# Calculating and Applying BSDFs in *Radiance*

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Anyhere Software

# Goals

- Support WINDOW 6 BSDF output (XML)
- Create WINDOW 6 BSDFs from geometric models using freeware (i.e., *Radiance*)
- Render accurate images with direct shading using **mkillum**
- Perform efficient annual simulations
- Support higher-resolution BSDF data

# Status

- WINDOW 3 BSDF format still subject to revision
- Support for reading and creating BSDFs is currently limited to transmittance data
- **mkillum** has been tested and refined to produce reasonable accuracy for diffusing systems
- New **genBSDF** tool for creating BSDF files from geometric (*Radiance* or MGF) descriptions
- Annual simulation for the **daring** with **rtcontrib**

# What Is a BSDF?

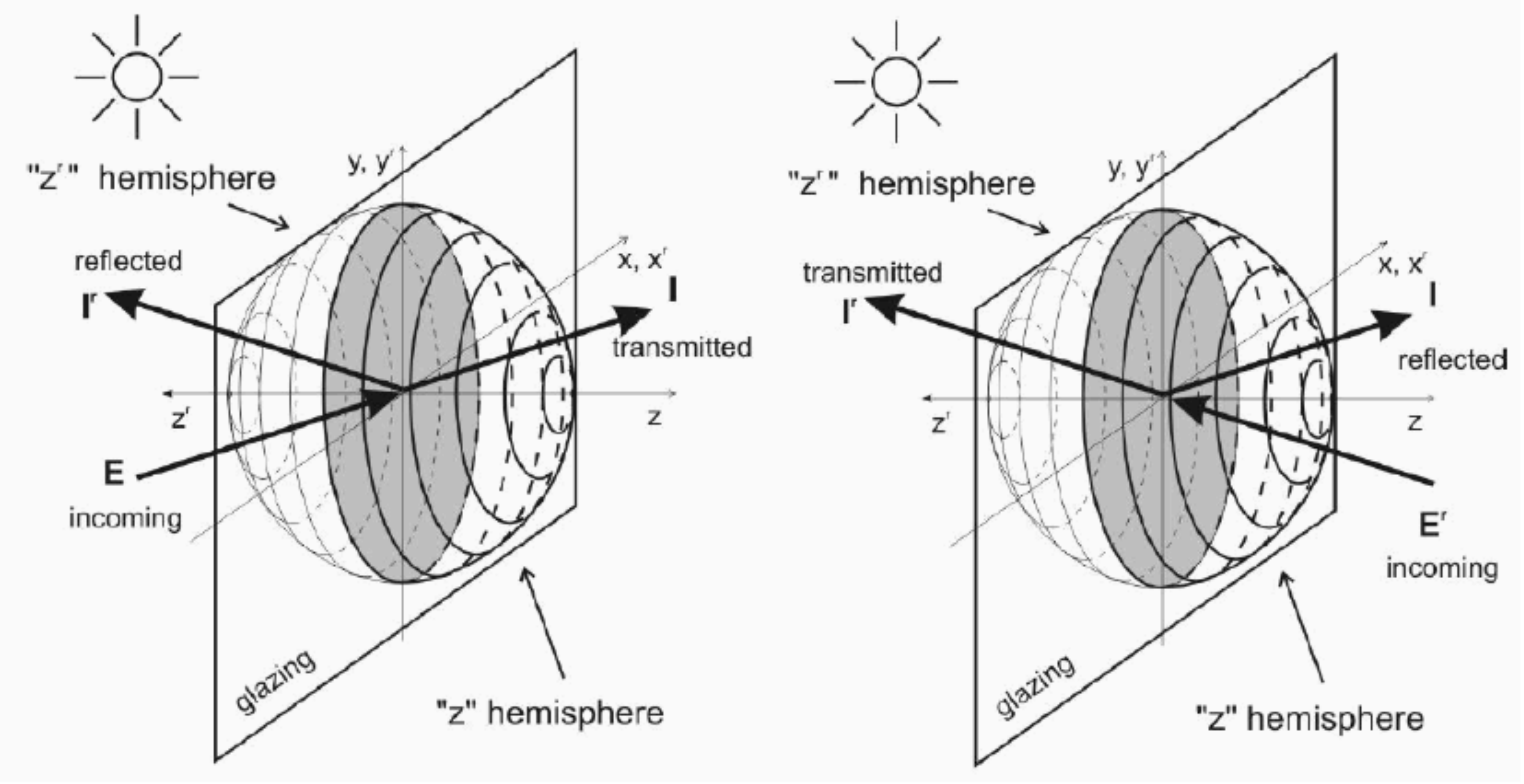
- "BSDF" stands for "Bidirectional Scattering Distribution Function" (BRDF + BTDF)
- Describes how light scatters off a surface
- Incl. wavelength, a 5-dimensional scalar function
  - unitless ratio of outgoing radiance over incoming irradiance (1/steradian)

