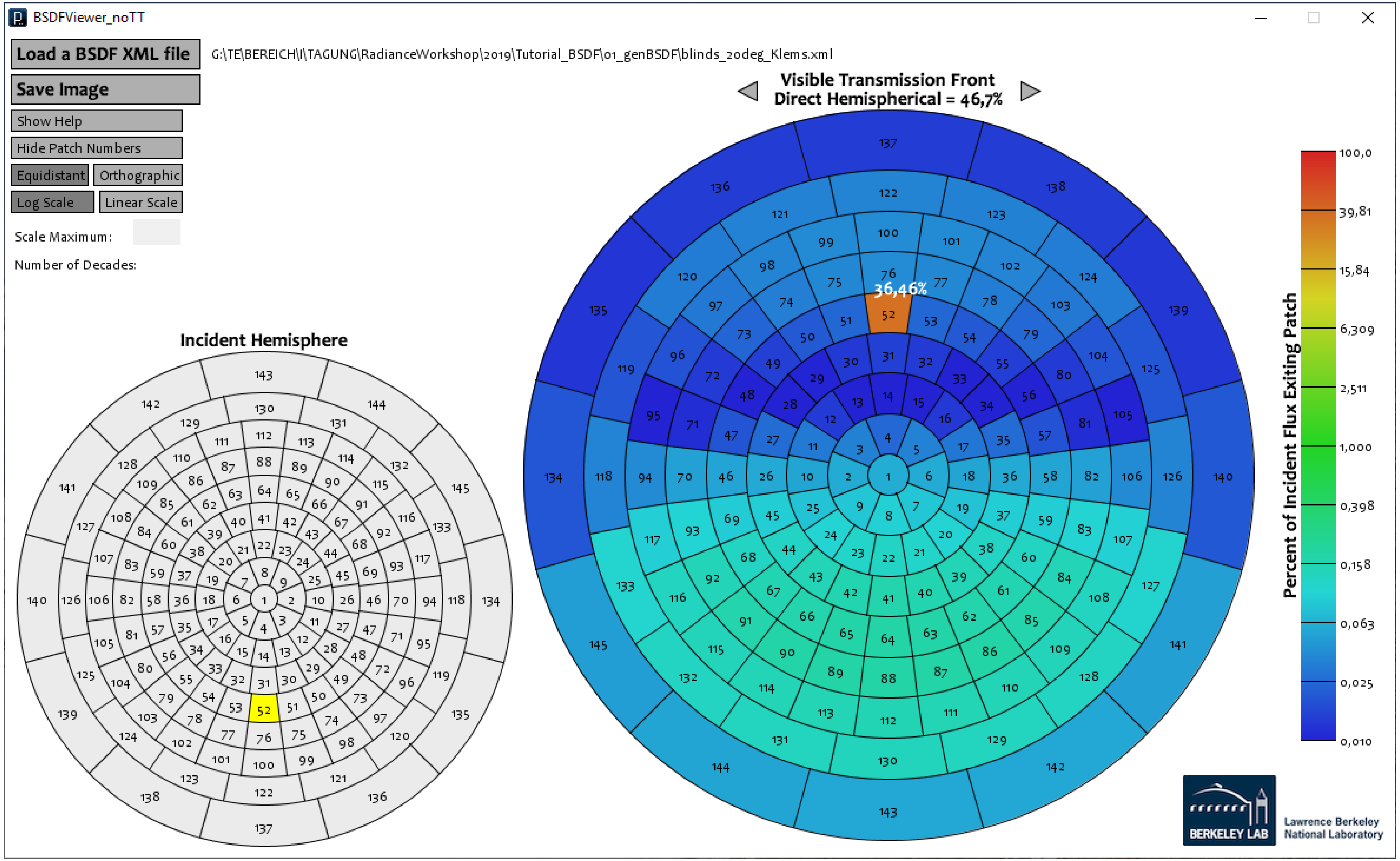
Viewing BSDFs

BSDFViewer



Viewing BSDFs

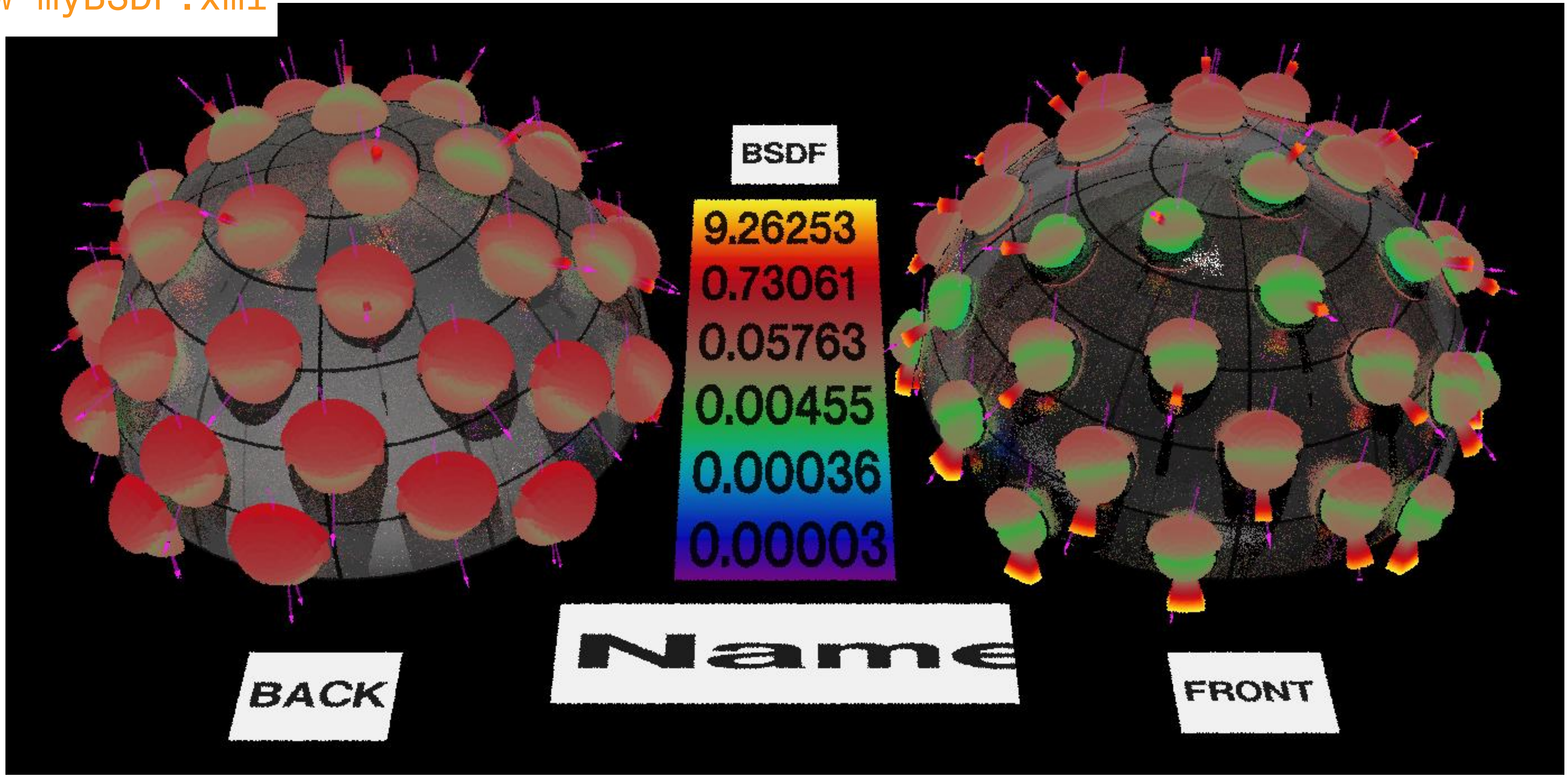
BSDFViewer



Viewing BSDFs

`bsdfview myBSDF.xml`

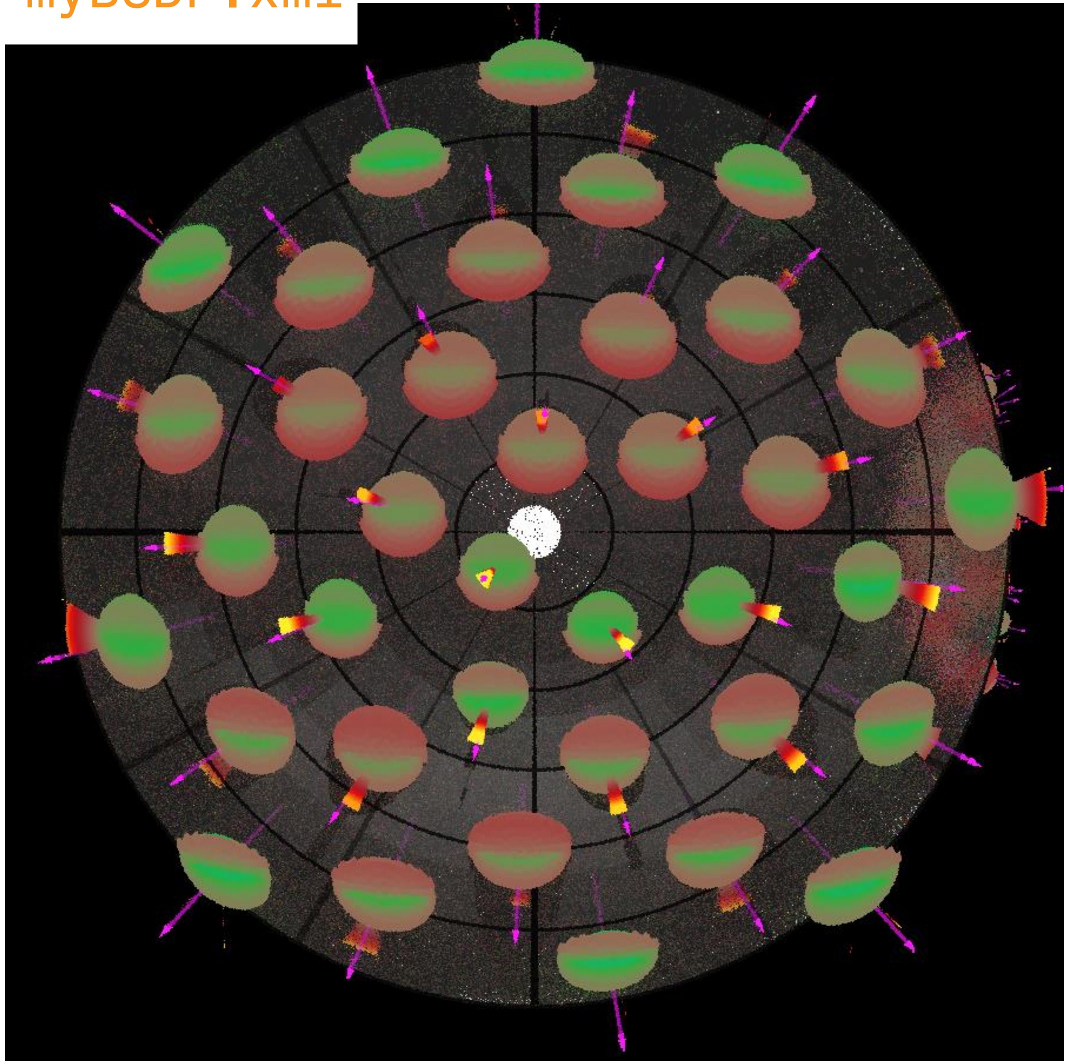
def: back and front reflection



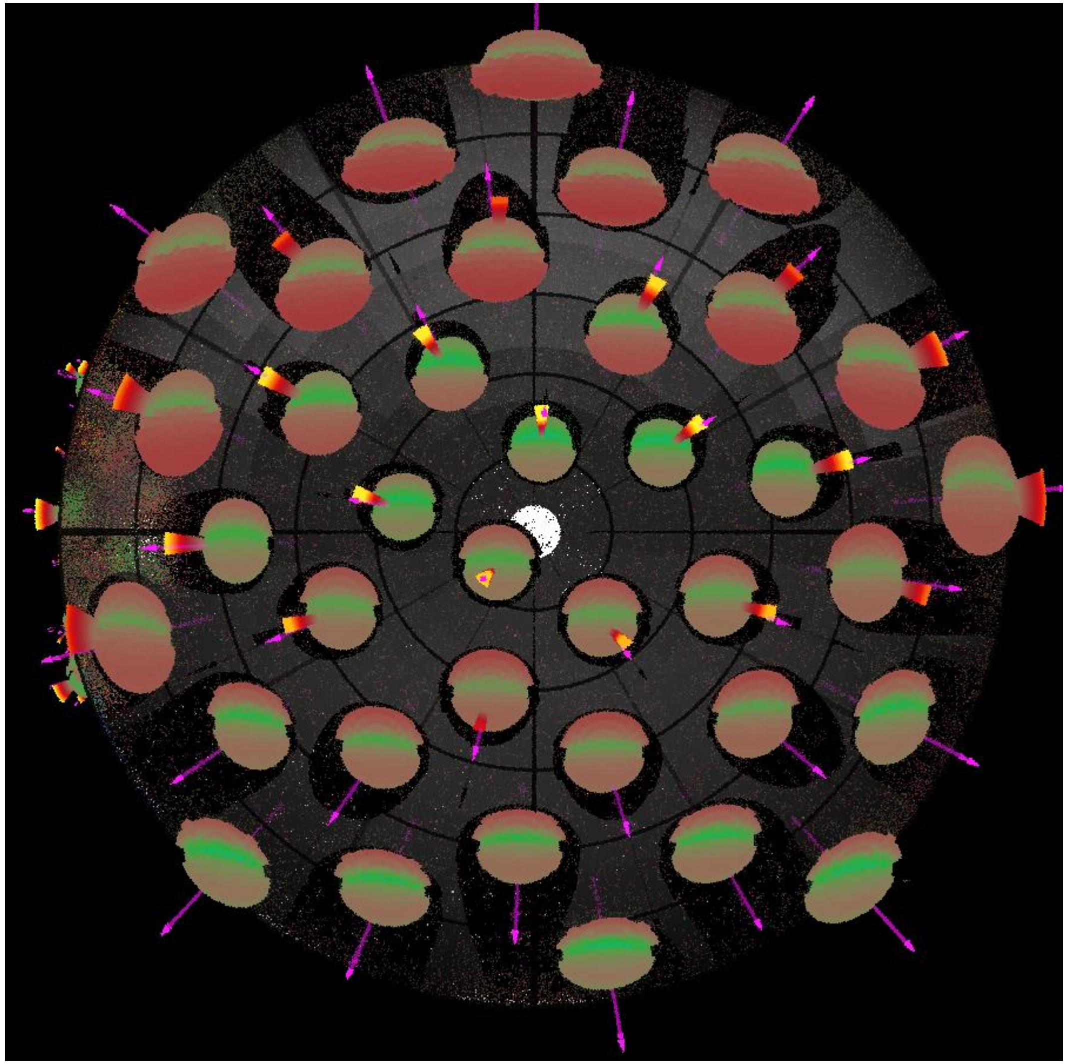
Viewing BSDFs

`bsdfview myBSDF.xml`

front transmission



back transmission



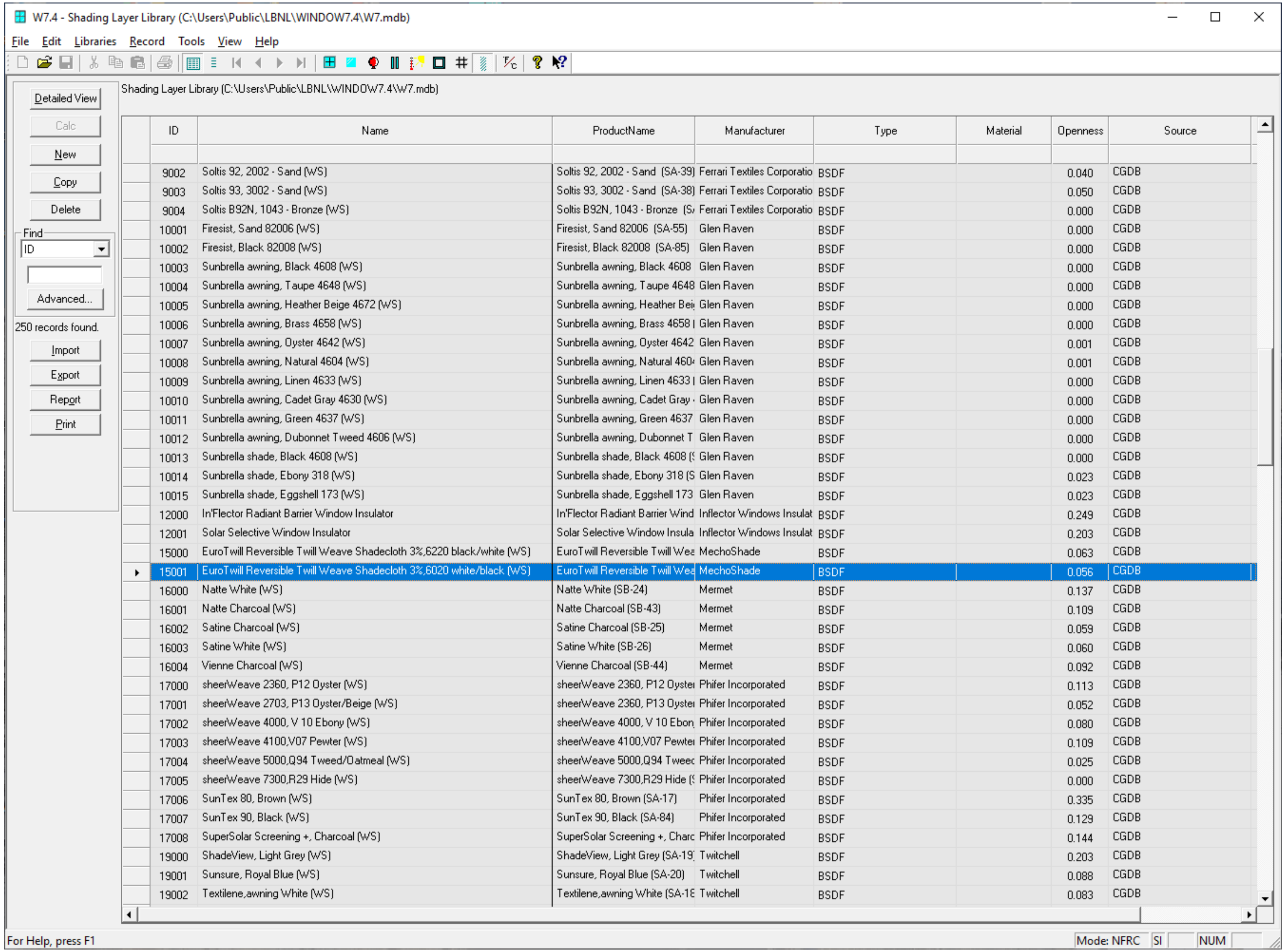
BSDF Generation (ii) – WINDOW7

Definition of system

a) Selection of system from CGDB

b) Geometrical modeling of blinds

c) Definition via XML file



ID	Name	ProductName	Manufacturer	Type	Material	Openness	Source
9002	Soltis 92, 2002 - Sand (WS)	Soltis 92, 2002 - Sand (SA-39)	Ferrari Textiles Corporatio	BSDF		0.040	CGDB
9003	Soltis 93, 3002 - Sand (WS)	Soltis 93, 3002 - Sand (SA-38)	Ferrari Textiles Corporatio	BSDF		0.050	CGDB
9004	Soltis B92N, 1043 - Bronze (WS)	Soltis B92N, 1043 - Bronze (S	Ferrari Textiles Corporatio	BSDF		0.000	CGDB
10001	Firesist, Sand 82006 (WS)	Firesist, Sand 82006 (SA-55)	Glen Raven	BSDF		0.000	CGDB
10002	Firesist, Black 82008 (WS)	Firesist, Black 82008 (SA-85)	Glen Raven	BSDF		0.000	CGDB
10003	Sunbrella awning, Black 4608 (WS)	Sunbrella awning, Black 4608	Glen Raven	BSDF		0.000	CGDB
10004	Sunbrella awning, Taupe 4648 (WS)	Sunbrella awning, Taupe 4648	Glen Raven	BSDF		0.000	CGDB
10005	Sunbrella awning, Heather Beige 4672 (WS)	Sunbrella awning, Heather Bei	Glen Raven	BSDF		0.000	CGDB
10006	Sunbrella awning, Brass 4658 (WS)	Sunbrella awning, Brass 4658 (	Glen Raven	BSDF		0.000	CGDB
10007	Sunbrella awning, Oyster 4642 (WS)	Sunbrella awning, Oyster 4642	Glen Raven	BSDF		0.001	CGDB
10008	Sunbrella awning, Natural 4604 (WS)	Sunbrella awning, Natural 460	Glen Raven	BSDF		0.001	CGDB
10009	Sunbrella awning, Linen 4633 (WS)	Sunbrella awning, Linen 4633 (	Glen Raven	BSDF		0.000	CGDB
10010	Sunbrella awning, Cadet Gray 4630 (WS)	Sunbrella awning, Cadet Gray	Glen Raven	BSDF		0.000	CGDB
10011	Sunbrella awning, Green 4637 (WS)	Sunbrella awning, Green 4637	Glen Raven	BSDF		0.000	CGDB
10012	Sunbrella awning, Dubonnet Tweed 4606 (WS)	Sunbrella awning, Dubonnet T	Glen Raven	BSDF		0.000	CGDB
10013	Sunbrella shade, Black 4608 (WS)	Sunbrella shade, Black 4608 (	Glen Raven	BSDF		0.000	CGDB
