Complex Fenestration in *Radiance*

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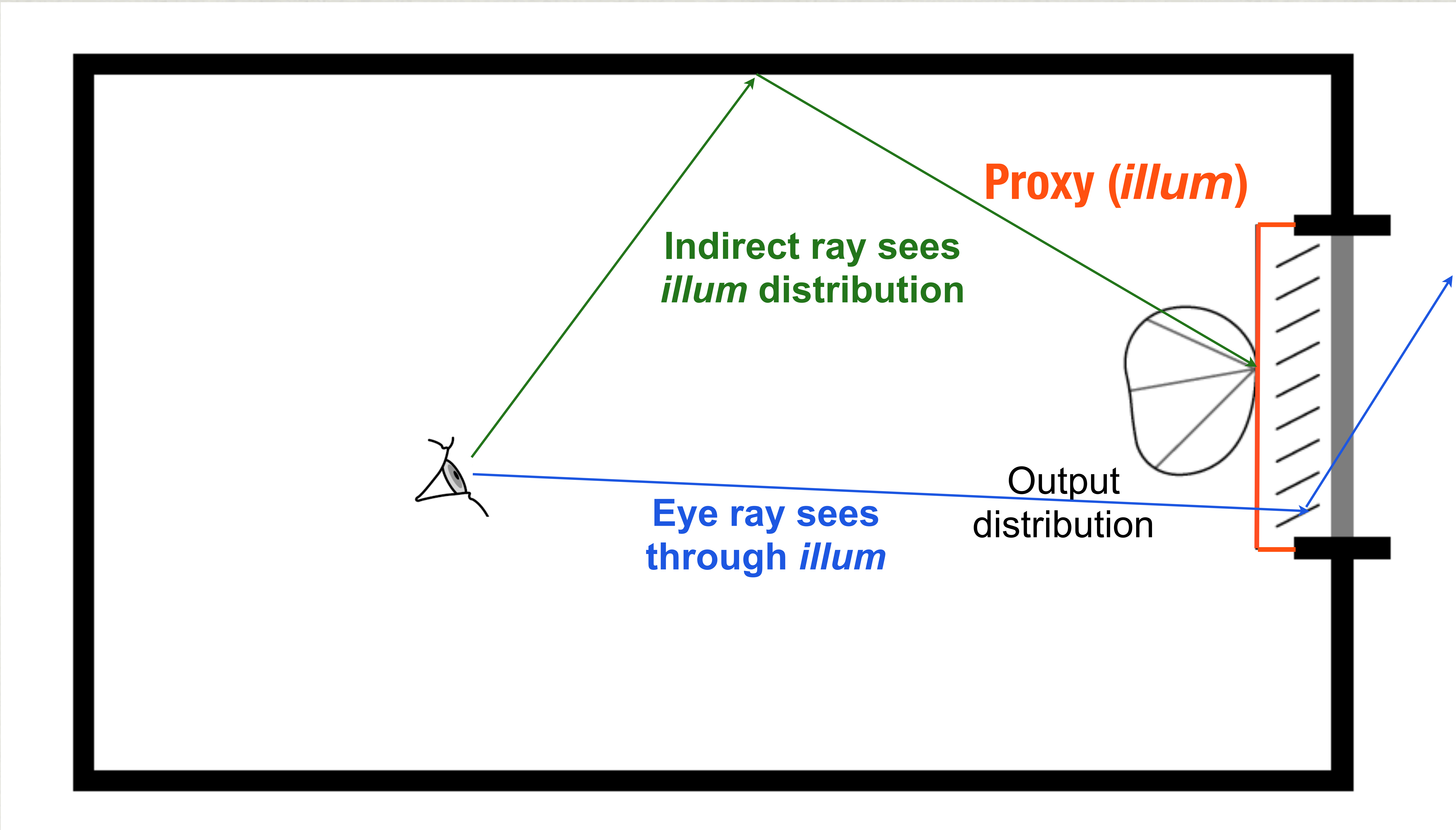
Talk Overview

- History of complex fenestration in *Radiance*
- WINDOW 6 input to **mkillum**
- Using **genBSDF** to compute bidirectional scattering distribution function for new system
- Three-phase DC method for annual simulations
- New developments