# WINDOW 6 BSDF

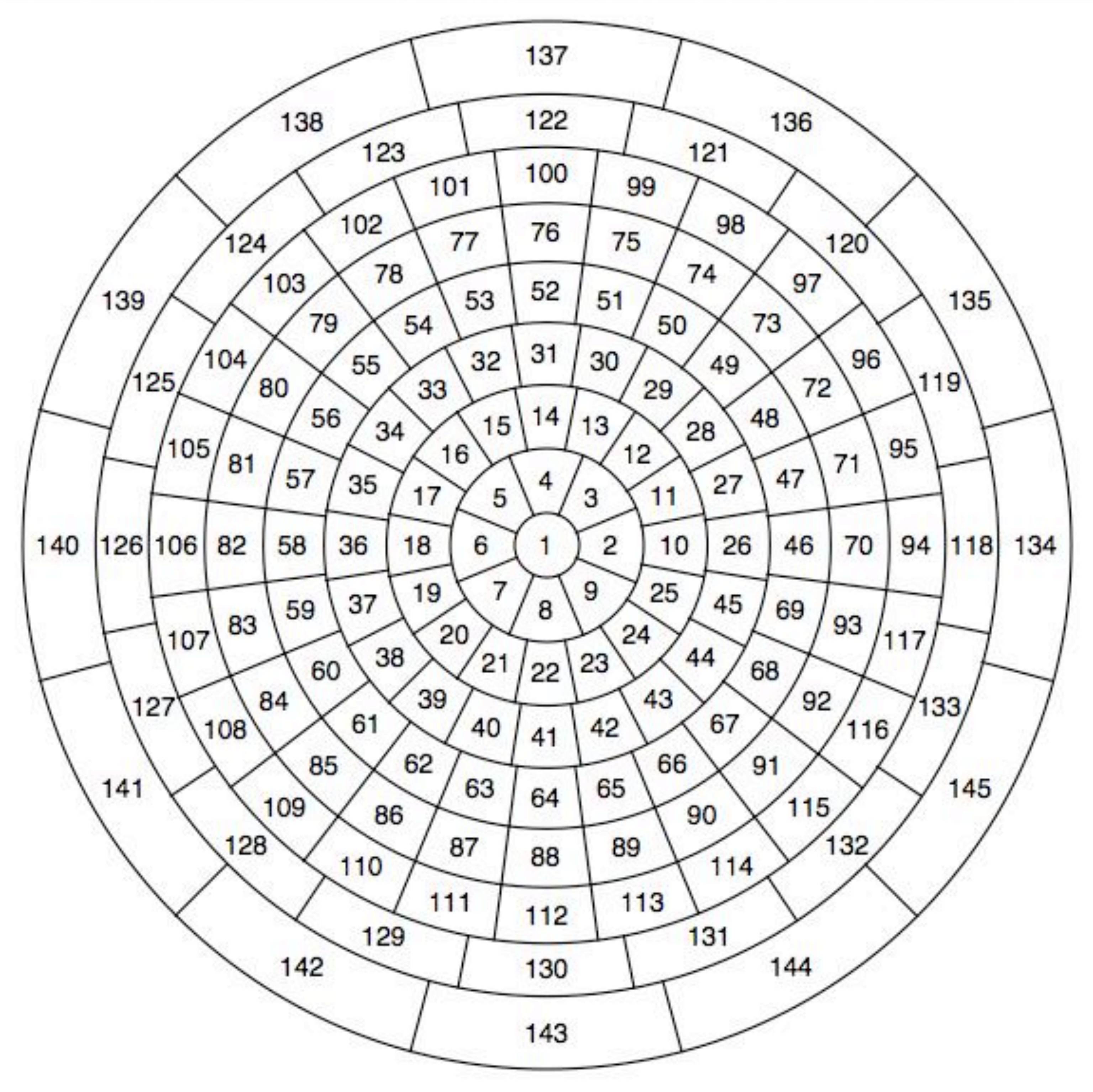
- Breaks BSDF into integrated spectra:
  - Visible (380-780 nm), Solar (300-2500 nm), NIR (780-2500 nm), FIR (5000- 40000 nm)
- Breaks scattering into four components:
  - Front Transmission, Back Transmission, Front Reflection, Back Reflection