10014	Sunbrella shade, Ebony 318 (WS)	Sunbrella shade, Ebony 318 (S	Glen Raven	BSDF		0.023	CGDB
10015	Sunbrella shade, Eggshell 173 (WS)	Sunbrella shade, Eggshell 173	Glen Raven	BSDF		0.023	CGDB
12000	In'Flector Radiant Barrier Window Insulator	In'Flector Radiant Barrier Wind	Inflector Windows Insulat	BSDF		0.249	CGDB
12001	Solar Selective Window Insulator	Solar Selective Window Insula	Inflector Windows Insulat	BSDF		0.203	CGDB
15000	EuroTwill Reversible Twill Weave Shadecloth 3%,6220 black/white (WS)	EuroTwill Reversible Twill Wea	MechoShade	BSDF		0.063	CGDB
15001	EuroTwill Reversible Twill Weave Shadecloth 3%,6020 white/black (WS)	EuroTwill Reversible Twill Wea	MechoShade	BSDF		0.056	CGDB
16000	Natte White (WS)	Natte White (SB-24)	Mermet	BSDF		0.137	CGDB
16001	Natte Charcoal (WS)	Natte Charcoal (SB-43)	Mermet	BSDF		0.109	CGDB
16002	Satine Charcoal (WS)	Satine Charcoal (SB-25)	Mermet	BSDF		0.059	CGDB
16003	Satine White (WS)	Satine White (SB-26)	Mermet	BSDF		0.060	CGDB
16004	Vienne Charcoal (WS)	Vienne Charcoal (SB-44)	Mermet	BSDF		0.092	CGDB
17000	sheerWeave 2360, P12 Oyster (WS)	sheerWeave 2360, P12 Oyster	Phifer Incorporated	BSDF		0.113	CGDB
17001	sheerWeave 2703, P13 Oyster/Beige (WS)	sheerWeave 2360, P13 Oyster	Phifer Incorporated	BSDF		0.052	CGDB
17002	sheerWeave 4000, V 10 Ebony (WS)	sheerWeave 4000, V 10 Ebon	Phifer Incorporated	BSDF		0.080	CGDB
17003	sheerWeave 4100,V07 Pewter (WS)	sheerWeave 4100,V07 Pewter	Phifer Incorporated	BSDF		0.109	CGDB
17004	sheerWeave 5000,Q94 Tweed/Oatmeal (WS)	sheerWeave 5000,Q94 Tweed	Phifer Incorporated	BSDF		0.025	CGDB
17005	sheerWeave 7300,R29 Hide (WS)	sheerWeave 7300,R29 Hide (	Phifer Incorporated	BSDF		0.000	CGDB
17006	SunTex 80, Brown (WS)	SunTex 80, Brown (SA-17)	Phifer Incorporated	BSDF		0.335	CGDB
17007	SunTex 90, Black (WS)	SunTex 90, Black (SA-84)	Phifer Incorporated	BSDF		0.129	CGDB
17008	SuperSolar Screening +, Charcoal (WS)	SuperSolar Screening +, Charc	Phifer Incorporated	BSDF		0.144	CGDB
19000	ShadeView, Light Grey (WS)	ShadeView, Light Grey (SA-19	Twitchell	BSDF		0.203	CGDB
19001	Sunsure, Royal Blue (WS)	Sunsure, Royal Blue (SA-20)	Twitchell	BSDF		0.088	CGDB
19002	Textilene,awning White (WS)	Textilene,awning White (SA-18	Twitchell	BSDF		0.083	CGDB