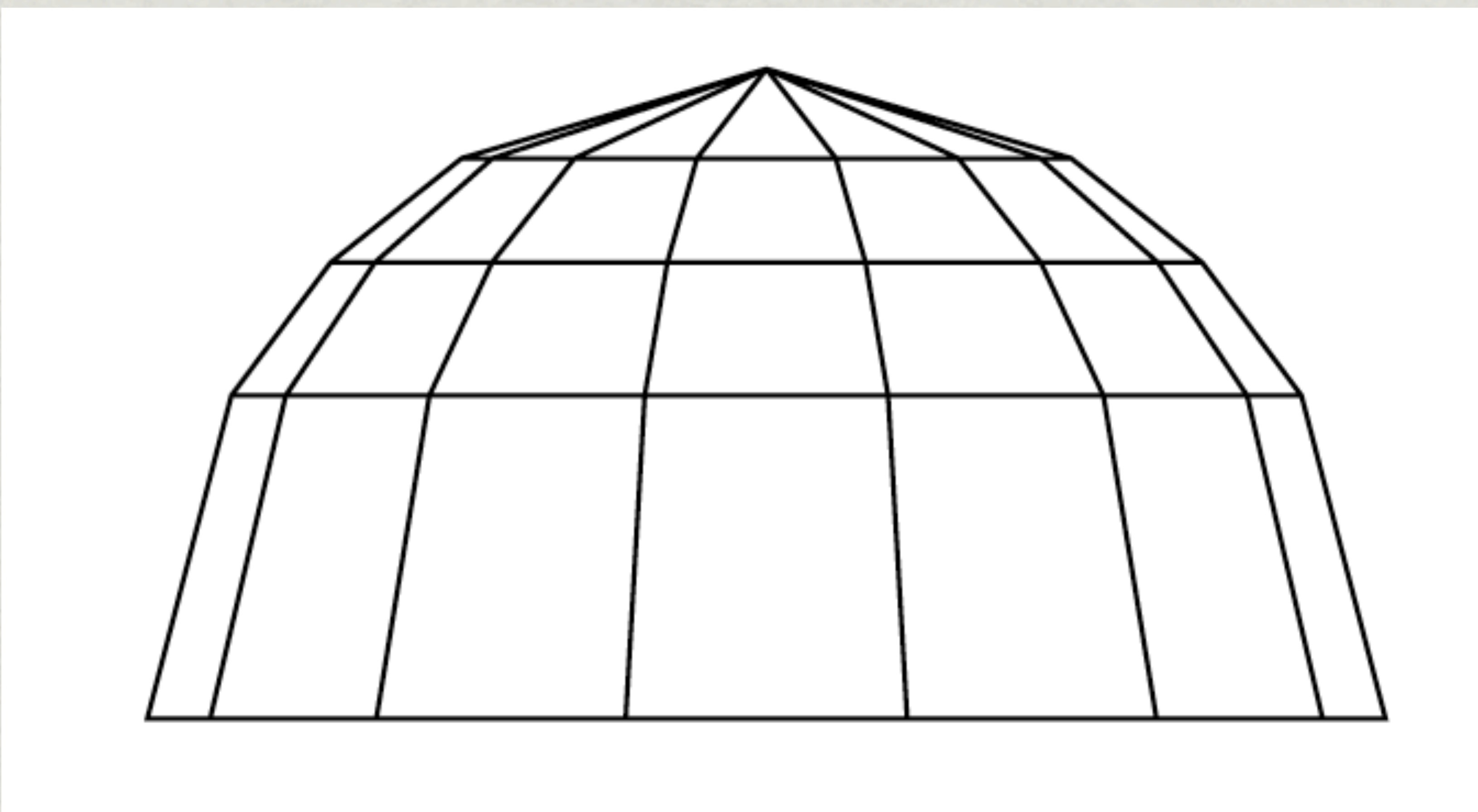
The History of CFS in *Radiance*

- Use *illum* concept of proxied “secondary sources”
- The **mkillum** program has been around since 1991
  - Added during sabbatical at EPFL
  - Turns complex fenestration into proxy sources
  - Fails for sunlight on curved, specular systems