# BSDF Coordinates (1)

## Klems/Window 6 system



# BSDF Coordinates (2)



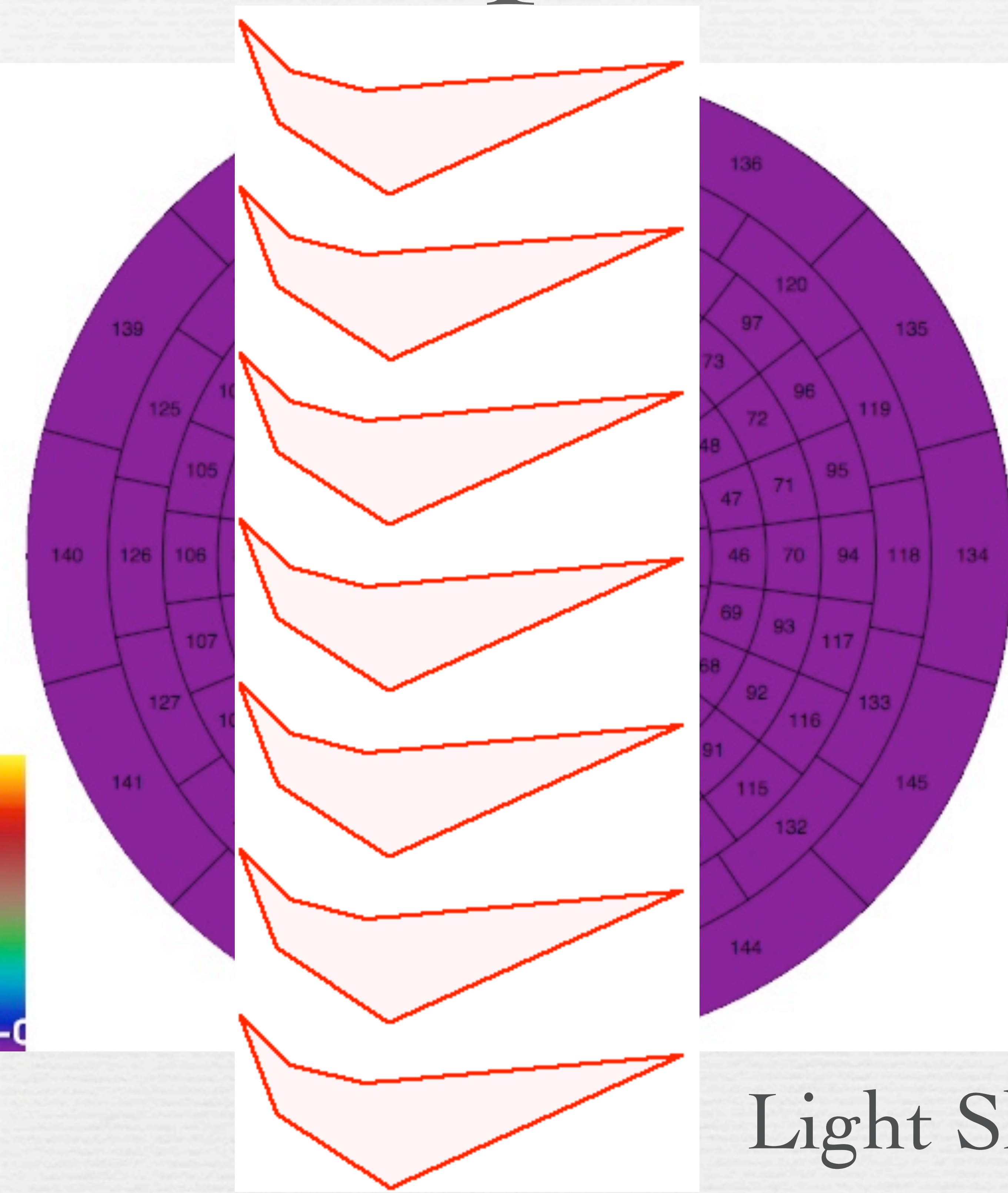
# WINDOW 6 XML File

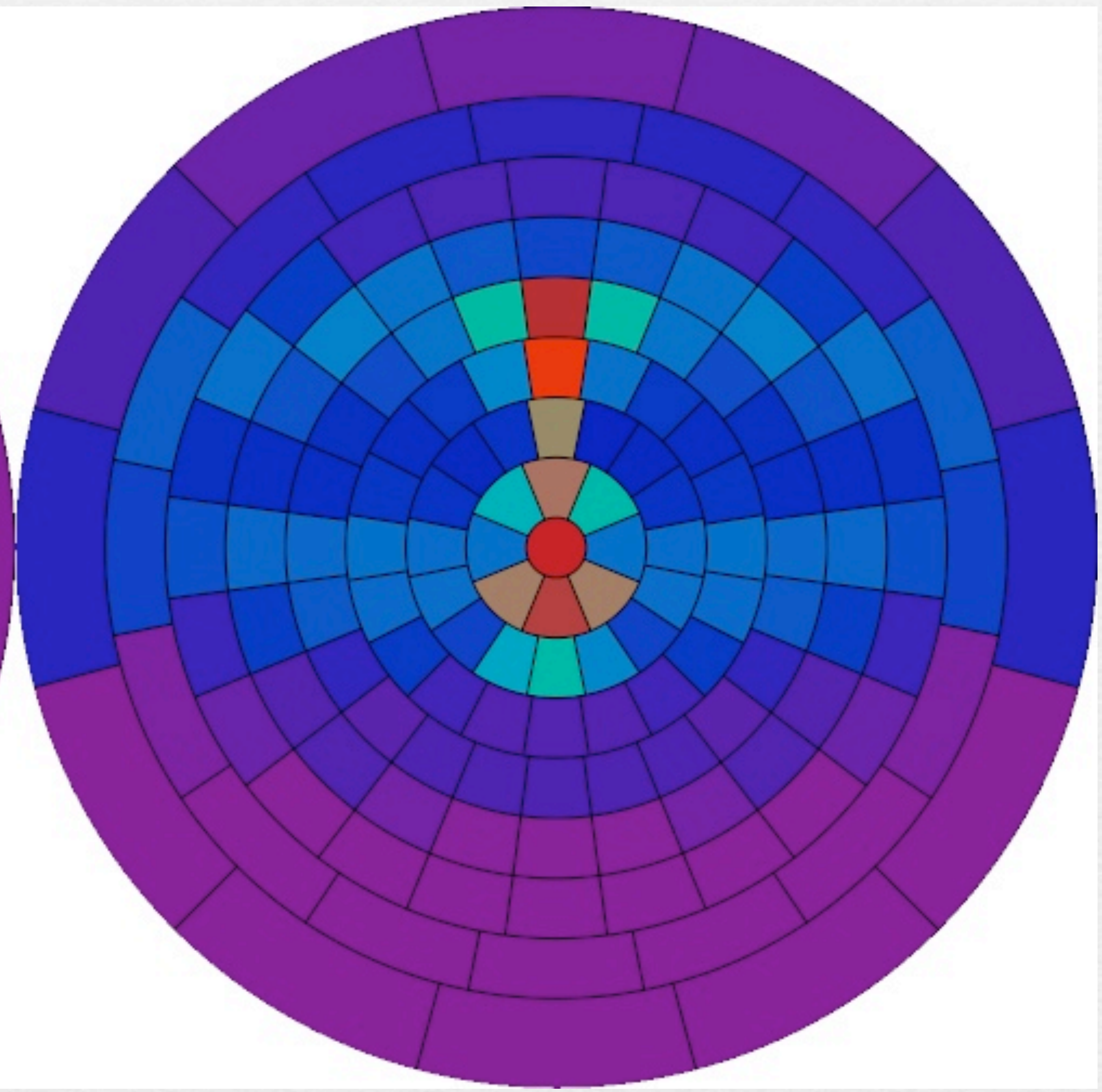

```
  <WavelengthData>
  <Wavelength unit="Integral">NIR</Wavelength>
  <SourceSpectrum>CIE Illuminant D65 1nm.ssp</SourceSpectrum>
  <DetectorSpectrum>ASTM E308 1931 Y.dsp</DetectorSpectrum>
  <WavelengthDataBlock>
      <WavelengthDataDirection>Transmission Front</WavelengthDataDirection>
      <ColumnAngleBasis>LBNL/Klems 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,
...
```