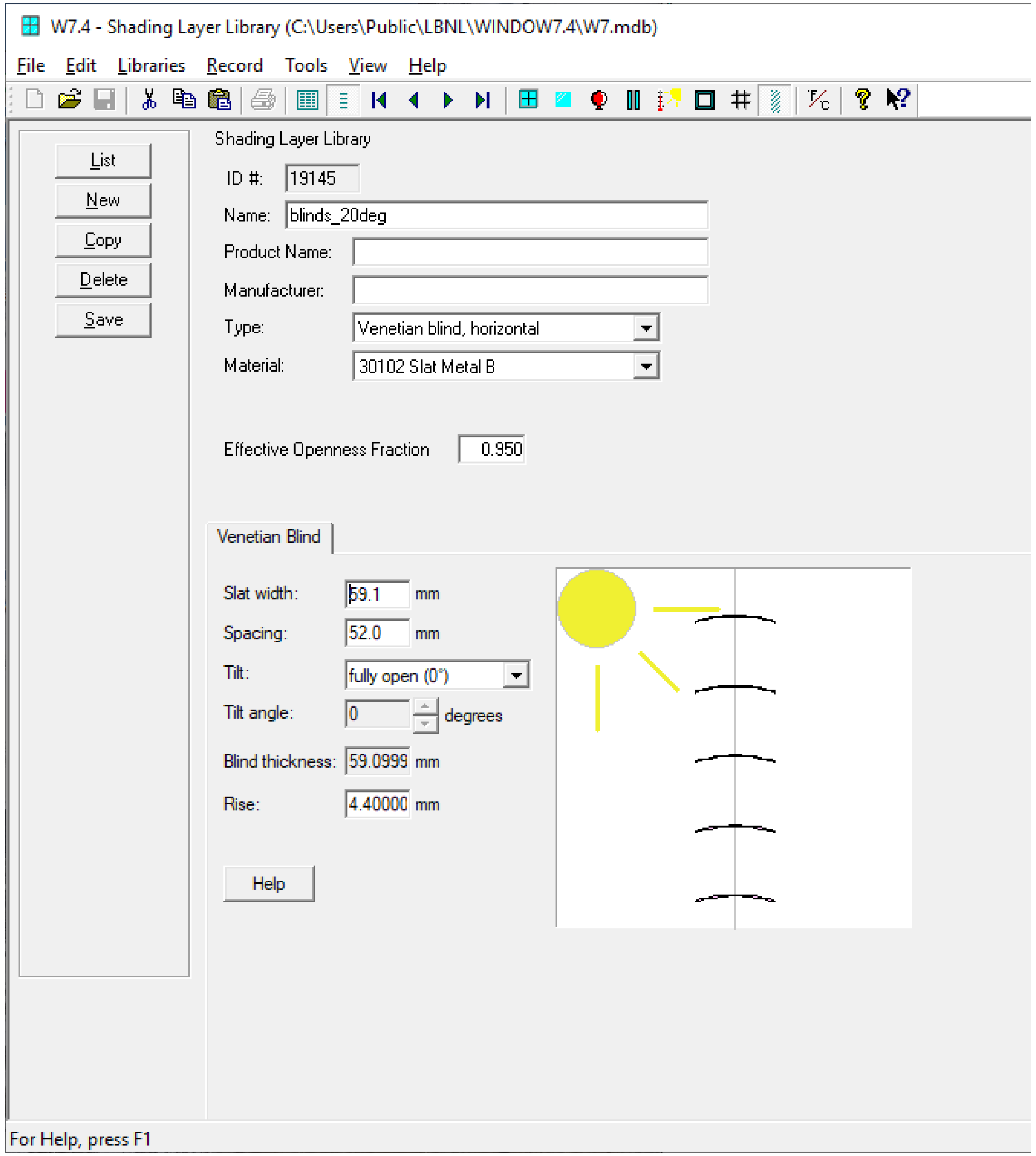
BSDF Generation (ii) – WINDOW7

Definition of system

a) Selection of system from CGDB

b) Geometrical modeling of blinds

c) Definition via XML file



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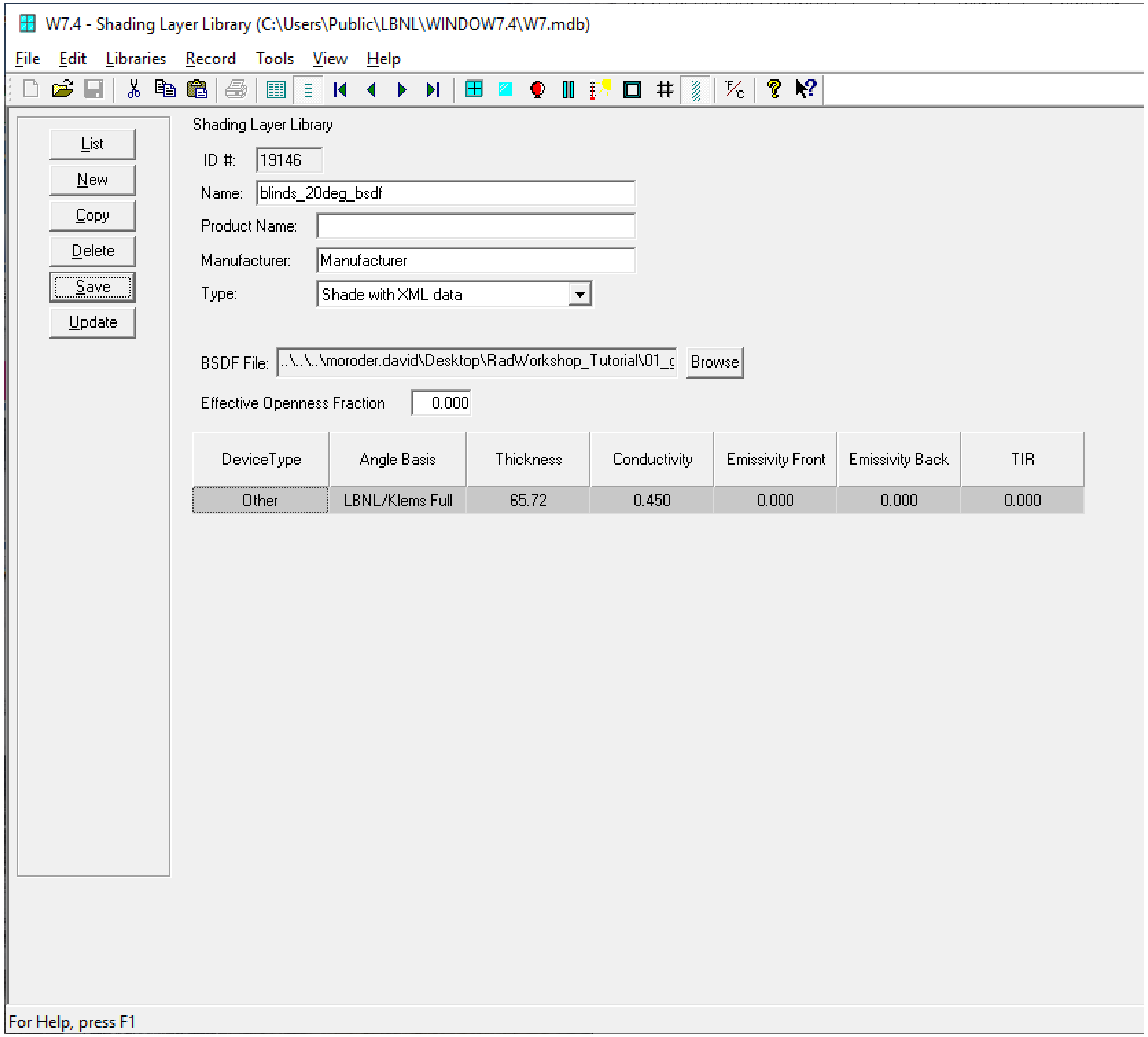
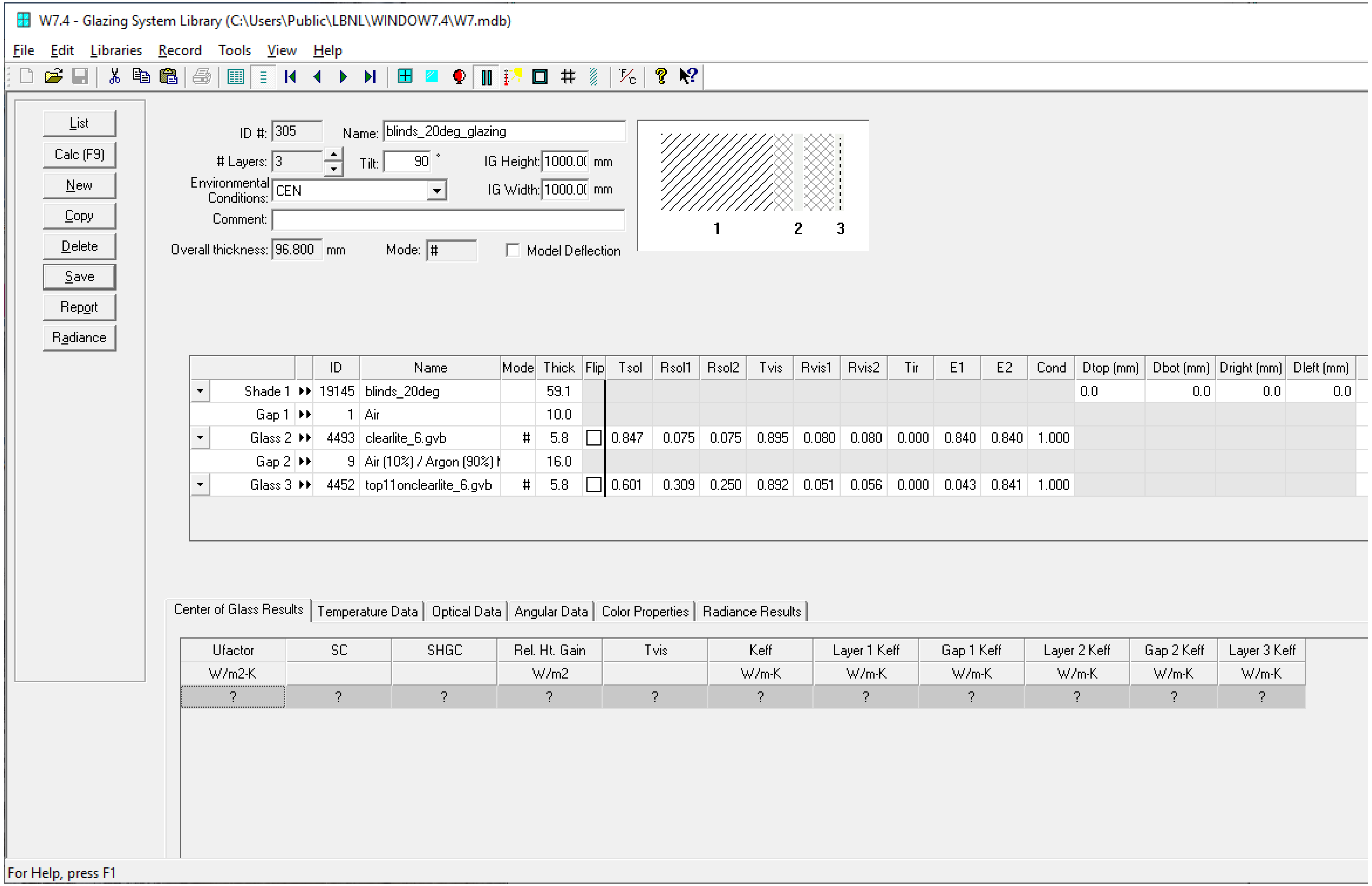