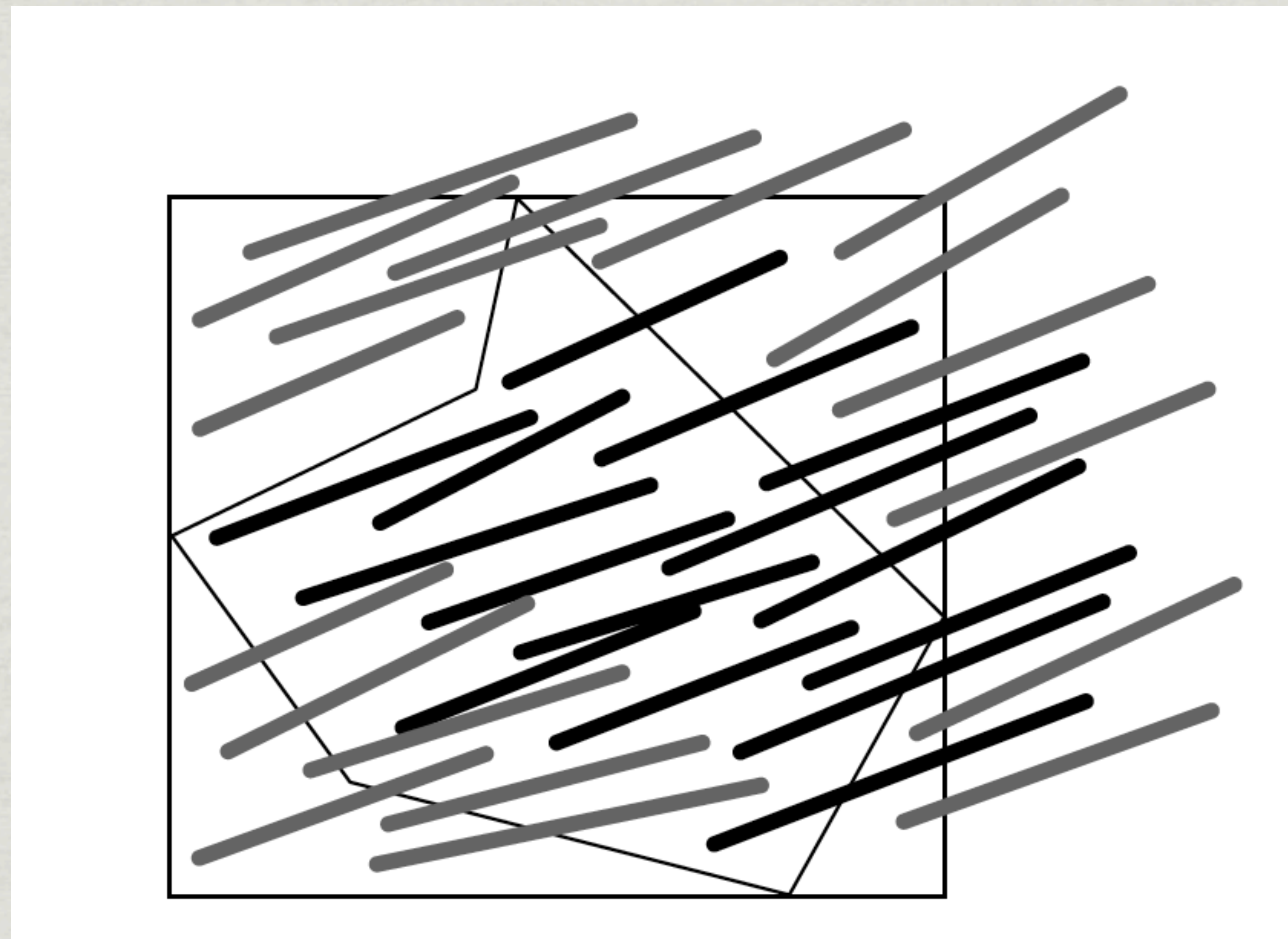
Example Space



mkillum Sampling

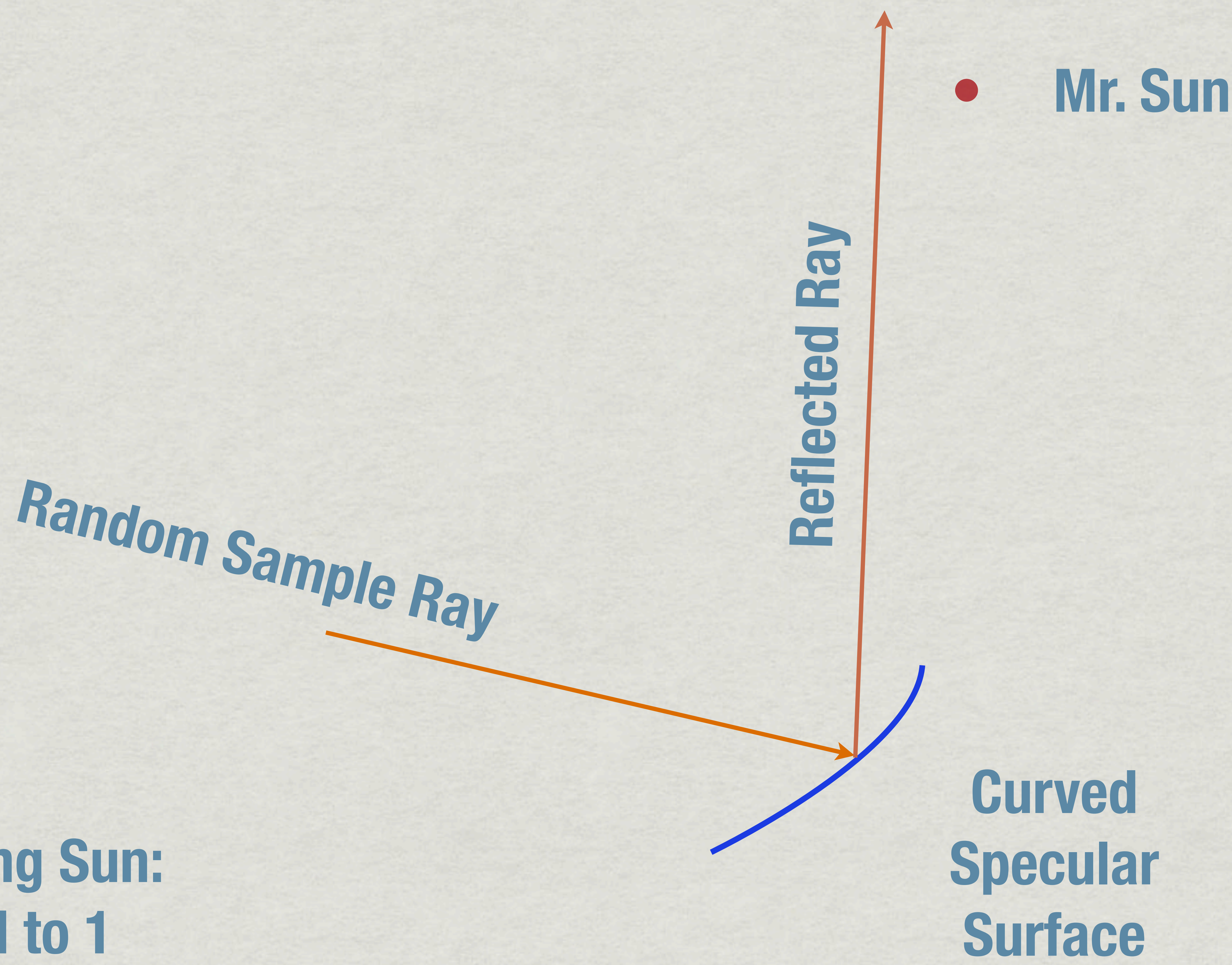


Hemispherical Sampling Directions



Polygon Rejection Sampling

Specular Sampling



Chance of Hitting Sun:
100 thousand to 1

WINDOW 6 Input to **mkillum**

- WINDOW 6 supports 4-dimensional BSDF data
  - New XML format defined by LBNL
  - 145 input directions → 145 output directions
- **mkillum** samples exterior and uses BTDF to compute interior *illum* distribution
  - Overcomes limitations with specular systems

WINDOW 6 XML File


```
  <WavelengthData>
  <Wavelength unit="Integral">NIR</Wavelength>
  <SourceSpectrum>CIE Illuminant D65 1nm.ssp</SourceSpectrum>
  <DetectorSpectrum>ASTM E308 1931 Y.dsp</DetectorSpectrum>
  <WavelengthDataBlock>
      <WavelengthDataDirection>Transmission Front</WavelengthDataDirection>
      <ColumnAngleBasis>LBNL/Klems Full</ColumnAngleBasis>
      <RowAngleBasis>LBNL/Klems Full</RowAngleBasis>
      <ScatteringDataType>BTDF</ScatteringDataType>
      <ScatteringData>
 2.443881,   0.047337,   0.041435,   0.038990,   0.041435,
0.047337,   0.048413,   0.046964,   0.048413,   0.047337,
0.040883,   0.035154,   0.031478,   0.030108,   0.031363,
0.035154,   0.040605,   0.047337,   0.048086,   0.044691,
0.042586,   0.042007,   0.042537,   0.044691,   0.047921,
0.047337,   0.038892,   0.031273,   0.025227,   0.021345,
0.020007,   0.021345,   0.025227,   0.031273,   0.038892,
...
```