# Getting BSDF Data

- WINDOW 6 will have access to a database of fenestration systems
- Systems may be combined in "layers" up to a point
- Some BSDFs are measured, most are simulated
  - BSDF measurements go into simulations, too
- New **genBSDF** program in *Radiance* 4.1

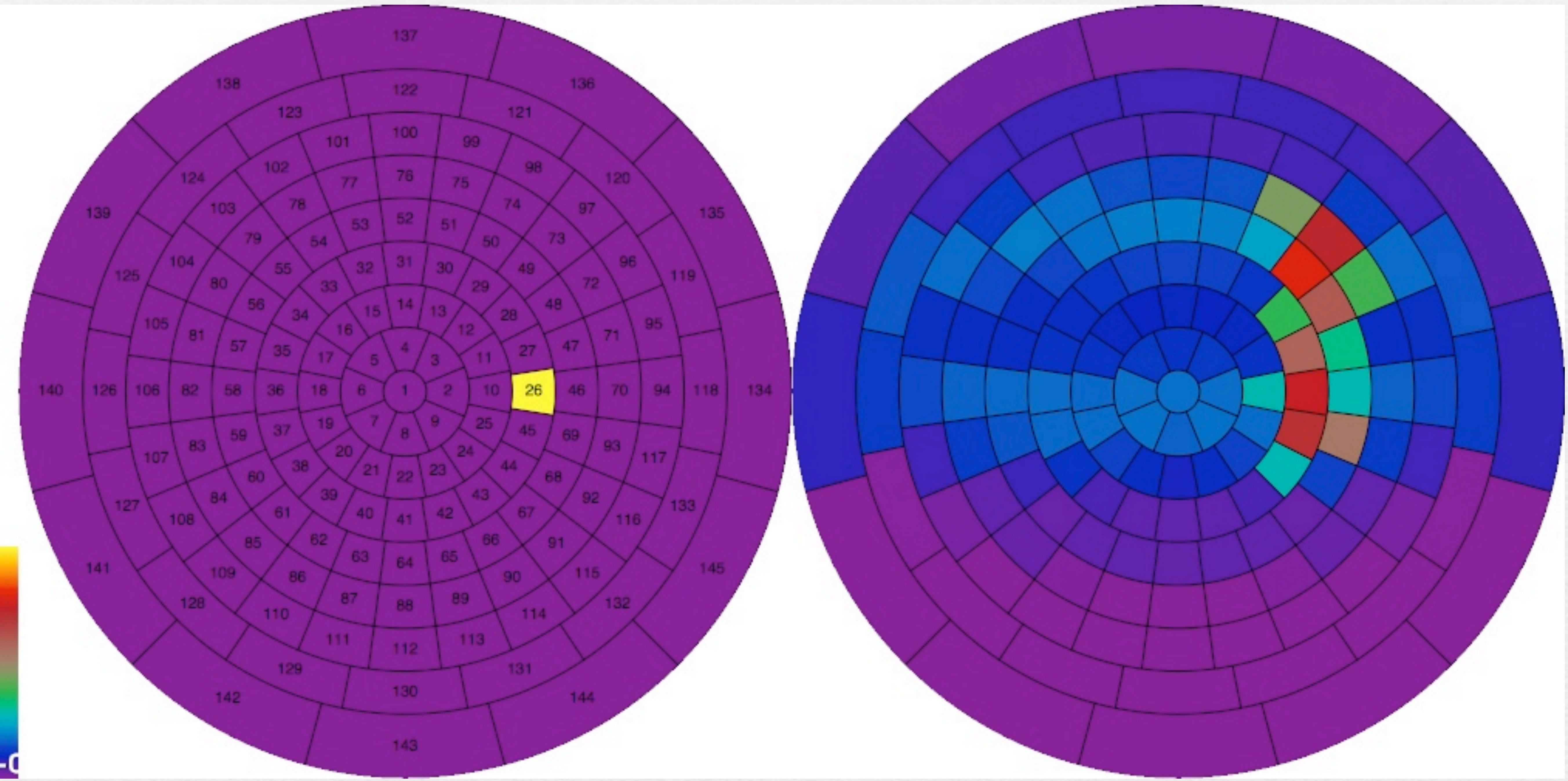
# Sample BTDF Data (1)