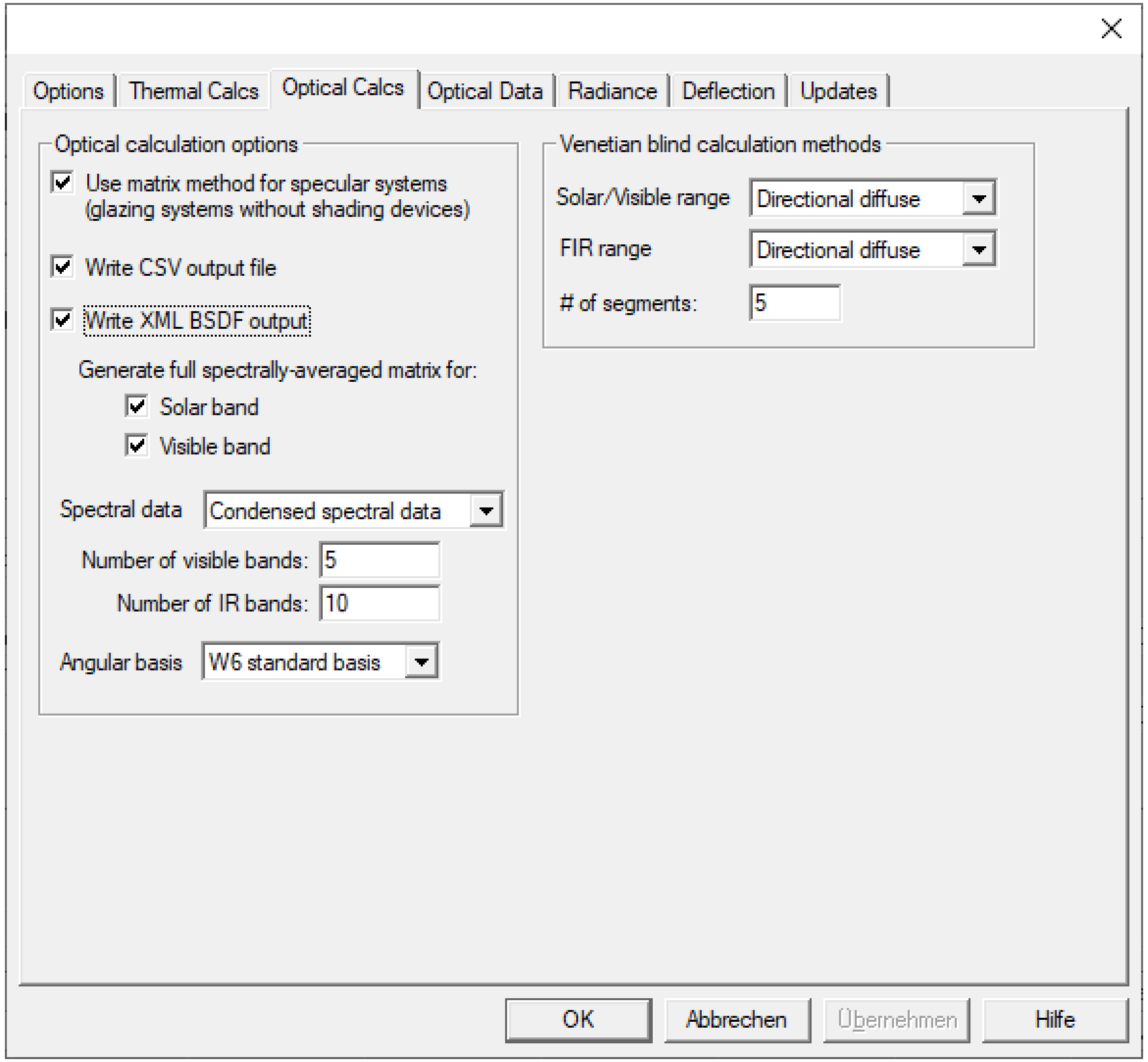
BSDF Generation (ii) – WINDOW7

Setup of IGU



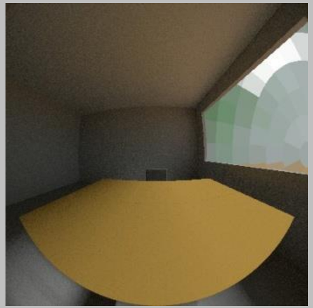
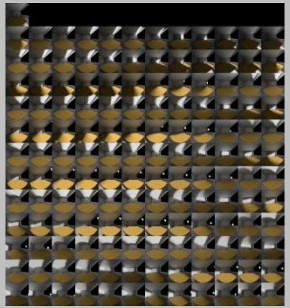
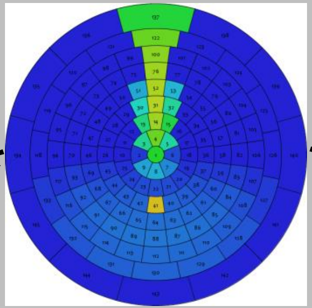
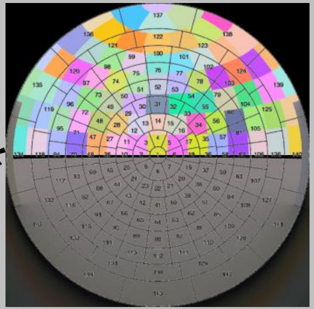
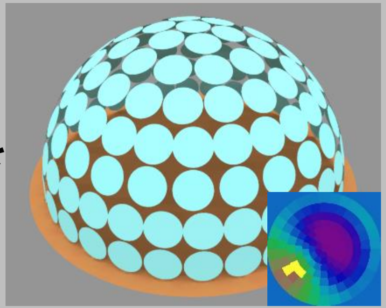
BSDF Generation (ii) – WINDOW7

Calculation settings



Using BSDFs in matrix-based, annual simulations with Radiance

Three-Phase Method

 =  *  *  * 

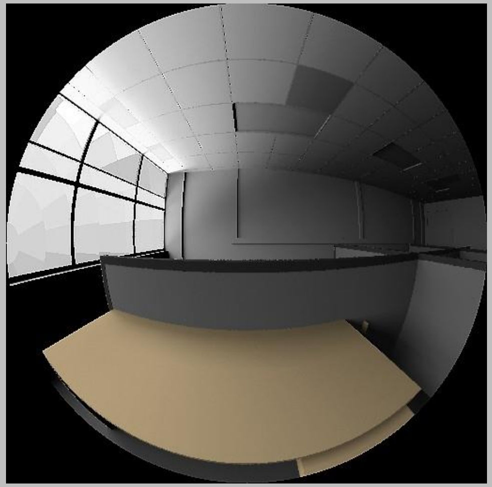
I	**V**	**T**	**D**	**S**
result	view matrix	BSDF	daylight matrix	sky distribution

I = VTDS

Five-Phase Method

=

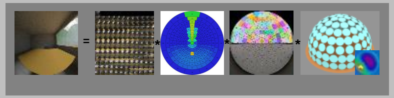
–



+

I
result

VTDS
Three-Phase Method



$\mathbf{V_dTD_dS_{ds}}$
direct solar (3-PM)

$\mathbf{(C_{R\text{-}ds}+C_{F\text{-}ds})S_{sun}}$
accurate direct solar

$$I = VTDS - V_dTD_dS_{ds} + (C_{R\text{-}ds}+C_{F\text{-}ds})S_{sun}$$

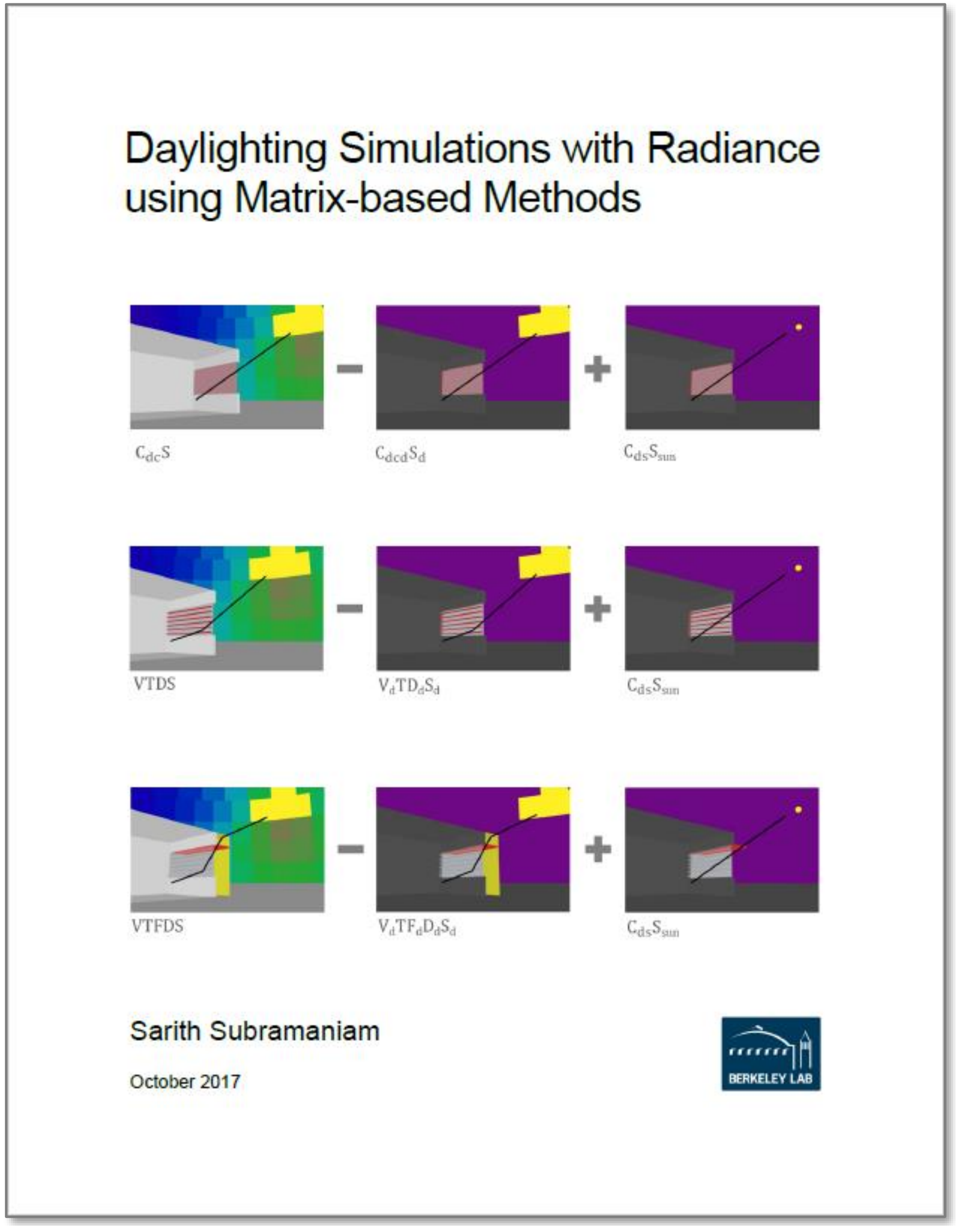
Documentation

Manual:

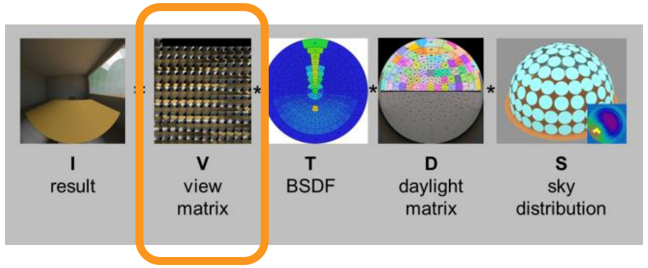
https://www.radiance-online.org/learning/tutorials/matrix-based-methods

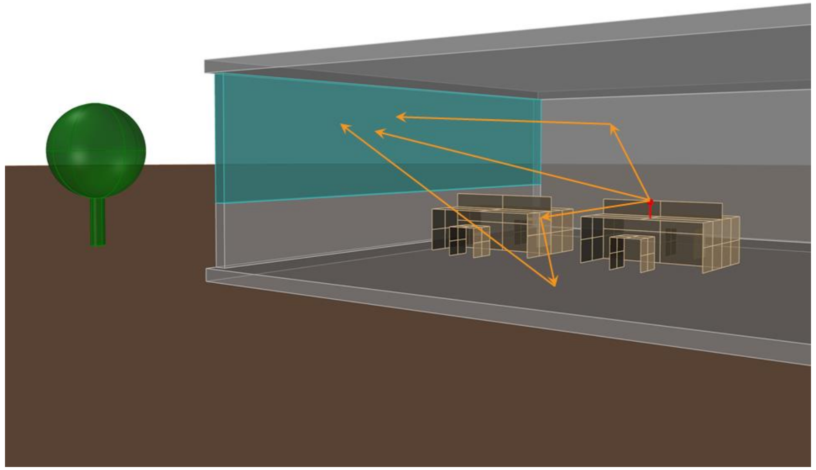
Example files:

https://www.radiance-online.org/learning/tutorials/radTutorialFiles-master.zip



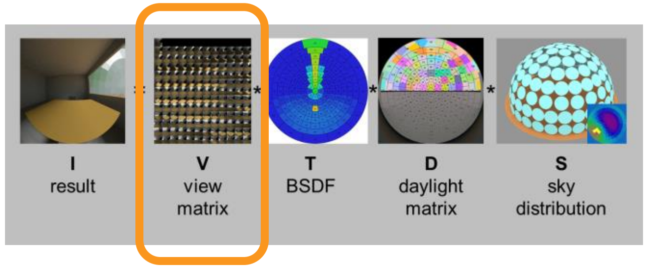
Three-Phase Method





includes	relevant settings
direct contribution leaving the system area	-ad stochastic sampling of façade area in Klems subdivision
all reflected components inside room	-ab n account for all relevant interior interreflections [-I] irradiance calculation

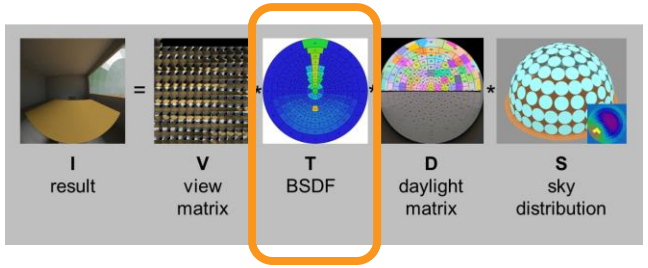
Three-Phase Method

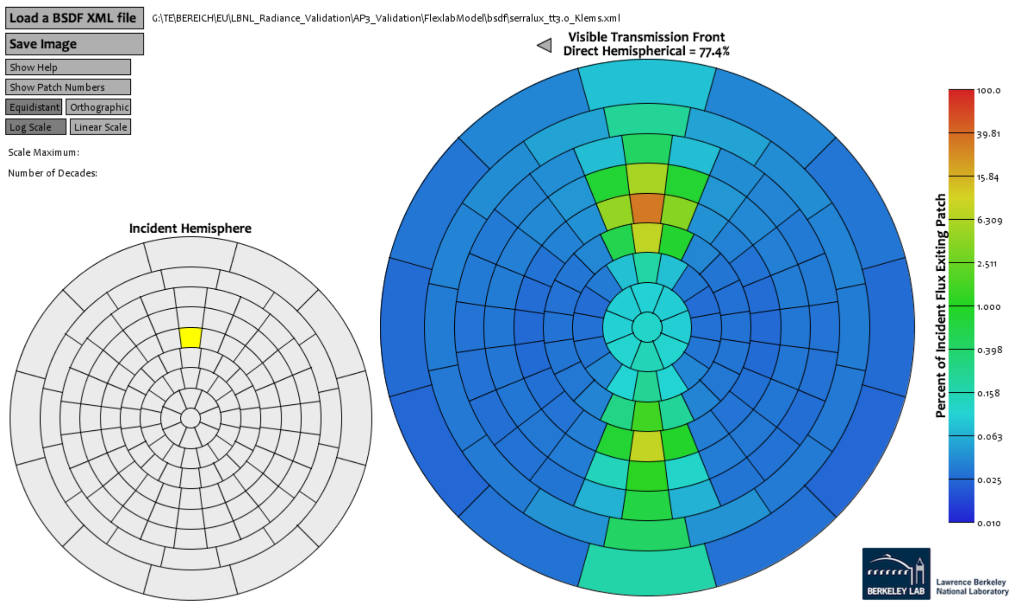



```
#illuminance sensors
rcopts=" -V- -n ${nprocs} -w- -I+ -ab 5 -ad 65536 -lw 1.0e-6 –faa "
rfluxmtx ${rcopts} \
  < pts/tutorial_workplane.pts - scene/tutorial_window_vmx_glow.rad \
  scene/tutorial_room_3pm.rad \
  > matrices/tutorial_room_3pm_sensors.vmx

#images
rcopts=" -V- -n ${nprocs} -w- -ab 5 -ad 16384 -lw 1.0e-6 -ffc „
res=500
vwrays -ff -vf view/view_fish_p01.vf -x ${res} -y ${res} | \
  rfluxmtx ${rcopts} `vwrays -vf view/view_fish_p01.vf -x ${res} -y ${res} -d` \
  - scene/tutorial_window_vmx_glow_img.rad \
  scene/tutorial_room_3pm.rad
```