Rendering Comparison 1

Radiance reference rendering

Rendering Comparison 2

mkillum from geometry only

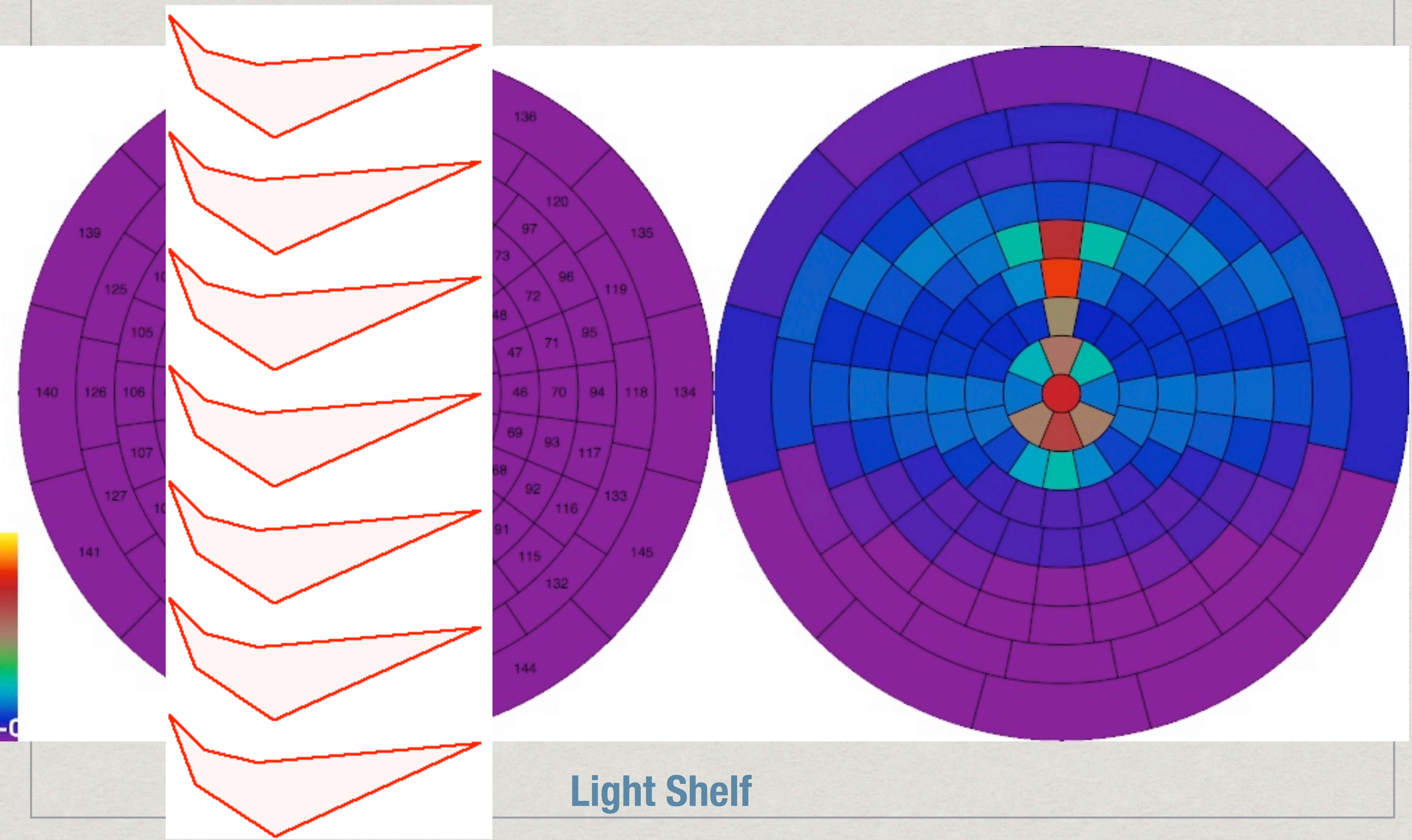
Rendering Comparison 3

mkillum using BTDF data from WINDOW 6

Computing BSDFs with **genBSDF**

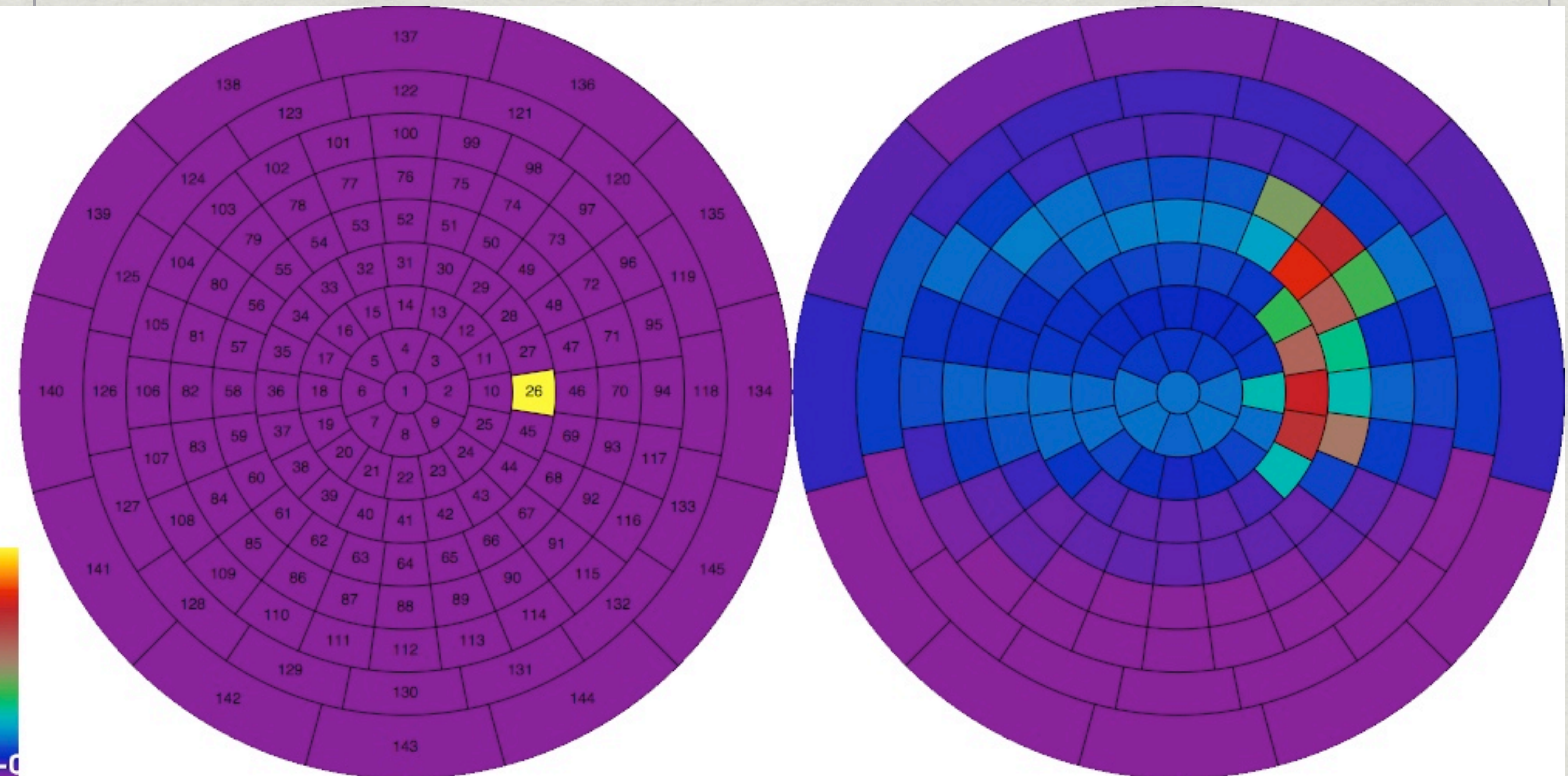
- Uses **rtcontrib** to sample *Radiance* model of complex fenestration system
- Assembles results into WINDOW 6 format XML file
- Output usable in WINDOW 6 as well as *Radiance*
- Can include MGF description of CFS geometry

Sample BTDF Data (1)



Light Shelf

Sample BTDF Data (2)