Light Shelf

# Sample BTDF Data (2)



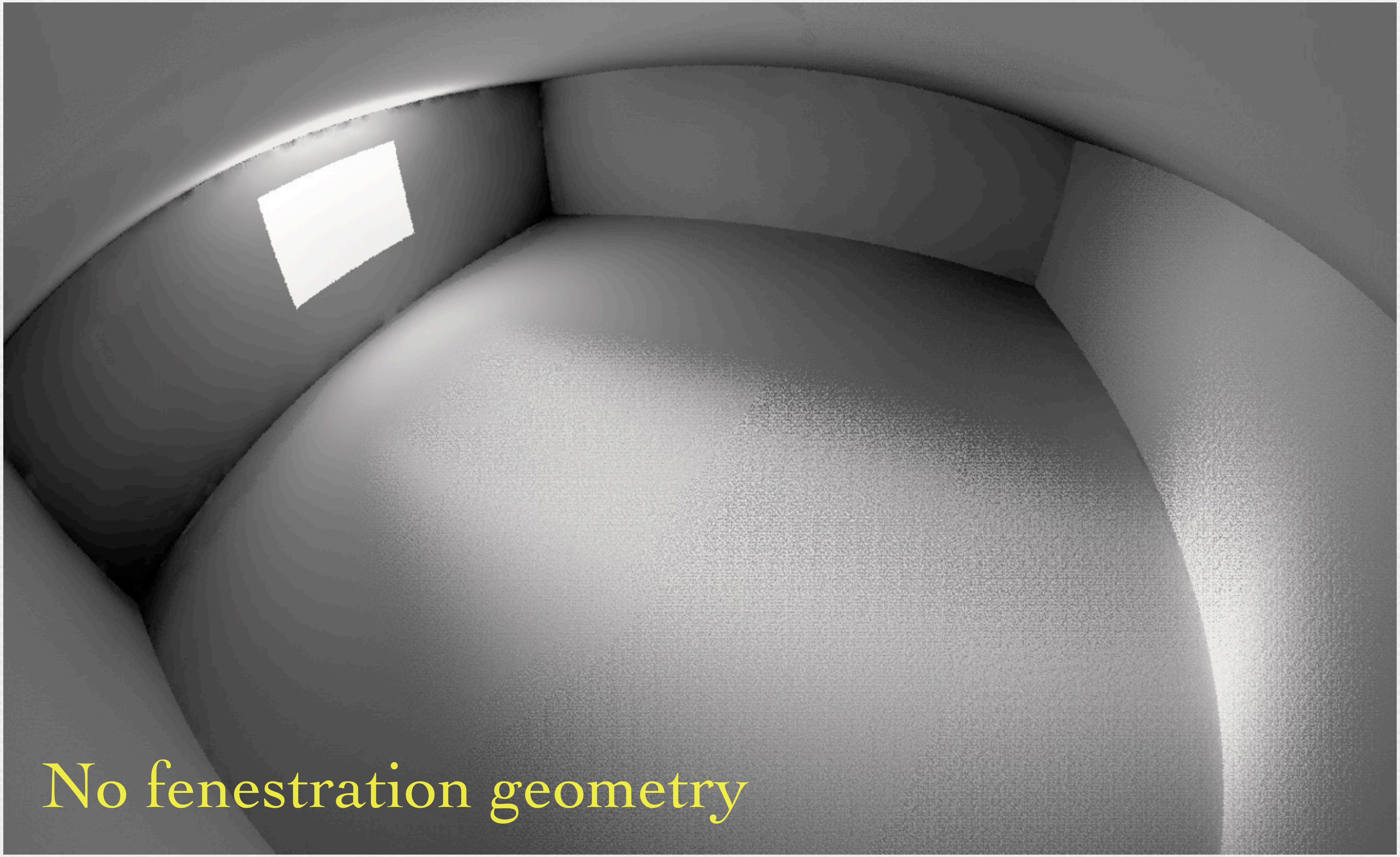

Light Shelf

Visualization by Andrew McNeil

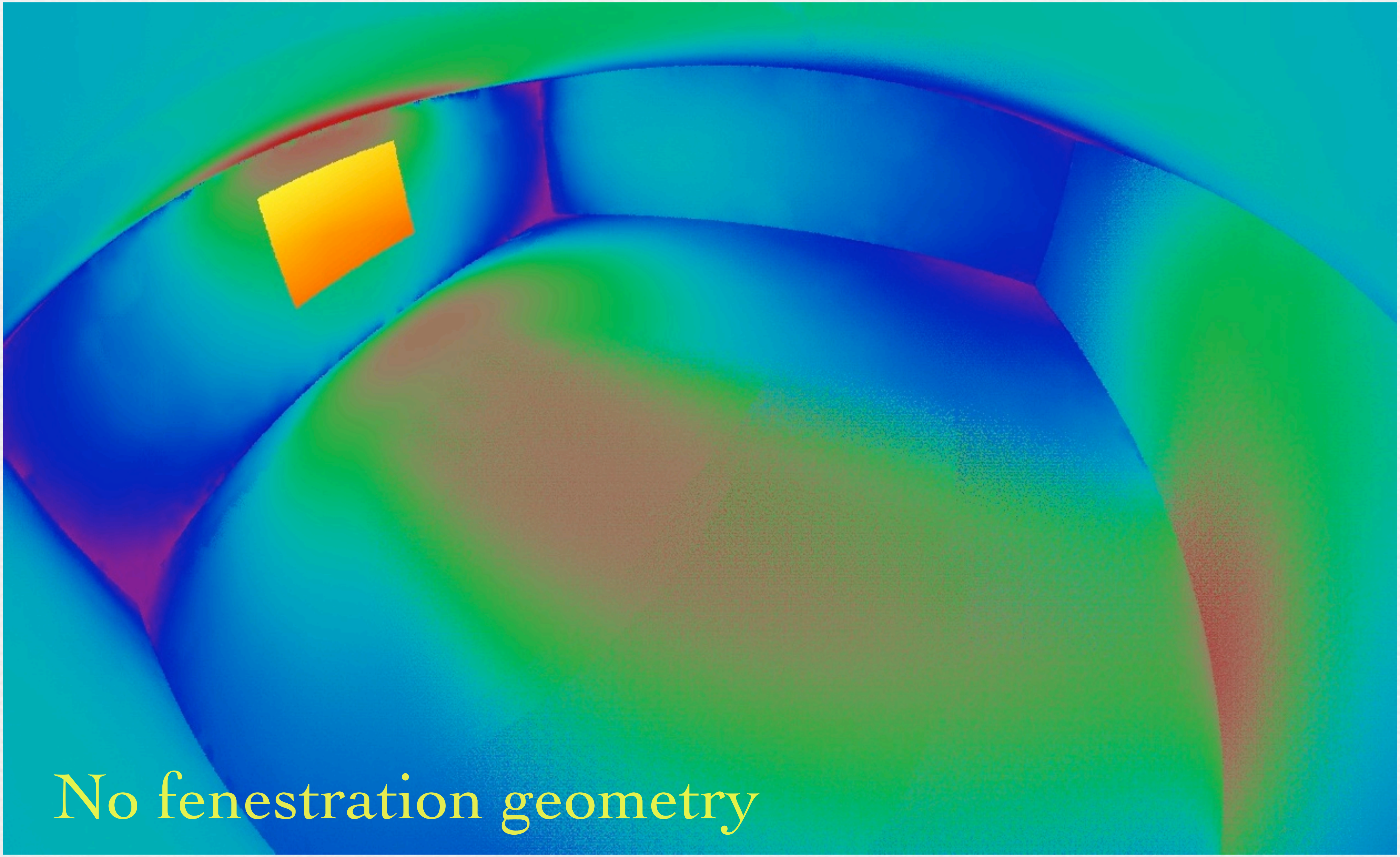
# BSDFs in **mkillum**

- Since 3.9 (2008), **mkillum** has supported BTDFs
  - fully debugged by 4.0 (Spring 2010)
- Works best when:
  - BTDF is somewhat diffuse, or
  - model includes geometry for direct component

# Example Results



# Averages Agree



# Specular Challenge

- 145 hemisphere directions cover 10-30° regions
  - The sun covers about 0.5°
- Breaking hemisphere further leads to drastic increases in computational load
  - 80000 divisions needed for sun-sized patches
  - that's an 80000x80000 BTDF (6.4e9 values)
  - ...and still no direct solar pattern on interior

# BSDF with Geometry

- Incorporate model of fenestration device in XML
- Use MGF (Materials and Geometry Format) developed for IESNA luminaire descriptions
    - simple, public <http://radsite.lbl.gov/mgf>
    - embeddable in XML
    - standard C parser makes support easy

# 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

# New **genBSDF** script

- Perl script calls **rtcontrib** to compute BTDF
  - forward transmittance only at this time
- Simple operation:
  - `genBSDF fenes1.rad > fenes1.xml`
- Default is to embed MGF geometry
  - options for number of samples, processes, etc.

# BSDFs in **mkillum**

Use *illum* BSDF Thickness (flag to use MGF)

```
#@mkillum l- c=a d=fenes.xml t=0 u=+Z
```

Up orientation

```
void polygon window
0
0
12
                    0                      4                      1
                    0                   6.25                      1
                    0                   6.25                    2.5
                    0                      4                    2.5
```

# When To Use "l+" with BTDF Data

- When the window geometry is unknown
- When there is no direct beam component
  - redirected components usually use BTDF