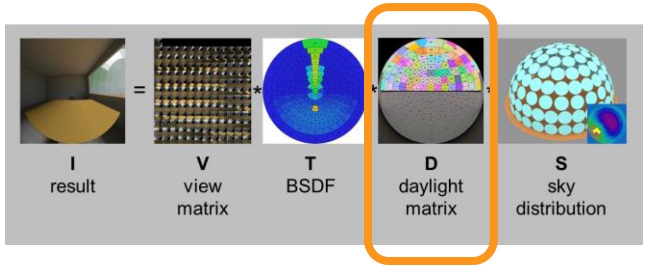
Three-Phase Method

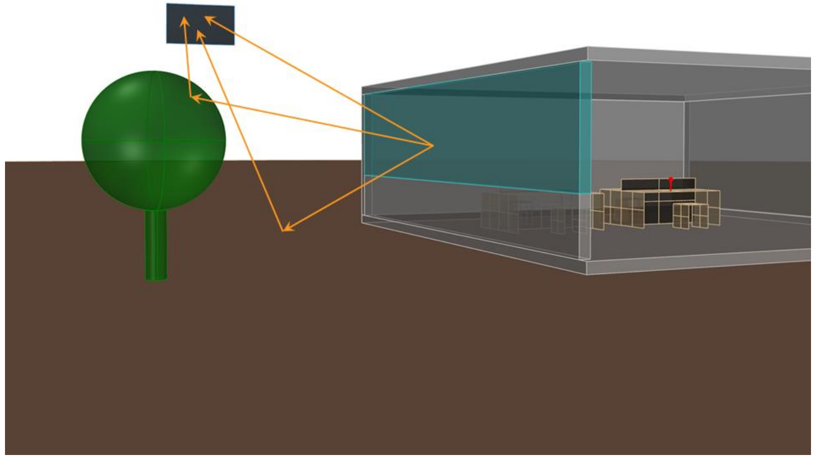




includes	relevant settings
all reflected components within the system	[in genBSDF] <u>-ab n & -lr ≥ n</u> account for all relevant optical paths within the system

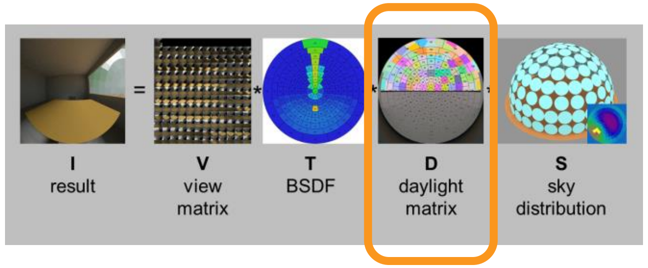
Three-Phase Method





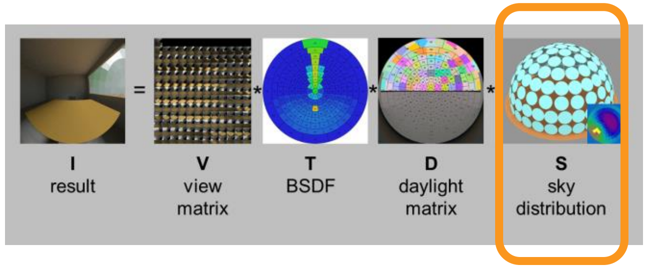
includes	relevant settings
direct contribution from sky / distant ground to façade all reflected components from surroundings	<u>-ab n</u> account for all relevant exterior interreflections

Three-Phase Method




```
#illuminance sensors & images
sky_subdiv=4
rcopts=" -V- -n ${nprocs} -w- -ab 3 -ad 1024 -lw 1.0e-6 –faa "
rfluxmtx ${rcopts} \
  scene/tutorial_window_dmx_dummy.rad misc/sky_glow1_rein${sky_subdiv}.rad \
  mat/tutorial_room.mat scene/tutorial_room.rad \
  > matrices/tutorial_room_3pm_rein${sky_subdiv}.dmx
```

Three-Phase Method

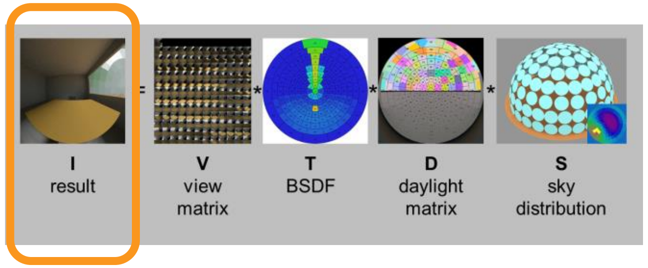



```
#illuminance sensors & images
sky_subdiv=4

# point in time
xform sky/NY_cie_sun_03211000.rad | genskyvec -m ${sky_subdiv} \
  > weather/NY_cie_sun_03211000.skyvec

# time series
epw2wea weather/USA_NY_New.York-Central.Park.725033_TMY3.epw weather/NY_sky.wea
gendaymtx -m ${sky_subdiv} weather/NY_sky.wea > weather/NY_sky.smx
```

Three-Phase Method

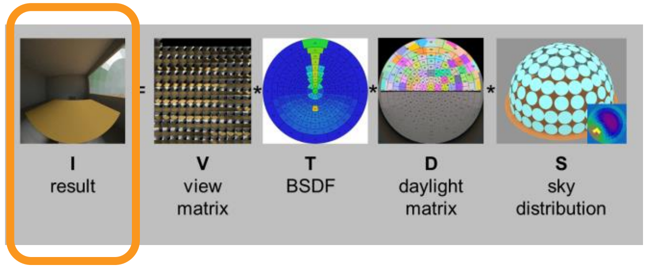


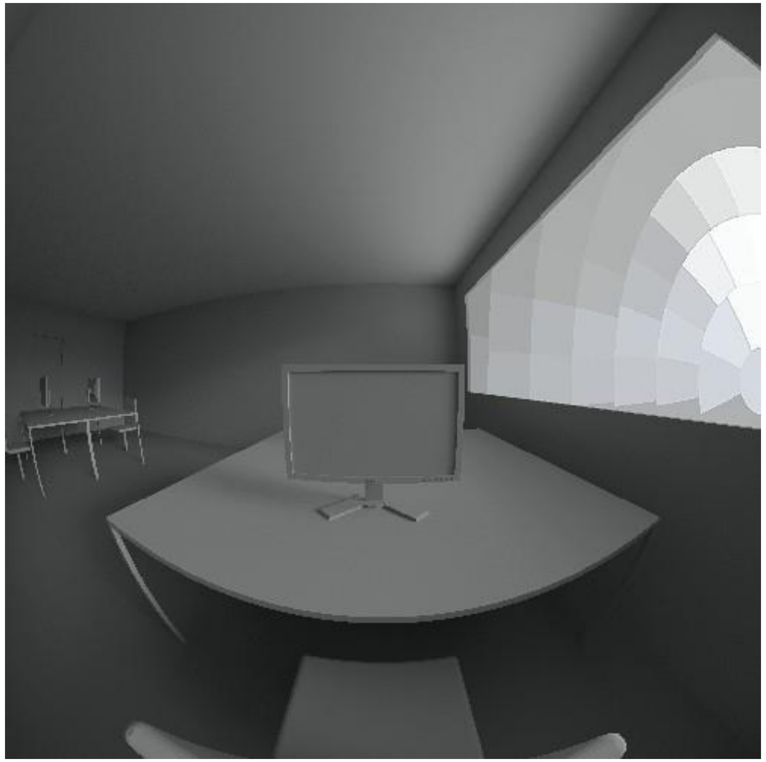

```
var=blinds_20deg
weather=NY_sky

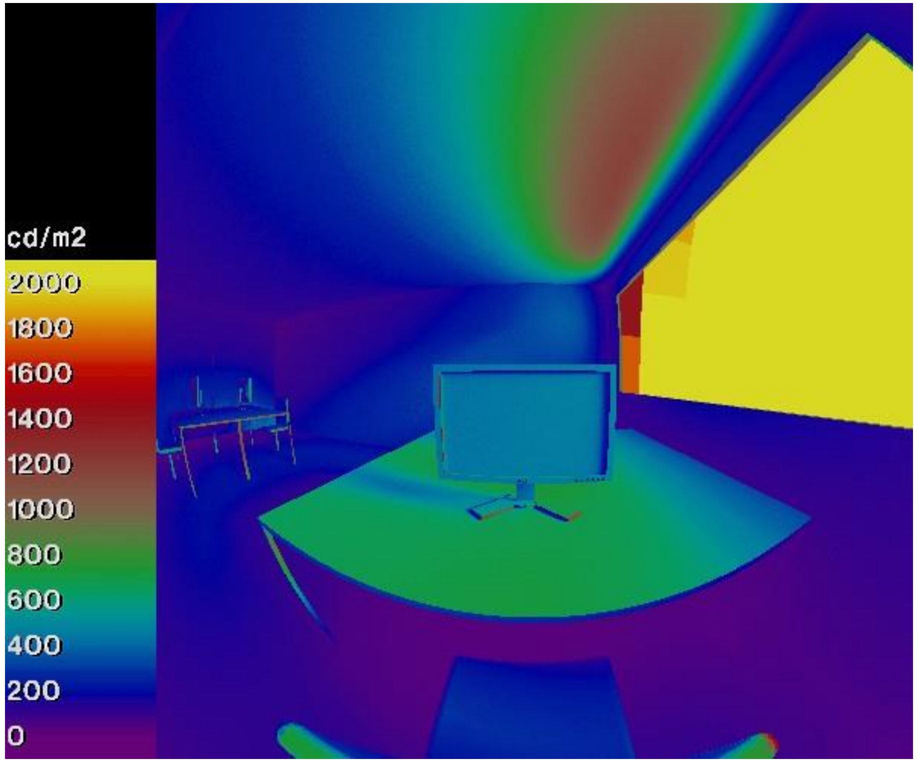
#illuminance sensors
dctimestep matrices/tutorial_room_3pm_sensors.vmx BSDF/${var}_Klems.xml \
  matrices/tutorial_room_3pm_rein1.dmx weather/${weather}.smx \
  > result/${var}_${weather}_3pm.dat
rmtxop -fa -c 47.448 119.951 11.601 -t result/${var}_${weather}_3pm.dat \
  > result/${var}_${weather}_3pm.ill

#images
dctimestep -o result/img_3pm/${var}_${weather}_%04d.hdr \
  matrices/img_vmx/tutorial_room_%03d.hdr BSDF/${var}_Klems.xml \
  matrices/tutorial_room_3pm_rein1.dmx weather/${weather}.smx
```