Light Shelf

Visualization by Andrew McNeil

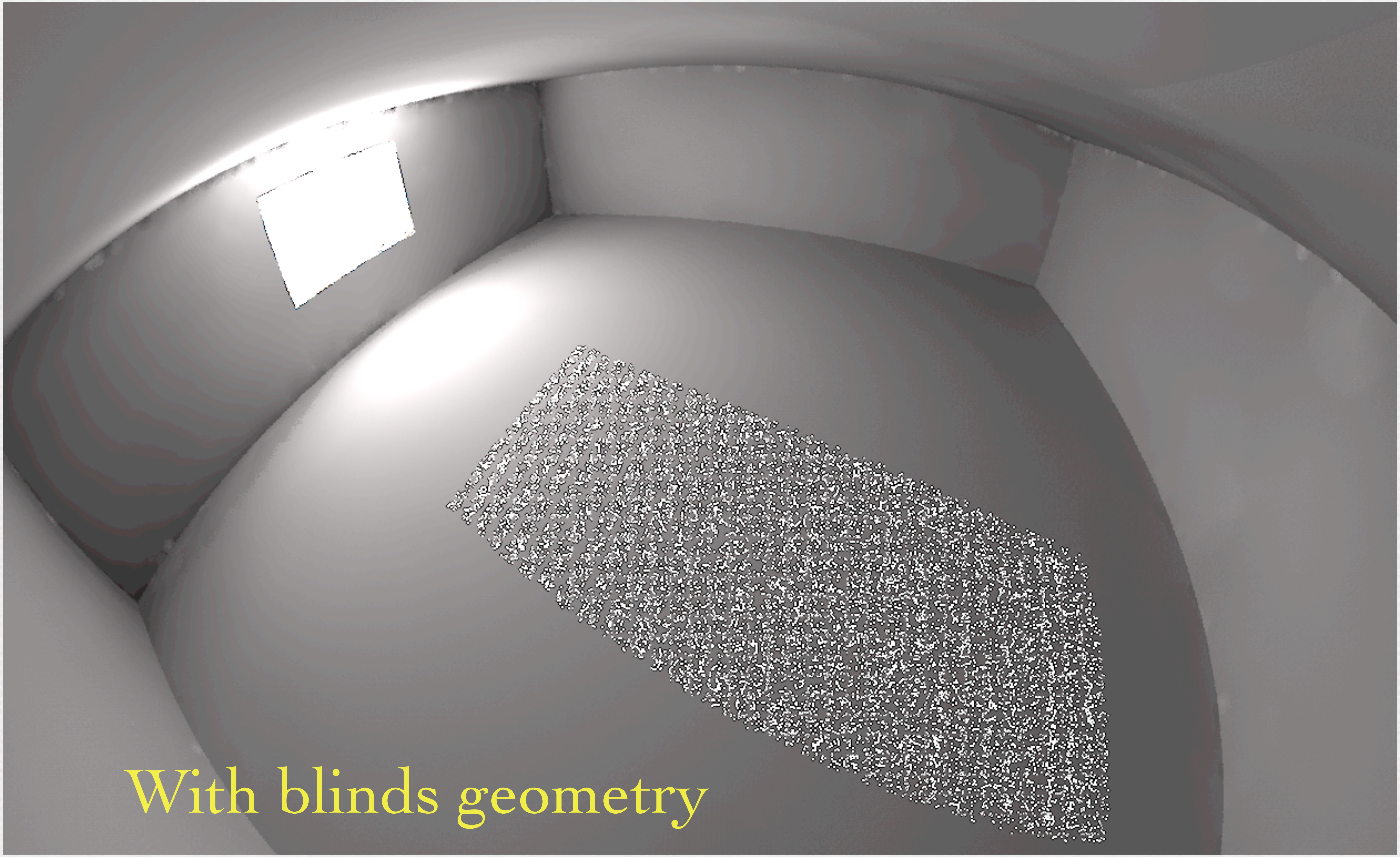
Sample MGF

XML embedding

```
<Geometry format="MGF" unit="Meter">
# Y-axis points "up", Z-axis into room, right-handed coordinates
m WhitePlastic =
     rd .7
     rs .02 0
     sides 2
o VenetianBlinds
xf -rx -60 -a 67 -t 0 .03 0
    o Slat
     v v1 =
         p -2 0 0
     v v2 =
         p 2 0 0
     v v3 =
         p 2 0 .04
     v v4 =
         p -2 0 .04
     f v1 v2 v3 v4
    o
xf
o
</Geometry>
```

Supports arrays

Example Results



Annual Simulation

- Using mkillum with BTDFs is fairly quick, but...
- Re-rendering a scene 2000+ times for each hour?
- We need something faster...
- Can we use daylight coefficients with BTDF data?

Three Phase Method

- **Phase I**:
  Use **rtcontrib** to get daylight coefficients relating sky patches to incident directions

- **Phase II**:
  Use **rtcontrib** to relate exiting portal directions to desired measurement locations (e.g., image)

- **Phase III** (time-step calculation):
  sky * incident * BTDF * exiting

Our Matrix Equation

i = VTDs

where:

i	is the desired result vector (radiances, irradiances, etc.)
V	is the "View" matrix defining the lighting connection between results and exiting directions for a window group
T	is the "Transmission" matrix defining the BTDF of the window group
D	is the "Daylight" matrix defining the coefficients between incoming directions for the window group and sky patches
s	is a vector of sky patch luminances for a particular time and date

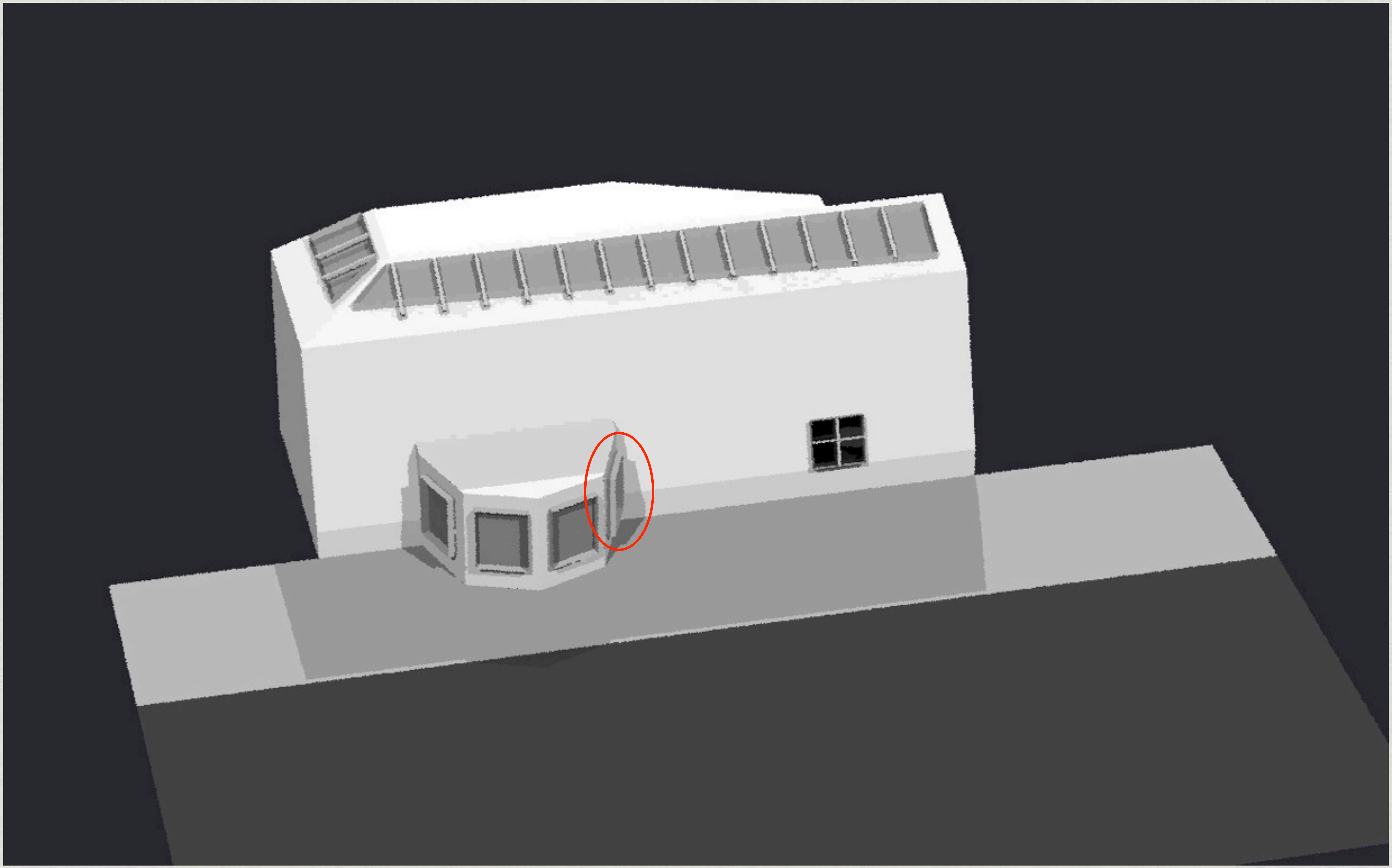
In a more explicit form, this would be:

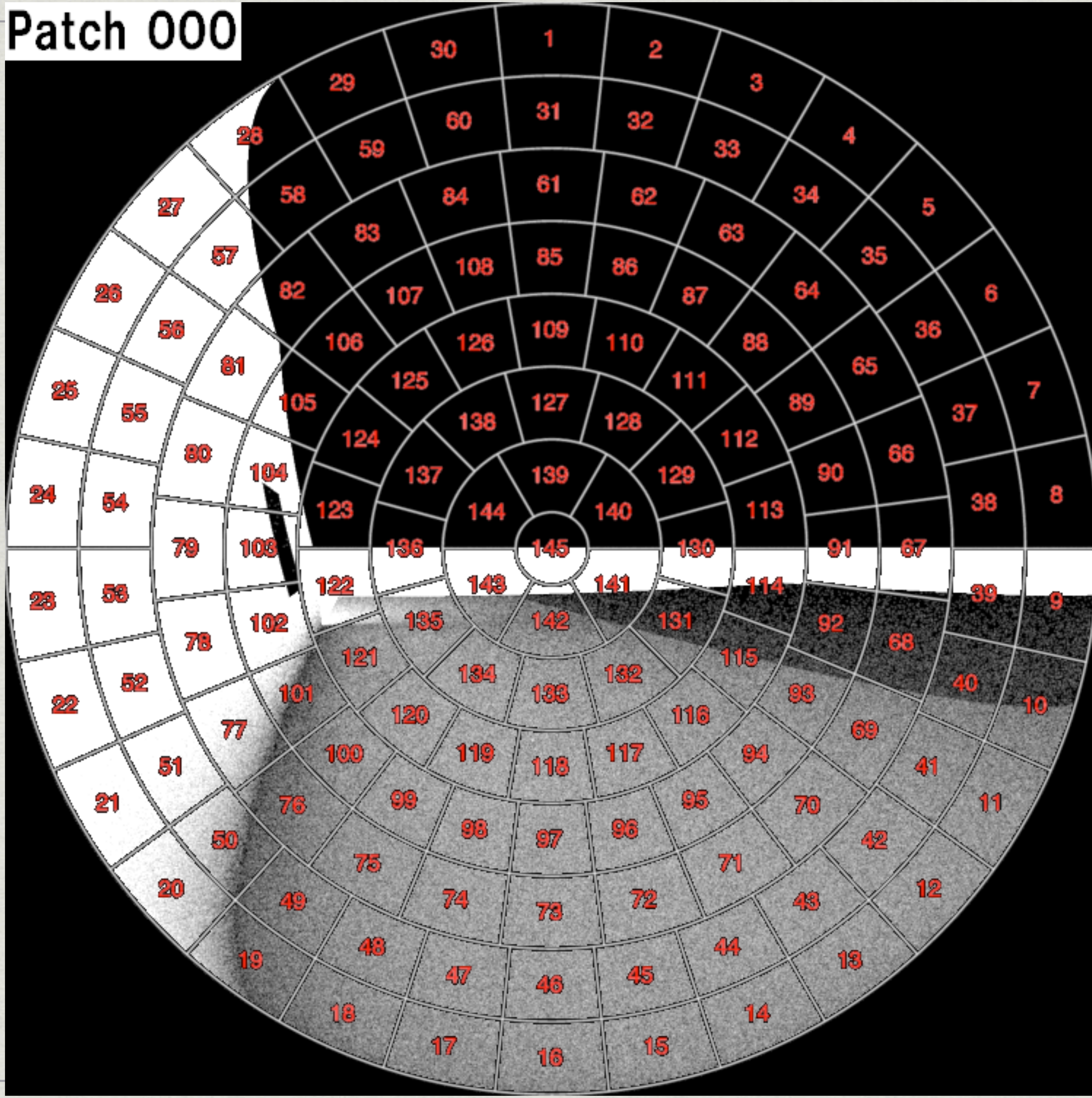
$$\begin{bmatrix} sens1 \\ \ldots \\ sensM \end{bmatrix} = \begin{bmatrix} sens1edir1 & \ldots & sens1edirN \\ \ldots & \ldots & \\ sensMedir1 & & sensMedirN \end{bmatrix} \begin{bmatrix} edir1idir1 & \ldots & edir1idirN \\ \ldots & \ldots & \\ edirNidir1 & & edirNidirN \end{bmatrix} \begin{bmatrix} idir1dc1 & \ldots & idir1dcK \\ \ldots & \ldots & \\ idirNdc1 & & idirNdcK \end{bmatrix} \begin{bmatrix} sky1 \\ \ldots \\ skyK \end{bmatrix}$$

Phase I: Compute **D**

- Apply **rtcontrib** to relate sky patches to incident directions on window exterior
  - Need separate calculation for each orientation and major geometric feature
  - **genklemsamp** utility generates samples over a given window group

Example Space




Patch 000
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30
31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60
61 62 63 64 65 66 67 68 69 70 71 72 73 74 75 76 77 78 79 80 81 82 83 84
85 86 87 88 89 90 91 92 93 94 95 96 97 98 99 100 101 102 103 104 105 106 107 108
109 110 111 112 113 114 115 116 117 118 119 120 121 122 123 124 125 126
127 128 129 130 131 132 133 134 135 136 137 138
139 140 141 142 143 144
145

Phase II: Compute **V**

- Use **rtcontrib** to relate sensor locations to exiting directions on window interiors
  - a single run can cover all window groups
  - **`klems_int.cal`** file maps to BTDF coord.