# 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 |

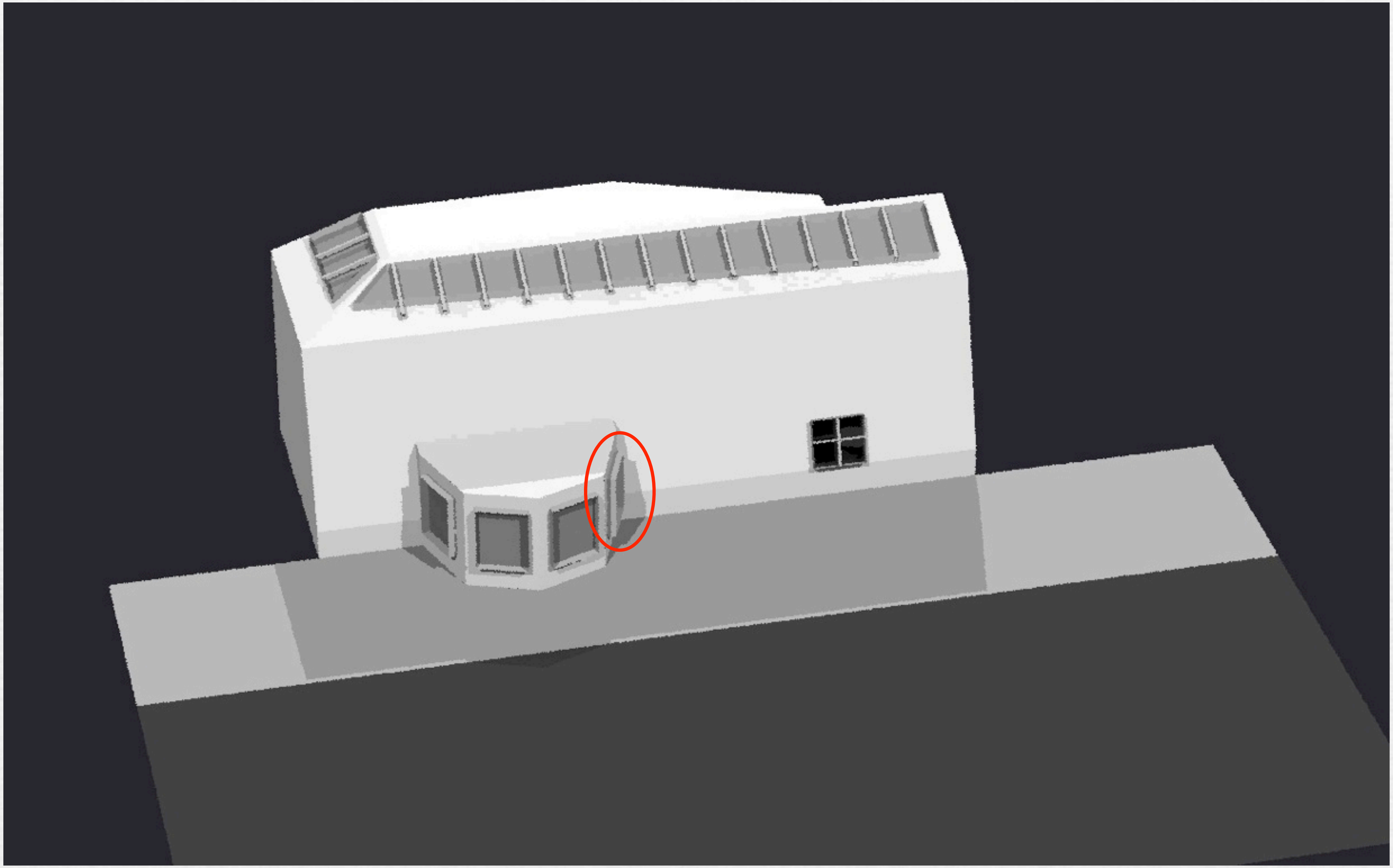
In a more explicit form, this would be:

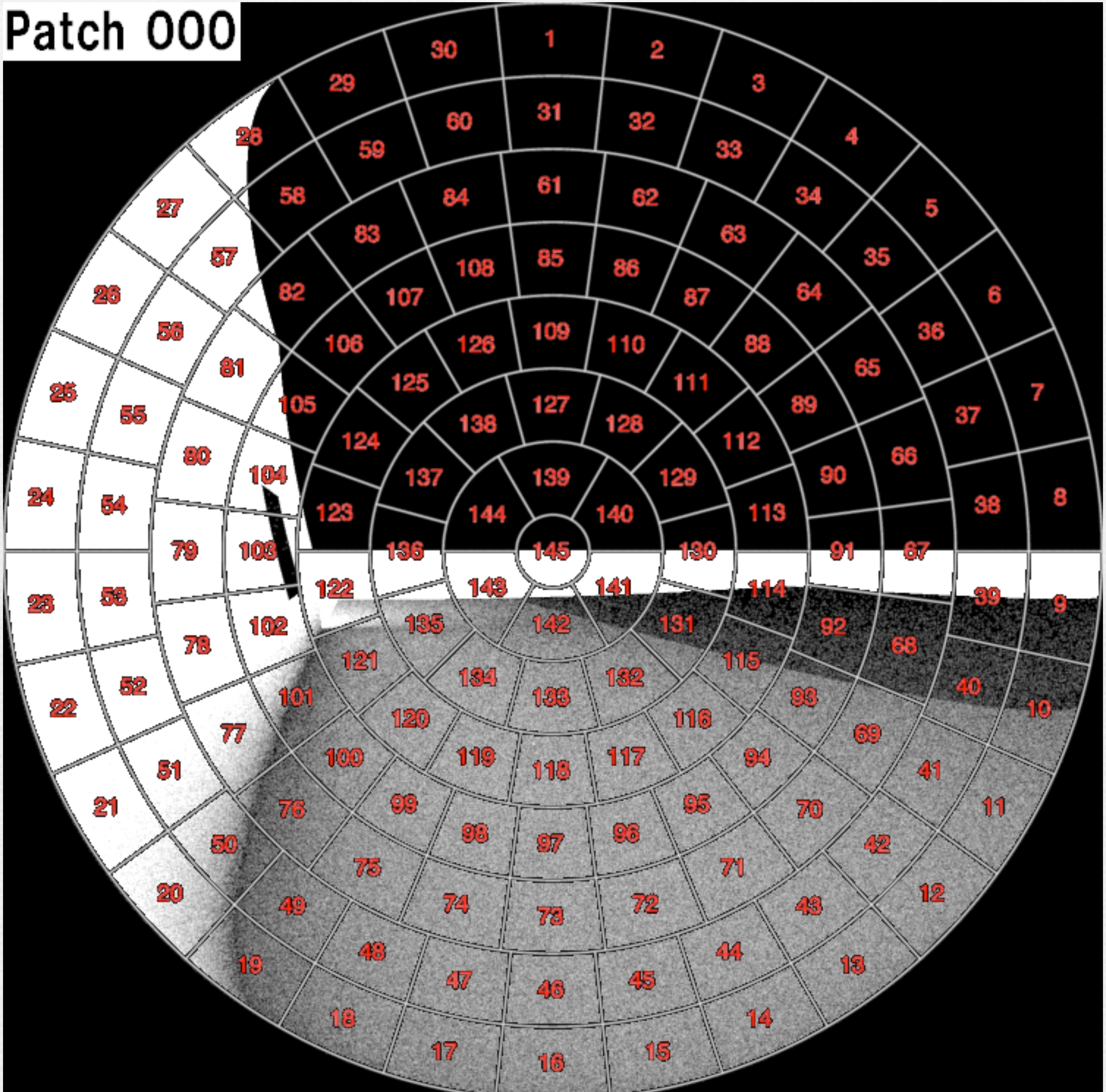
$$\begin{bmatrix} sens1 \\ \dots \\ sensM \end{bmatrix} = \begin{bmatrix} sens1edir1 & \dots & sens1edirN \\ \dots & \dots & \\ sensMedir1 & & sensMedirN \end{bmatrix} \begin{bmatrix} edir1idir1 & \dots & edir1idirN \\ \dots & \dots & \\ edirNidir1 & & edirNidirN \end{bmatrix} \begin{bmatrix} idir1dc1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