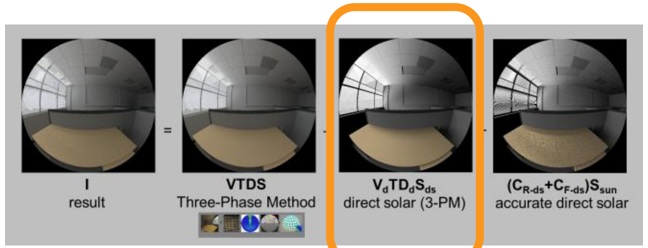
Three-Phase Method



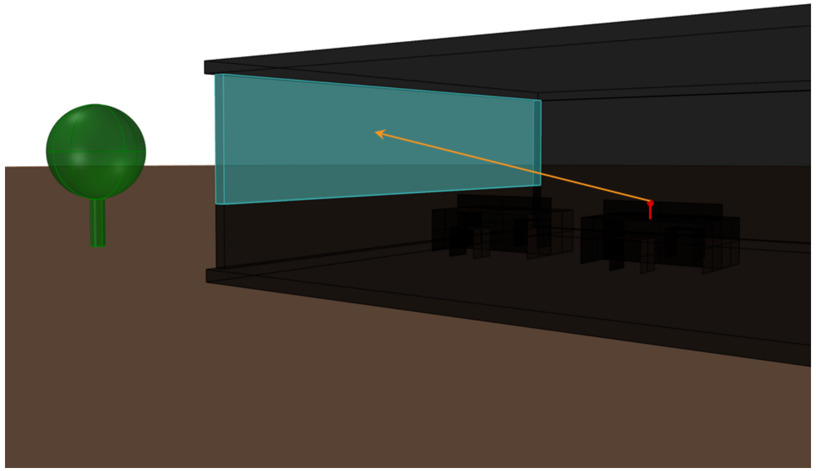




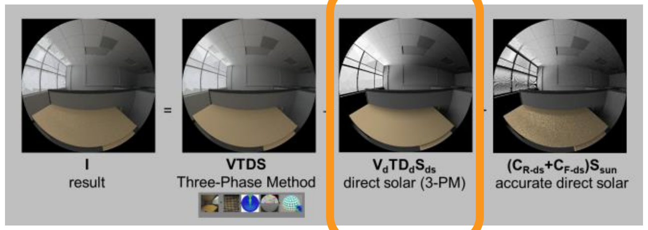
Five-Phase Method



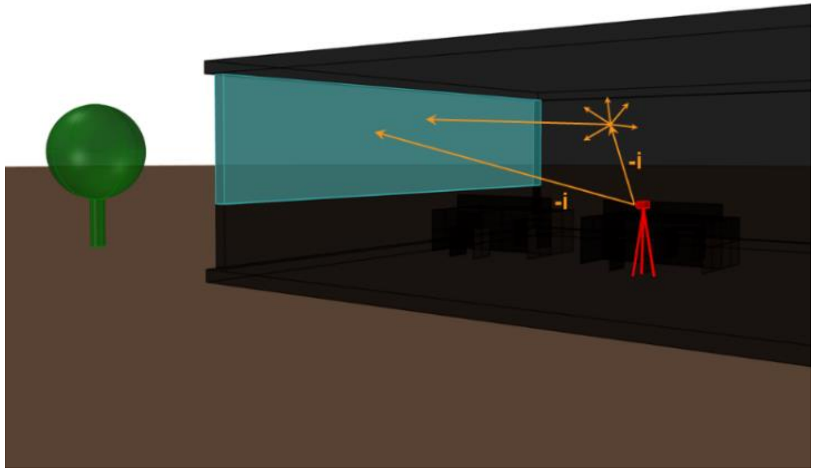
a) direct view matrix

Sensors	Includes	relevant settings
	direct contribution leaving the system area	<u>-xform -m black</u> Set all interior surfaces to black to avoid also specular reflections <u>-I</u> irradiance calculation <u>-ad</u> stochastic sampling of façade area in Klems subdivision <u>-ab 1</u> allow irradiance calculation from façade glow surface

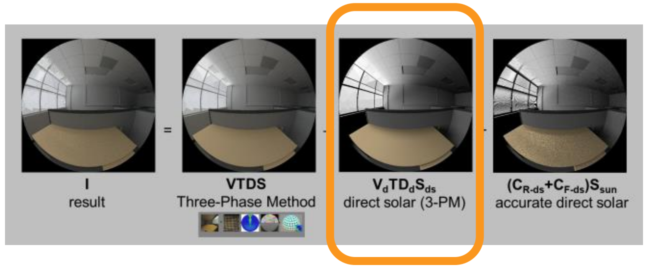
Five-Phase Method



a) direct view matrix

Images	Includes	relevant settings
 The irradiance calculation returns radiance values for the glow surface.	direct contribution on interior surfaces leaving the system area and the direct contribution at view point leaving the system area	-xform -m black Set all interior surfaces to black to avoid also specular reflections -i irradiance calculation -ab 1 allow direct contribution from facade glow surface -ad stochastic sampling of façade area in Klems subdivision vs. number of pixels

Five-Phase Method

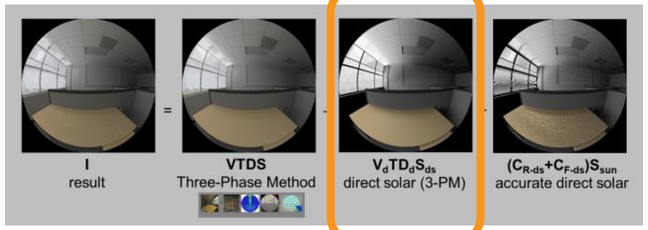


a) direct view matrix

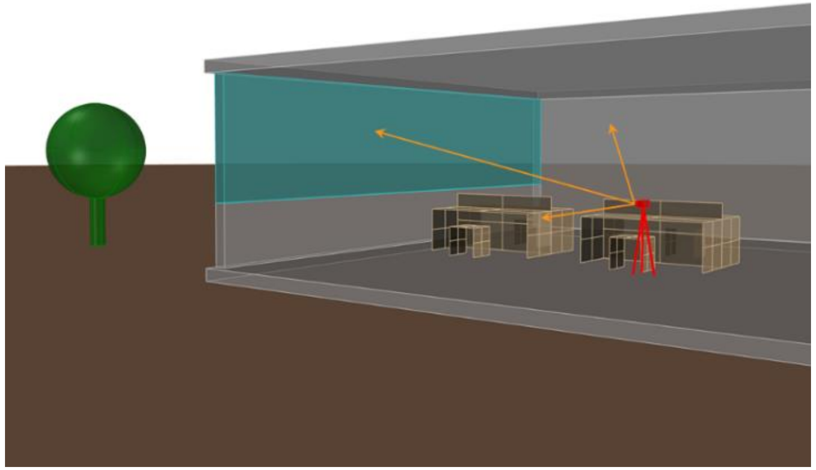
```
#illuminance sensors
rcopts=" -V- -n ${nprocs} -w- -I+ -ab 1 -ad 65536 -lw 1.0e-6 -faa "
rfluxmtx ${rcopts} \
  < pts/tutorial_workplane.pts - scene/tutorial_window_vmx_glow.rad  \
  scene/tutorial_room_5pm_black.rad \
  > matrices/tutorial_room_5pm_sensors.dvmx

#images
rcopts=" -V- -n ${nprocs} -w- -i -ab 1 -ad 16384 -lw 1.0e-6 -ffc "
res=500
vwrays -ff -vf view/view_fish_p01.vf  -x ${res} -y ${res} | \
  rfluxmtx ${rcopts} `vwrays -vf view/view_fish_p01.vf -x ${res} -y ${res} -d` \
  - scene/tutorial_window_vmx_glow_img_dir.rad \
  scene/tutorial_room_5pm_black.rad
```

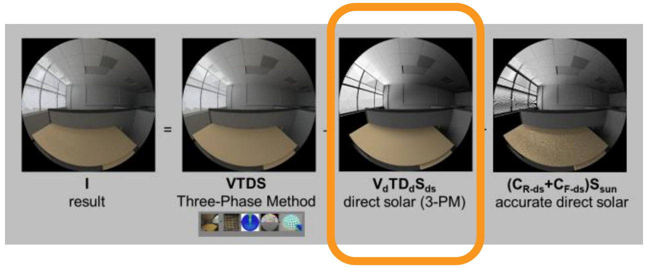
Five-Phase Method



b) convert illuminance to luminance (images)

Images	Includes	relevant settings
	factor for converting illuminance on interior surfaces into luminances and preserve luminances directly at the system	-xform -m glow1 set the system surface to a uniform glowing with radiance = 1 (or just use the glow1 surface as used in the 3 Phase Method View Matrix V) -ab 0 -av 1/π 1/π 1/π

Five-Phase Method



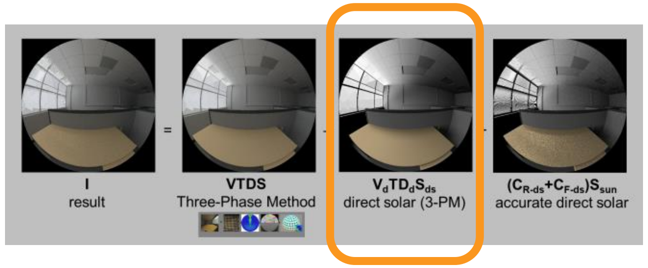
b) convert illuminance to luminance (images)

```
res=500

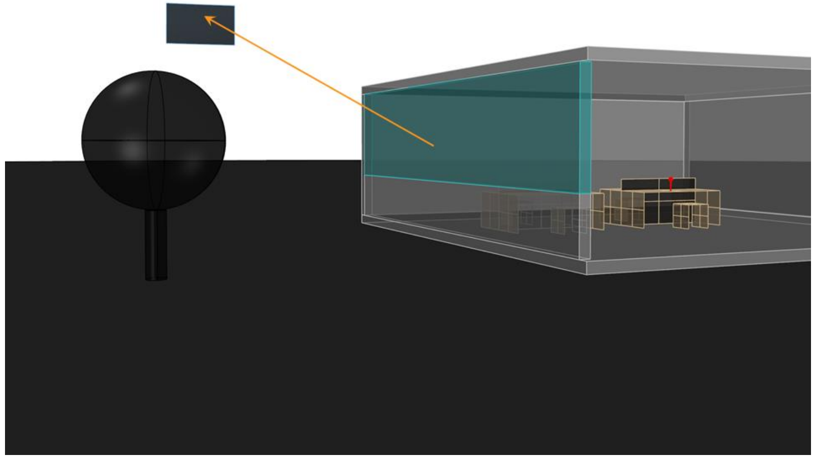
material map 1
oconv -w scene/tutorial_window_vmx_glow_img.rad scene/tutorial_room_3pm.rad > ${oct}
rpict -x ${res} -y ${res} -ps 1 -av 0.31831 0.31831 0.31831 -ab 0 \
  -vf view/view_fish_p01.vf ${oct} > matrices/img_reflmaps/tutorial_room_reflmap_M1.hdr

for img in matrices/img_vmx_dir/*.hdr; do
  pcomb -h -e 'ro=ri(1)*ri(2);go=gi(1)*gi(2);bo=bi(1)*bi(2)' \
  -o matrices/img_reflmaps/tutorial_room_reflmap_M1.hdr -o ${img} \
  > matrices/img_vmx_dir_lum/${img}
done
```

Five-Phase Method

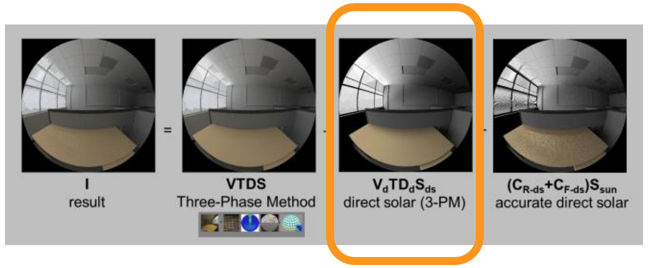


c) direct daylight matrix



Includes	relevant settings
direct contribution from sky / distant ground to façade	<u>-xform -m black</u> Set all exterior surfaces to black to avoid also specular reflections <u>-ab 0</u>

Five-Phase Method

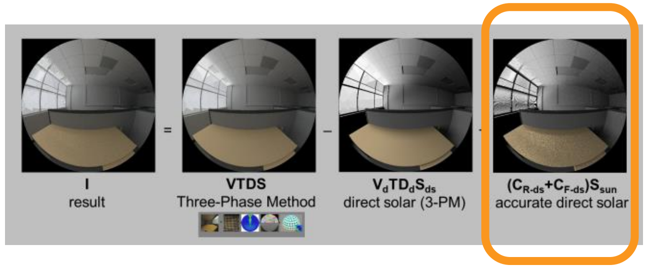


c) direct daylight matrix

```
sky_subdiv=4

#illuminance sensors & images
rcopts=" -V- -n ${nprocs} -w- -ab 0 -ad 1024 -lw 1.0e-6 -faa "
rfluxmtx ${rcopts} \
  scene/tutorial_window_dmx_dummy.rad misc/sky_glow1_rein${sky_subdiv}.rad \
  scene/tutorial_room_5pm_black.rad \
  > matrices/tutorial_room_5pm_rein${sky_subdiv}.ddmx
```