Outgoing Directions for One Window Group

Phase III: Time Step

- Use **genskyvec** to create sky patch vector **s**
- Use **dctimestep** to multiply it all together

BTDF

Result Vector

Sky Patch Vector

$$\mathbf{i} = \mathbf{VTDs}$$

View Matrix

Daylight Matrix

Phase III Example

```
gensky 9 21 12:00 -a 37.71 -o 122.21 -m 120 | genskyvec > sky.dat
pcomb '!dctimestep comp/back_SouthGroup%03d.hdr blinds1.xml SouthGroup.dmx sky.dat' \
   '!dctimestep comp/back_WestGroup%03d.hdr blinds2.xml WestGroup.dmx sky.dat' \
   '!dctimestep comp/back_NorthGroup%03d.hdr blinds2.xml NorthGroup.dmx sky.dat' \
   '!dctimestep comp/back_EastGroup_%03d.hdr blinds1.xml EastGroup.dmx sky.dat' \
  > back_9-21_1200.hdr
rm sky.dat
```

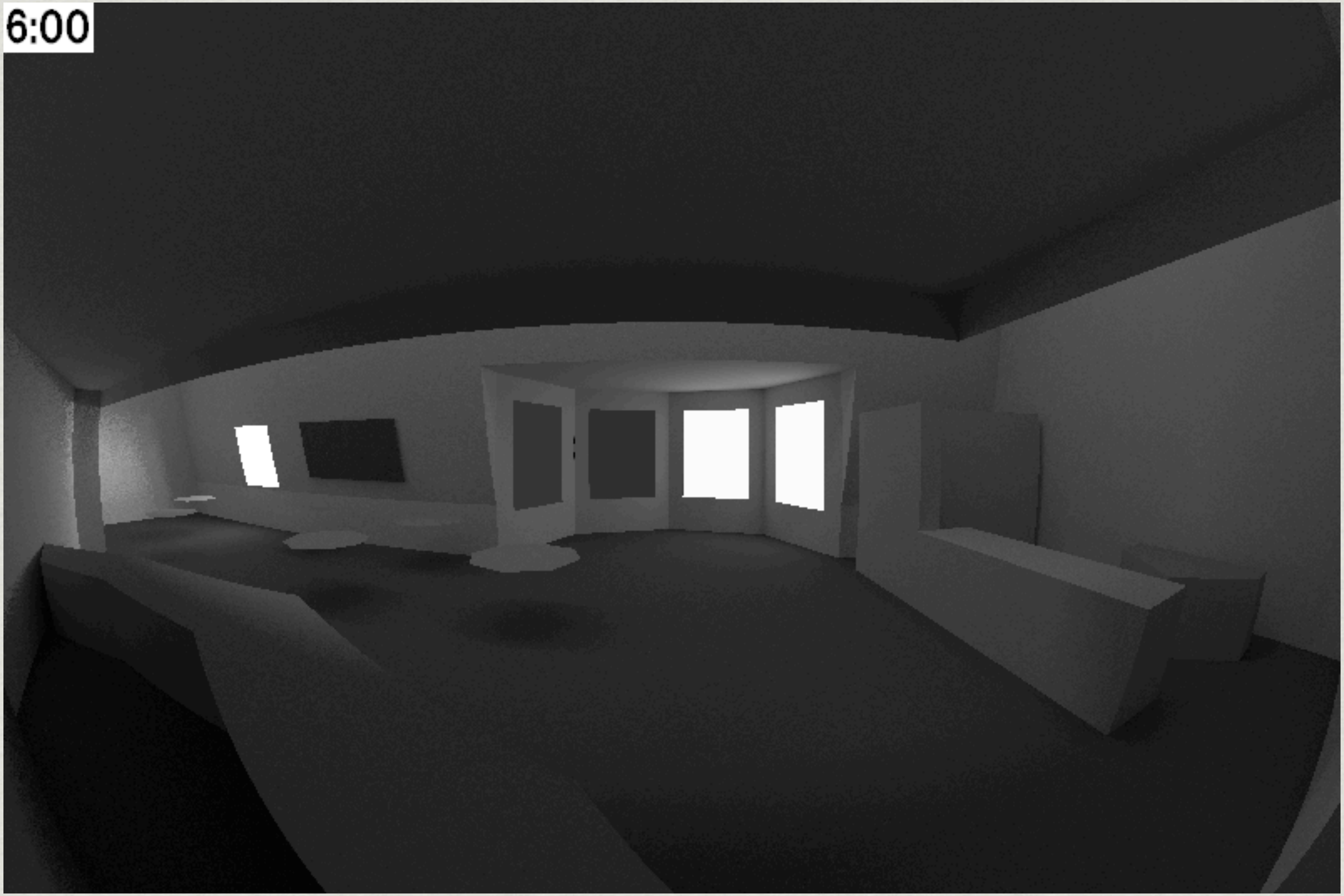
Phase III Example

Generate sky vector for noon at the Autumn equinox

```
gensky 9 21 12:00 -a 37.71 -o 122.21 -m 120 | genskyvec > sky.dat
pcomb '!dctimestep comp/back_SouthGroup%03d.hdr blinds1.xml SouthGroup.dmx sky.dat' \
   '!dctimestep comp/back_WestGroup%03d.hdr blinds2.xml WestGroup.dmx sky.dat' \
   '!dctimestep comp/back_NorthGroup%03d.hdr blinds2.xml NorthGroup.dmx sky.dat' \
   '!dctimestep comp/back_EastGroup_%03d.hdr blinds1.xml EastGroup.dmx sky.dat' \
  > back_9-21_1200.hdr
rm sky.dat
```

Each call to **dctimestep** computes contributions of one window group

Time to run the above is less than 4 seconds on my laptop



Equinox Simulation

New Developments

- Until now, BTDF data (but not BRDF) could be used in specific *Radiance* settings:
  - **mkillum** (neglecting interior window reflections)
  - Annual simulations using 3-phase DC method
- *Radiance* 4.1 will support BSDF data directly
  - Including new variable-resolution specification