# 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
  - New **genklemsamp** utility generates samples over a given window group
    - written in Perl

# Example Space




Patch 000
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# 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

Sky Patch Vector

Result Vector

$$i = VTDs$$

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
```

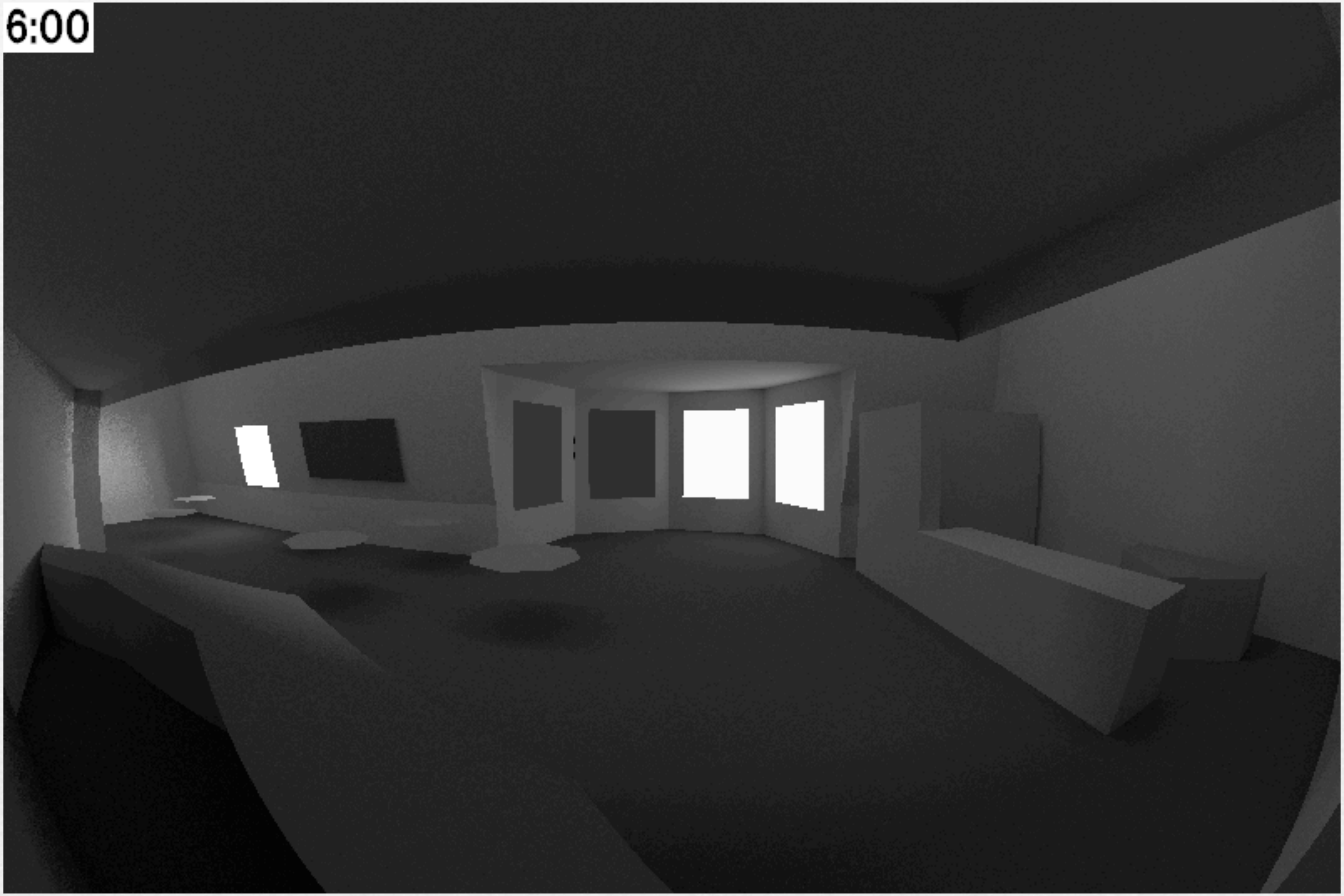
# Phase III Example

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 8 seconds on my laptop




Equinox Simulation

# Future Work

- Support for BRDF (reflection) data
- Further validation on appropriate use
- Variable-resolution & native BSDF types
- Documentation and tutorials
- What about a user interface?
  - always my last question, always unanswered