Five-Phase Method

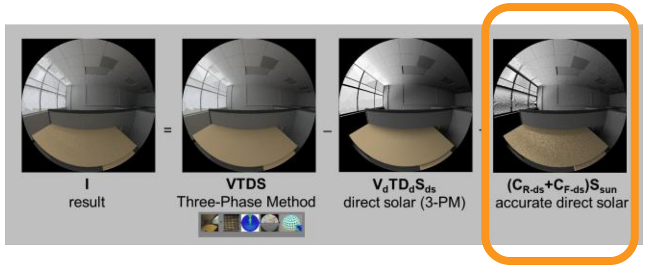


a) direct sun matrix – sun positions

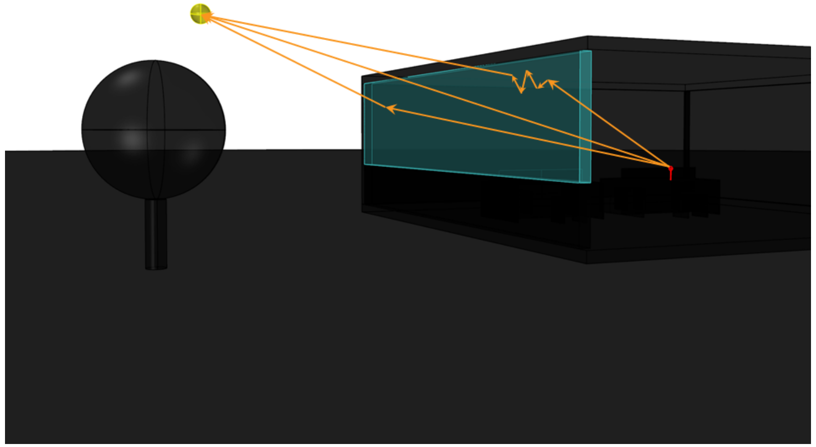
```
mf_sun_pos=6
num_sun_pos=$( ev 144*${mf_sun_pos}*${mf_sun_pos}+1 )

printf "#@rfluxmtx h=r${mf_sun_pos} u=Y\n"     > misc/suns_rein${mf_sun_pos}.rad
printf "void light solar 0 0 3 1e6 1e6 1e6\n" >> misc/suns_rein${mf_sun_pos}.rad
cnt ${num_sun_pos} | rcalc -e MF:${mf_sun_pos} -f reinsrc.cal -e Rbin=recno \
  -o 'solar source sun 0 0 4 ${ Dx } ${ Dy } ${ Dz } 0.5' \
                                              >> misc/suns_rein${mf_sun_pos}.rad
```

Five-Phase Method

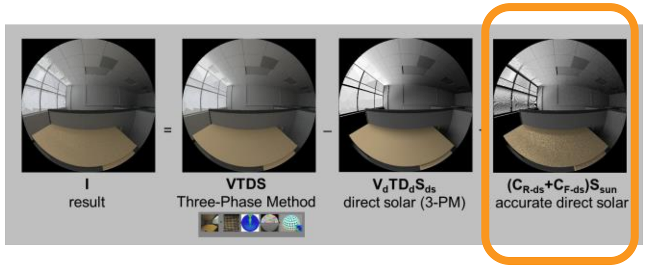


b) direct sun matrix – sensors



Includes	relevant settings
direct sun contribution following the path sun – system – sensor without exterior or interior interreflections	-xform -m black Set all surfaces to black to avoid also specular reflections -I irradiance calculation -ab 1 *[n]* sampling off the BSDF surface for scattered contributions *or account for all relevant optical paths within the system* -ad sampling of façade area with high resolution BSDF

Five-Phase Method



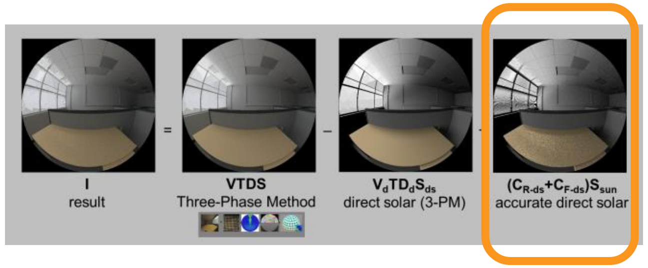
b) direct sun matrix – sensors

```
var=blinds_20deg_BSDF
oconv -w misc/suns_rein${mf_sun_pos}.rad scene/tutorial_room_5pm_dsunmx_${var}.rad > ${oct}

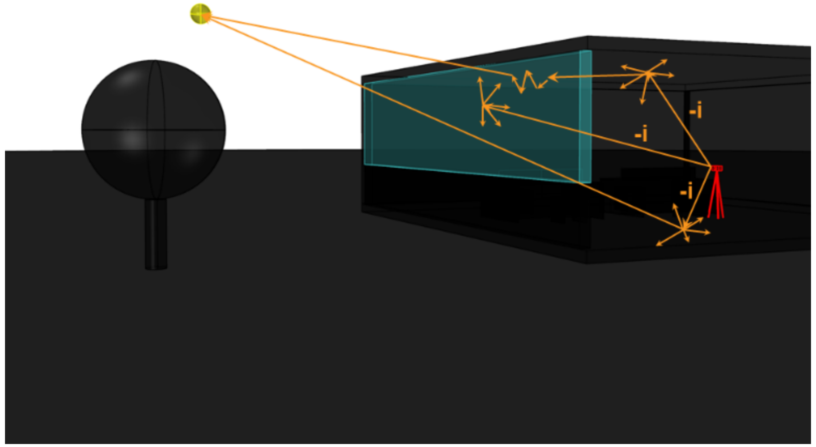
#illuminance sensors
rcopts=" -V- -n ${nprocs} -w- -I+ -ab 1 -ad 65536 -lw 1.0e-6 -dc 1 -dt 0 -dj 0 -faa "

rcontrib < pts/tutorial_workplane.pts ${rcopts} \
  -e MF:${mf_sun_pos} -f reinhart.cal -b rbin -bn Nrbins -m solar ${oct} \
  > matrices/tutorial_room_5pm_sensors_${var}.dsmx
```

Five-Phase Method

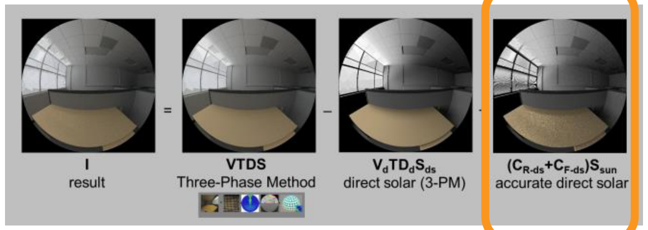


c) direct sun matrix – images room



Includes	relevant settings
direct sun contribution following the path sun – system – sensor without exterior or interior interreflections	-xform -m black Set all surfaces to black to avoid also specular reflections -i irradiance calculation -ab 1 *[n]* sampling off the BSDF surface for scattered contributions *or account for all relevant optical paths within the system* -ad sampling of façade area with high resolution BSDF

Five-Phase Method

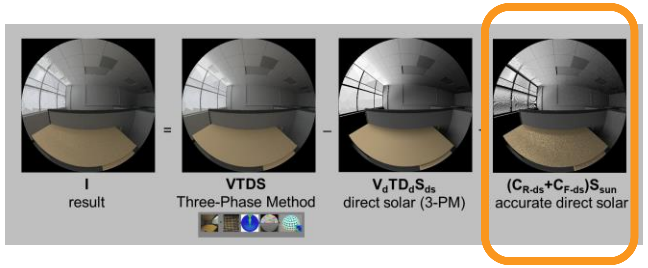


c) direct sun matrix – images room

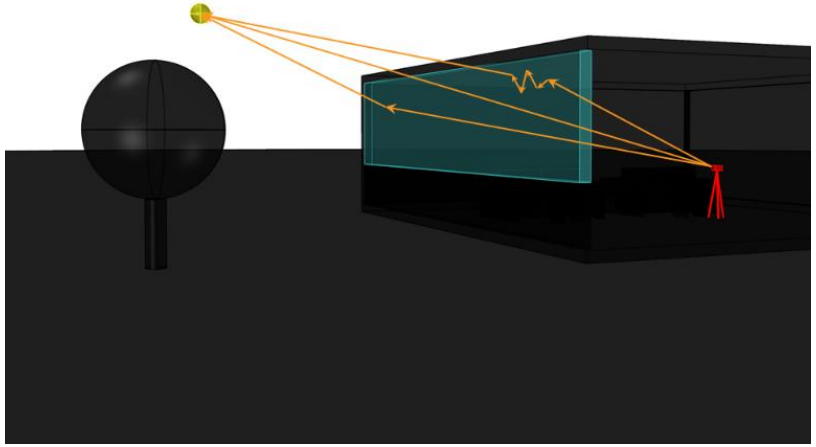
```
var=blinds_20deg_BSDF
oconv -w misc/suns_rein${mf_sun_pos}.rad scene/tutorial_room_5pm_dsunmx_${var}.rad > ${oct}

#images
rcopts=" -V- -n ${nprocs} -w- -i -ab 1 -ad 16384 -lw 1.0e-6 -ffc "
res=500
vwrays -ff -vf view/view_fish_p01.vf  -x ${res} -y ${res} | \
  rcontrib ${rcopts} `vwrays -vf view/view_fish_p01.vf -x ${res} -y ${res} -d` \
  -o matrices/img_vmx_sun_room/tutorial_room_${var}_%04d.hdr \
  -e MF:${mf_sun_pos} -f reinhart.cal -b rbin -bn Nrbins -m solar ${oct}
```

Five-Phase Method

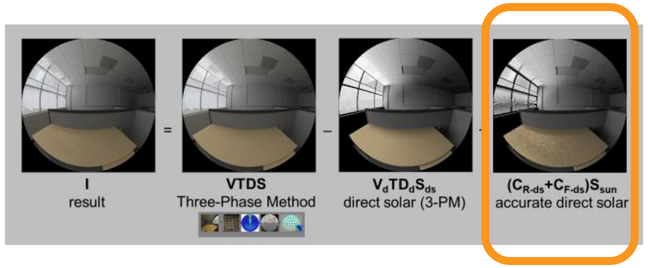


d) direct sun matrix – images facade



Includes	relevant settings
direct sun contribution following the path sun – system – camera without exterior or interior interreflections, i.e. the view of the façade with sun only	-xform -m black Set all surfaces to black to avoid also specular reflections -ab 1 *[n]* sampling off the BSDF surface for scattered contributions *or account for all relevant optical paths within the system* -ad sampling of the BSDF surface for scattered contributions

Five-Phase Method

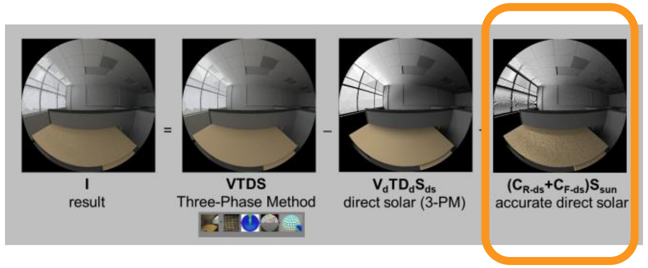


d) direct sun matrix – images facade

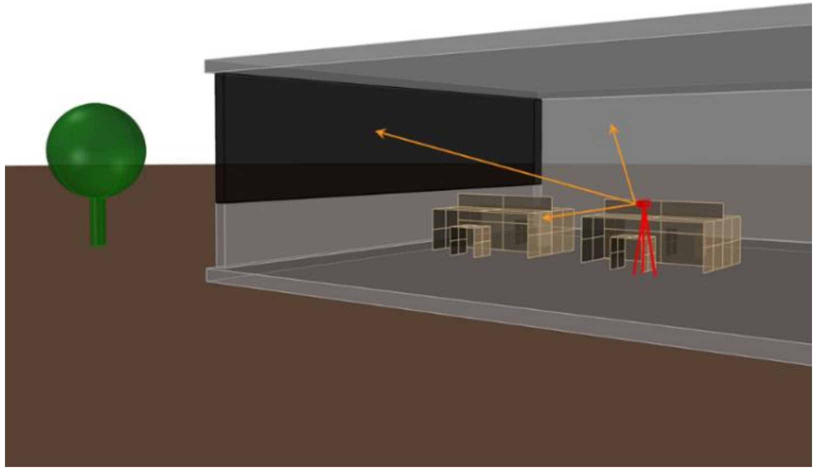
```
var=blinds_20deg_BSDF
oconv -w misc/suns_rein${mf_sun_pos}.rad scene/tutorial_room_5pm_dsunmx_${var}.rad > ${oct}

#images
rcopts=" -V- -n ${nprocs} -w- -ab 5 -ad 16384 -lw 1.0e-6 -ffc "
res=500
vwrays -ff -vf view/view_fish_p01.vf  -x ${res} -y ${res} | \
  rcontrib ${rcopts} `vwrays -vf view/view_fish_p01.vf -x ${res} -y ${res} -d` \
  -o matrices/img_vmx_sun_fac/tutorial_room_${var}_%04d.hdr \
  -e MF:${mf_sun_pos} -f reinhart.cal -b rbin -bn Nrbins -m solar ${octree}
```

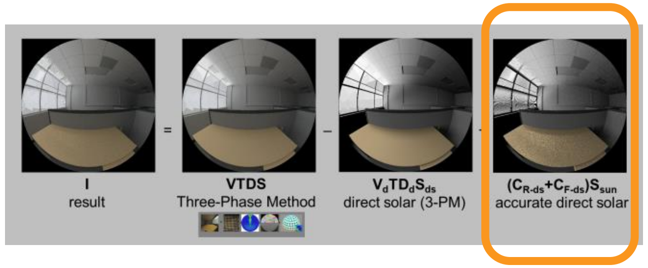
Five-Phase Method



e) convert illuminance to luminance (room images) and add room & facade

Images	Includes	relevant settings
	factor for converting illuminance on interior surfaces into luminances and preserve luminances directly at the system	-xform -m glow1 set the system surface to a uniform glowing with radiance = 1 (or just use the glow1 surface as used in the 3 Phase Method View Matrix V) -ab 0 -av 1/π 1/π 1/π

Five-Phase Method



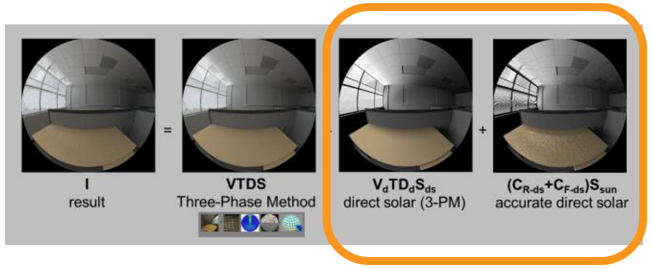
e) convert illuminance to luminance (room images) and add room & facade

```
res=500

material map 2 (for direct sun matrix)
oconv -w scene/tutorial_window_vmx_sun_black.rad scene/tutorial_room_3pm.rad >${oct}
rpict -x ${res} -y ${res} -ps 1 -av 0.31831 0.31831 0.31831 -ab 0 \
  -vf view/view_fish_p01.vf ${oct} > matrices/img_reflmaps/tutorial_room_reflmap_M2.hdr

for img in matrices/img_vmx_sun_room/*.hdr; do
  pcomb -h -e 'ro=ri(1)*ri(2)+ri(3);go=gi(1)*gi(2)+gi(3);bo=bi(1)*bi(2)+bi(3)‘ \
  -o matrices/img_reflmaps/tutorial_room_reflmap_M2.hdr -o ${img} \
  -o matrices/img_vmx_sun_fac/${img}.hdr \
  > matrices/img_vmx_sun_all/${img}.hdr
done
```

Five-Phase Method



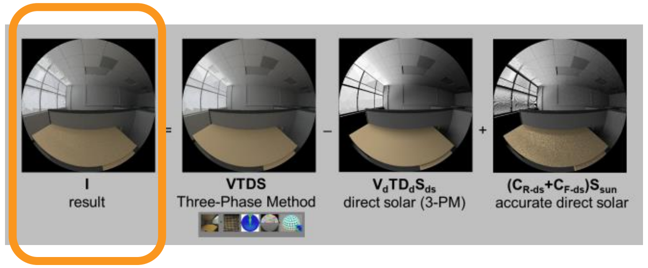
a) direct sky and sun

```
#illuminance sensors & images
sky_subdiv=4
mf_sun_pos=6

# point in time
xform sky/NY_cie_sun_03211000.rad | genskyvec -d -m ${sky_subdiv} \
  > weather/NY_cie_sun_03211000_direct.skyvec
xform sky/NY_cie_sun_03211000.rad | genskyvec -5 -d -m ${mf_sun_pos} \
  > weather/NY_cie_sun_03211000_direct_sun.skyvec

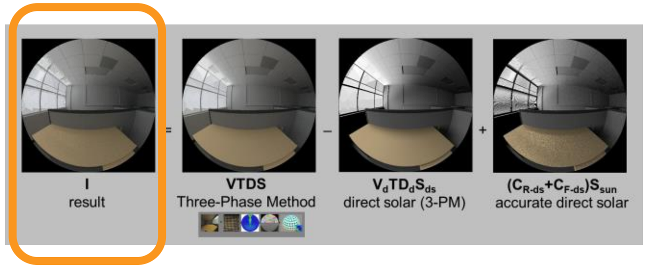
# time series
gendaymtx -d -m ${sky_subdiv} weather/NY_sky.wea \
  > weather/NY_sky_direct.smx
gendaymtx -5 0.5 -d -m ${mf_sun_pos} weather/NY_sky.wea \
  > weather/NY_sky_direct_sun.smx
```

Five-Phase Method



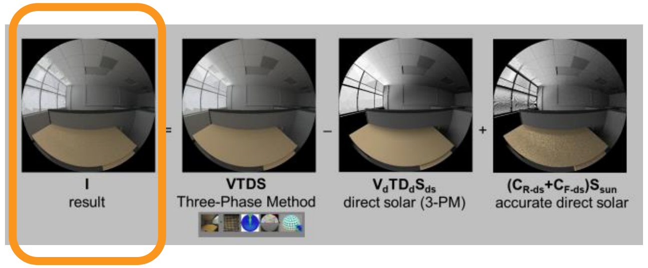

```
weather=NY_sky
var=blinds_20deg
#illuminance sensors
# (1) 3PM direct
dctimestep matrices/tutorial_room_5pm_sensors.dvmx BSDF/${var}_Klems.xml \
  matrices/tutorial_room_5pm_rein1.ddmx weather/${weather}_direct.smx \
  > result/${var}_${weather}_3pm_dir.dat
# (2) 5PM accurate direct
sys=blinds_20deg_BSDF
dctimestep matrices/tutorial_room_5pm_sensors_${sys}.dsmx \
  weather/${weather}_direct_sun.smx > result/${sys}_${weather}_5pm_dir_sun.dat
# (3) calc (3PM - 3PM_dir + 5PM_dir) ...
rmtxop result/${var}_${weather}_3pm.dat + -s -1 result/${var}_${weather}_3pm_dir.dat + \
  result/${sys}_${weather}_5pm_dir_sun.dat | \
  rmtxop -fa -c 47.448 119.951 11.601 -t - > result/${sys}_${weather}_5pm.ill
```

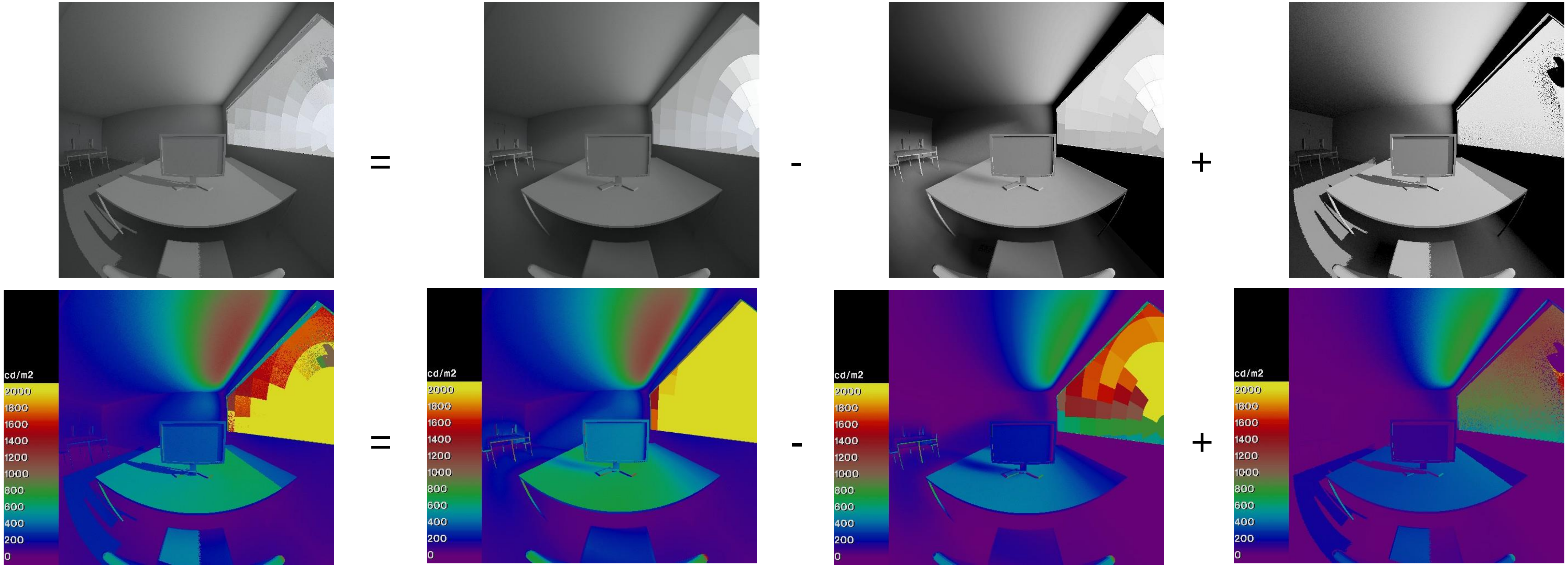
Five-Phase Method




```
#images
# (1) 3PM direct
dctimestep -o result/img_3pm_dir/${var}_${weather}_%04d.hdr \
  matrices/img_vmx_dir_lum/tutorial_room_%03d_lum.hdr BSDF/${var}_Klems.xml \
  matrices/tutorial_room_5pm_rein1.ddmx weather/${weather}_direct.smx
# (2) 5PM accurate direct
sys=blinds_20deg_BSDF
dctimestep -o result/img_5pm_dir_sun/${var}_${weather}_%04d_${sys}.hdr \
  matrices/img_vmx_sun_all/tutorial_room_${sys}_%04d.hdr weather/${weather}_direct_sun.smx
# (3) calc (3PM - 3PM_dir + 5PM_dir) ...
for img in result/img_3pm/${var}_${weather}_????.hdr; do
  img_b=$(basename ${img} .hdr)
  pcomb -h -e 'ro=ri(1)-ri(2)+ri(3);go=gi(1)-gi(2)+gi(3);bo=bi(1)-bi(2)+bi(3)' \
  -o ${img} -o result/img_3pm_dir/${img}.hdr -o result/img_5pm_dir_sun/${img_b}_${sys}.hdr \
  > result/img_5pm/${img_b}_${sys}.hdr
done
```

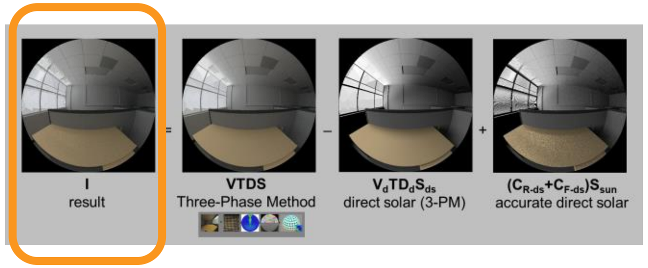
Five-Phase Method

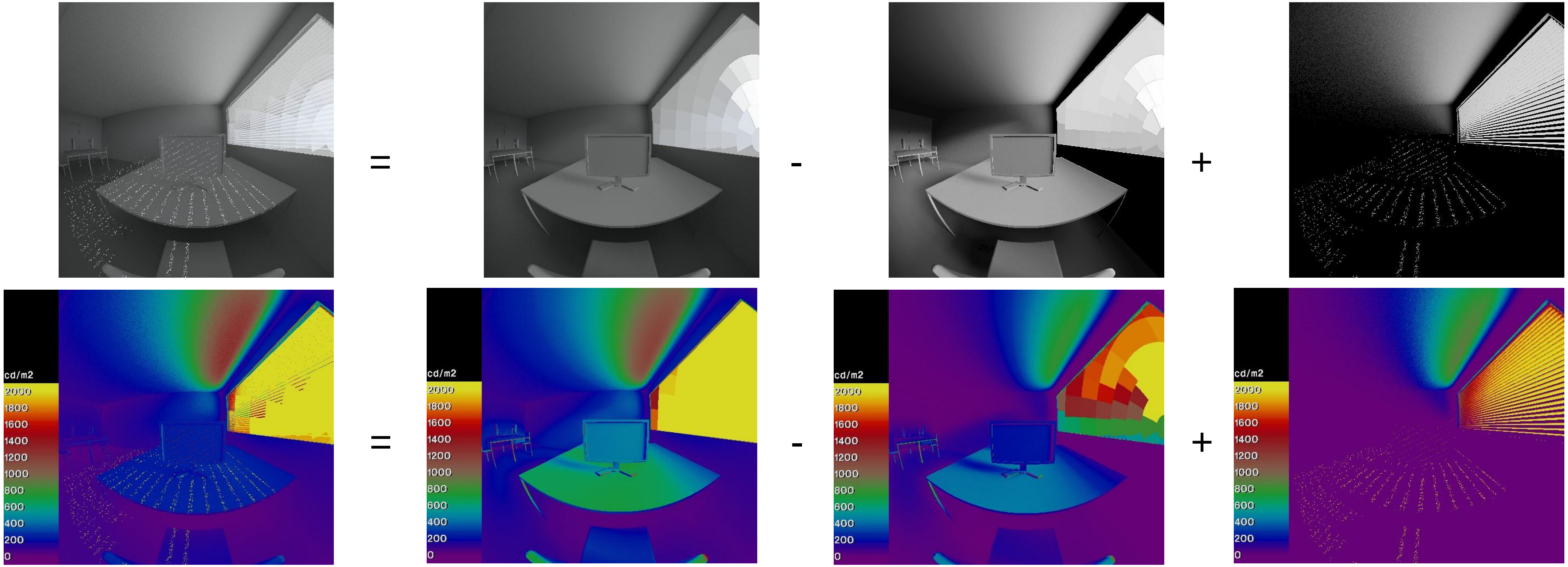




Five-Phase-Method Three-Phase-Method Three-Phase direct accurate direct

Five-Phase Method





Five-Phase-Method Three-Phase-Method Three-Phase direct accurate direct