Measuring and Modeling the Appearance of Objects and Materials

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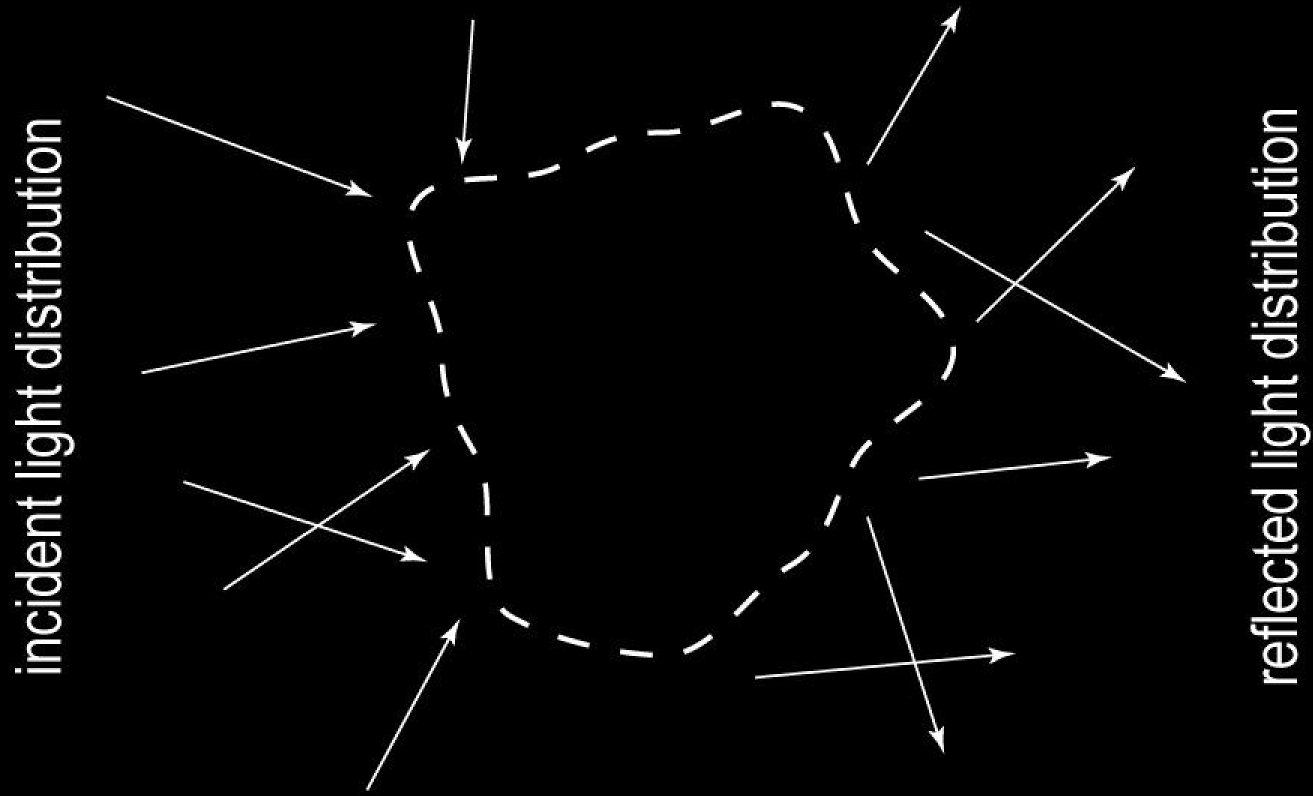
1. Appearance
2. Representing appearance
   (a scattering function taxonomy)

– break –

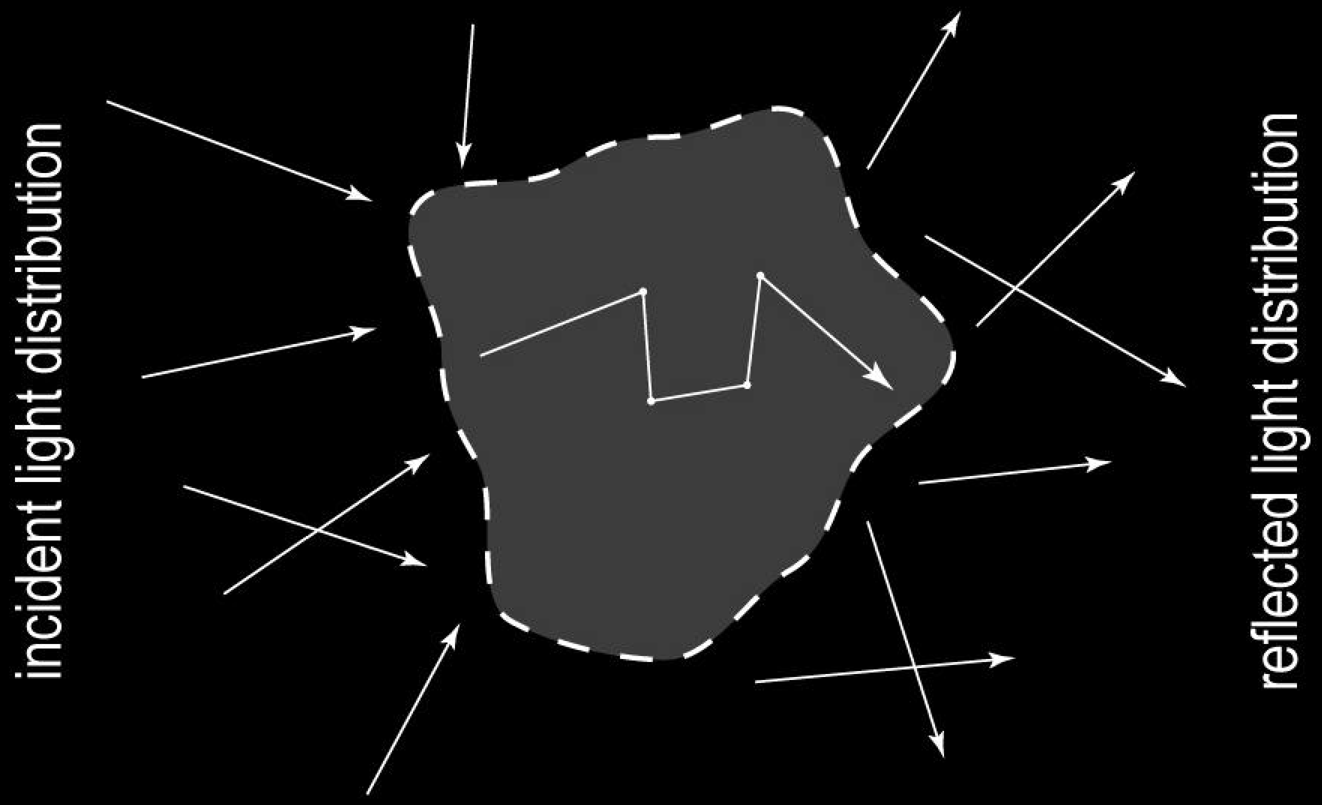
3. Measuring appearance
   (three image-based methods)

Appearance



You can model what's in the box
or you can treat it as a general function

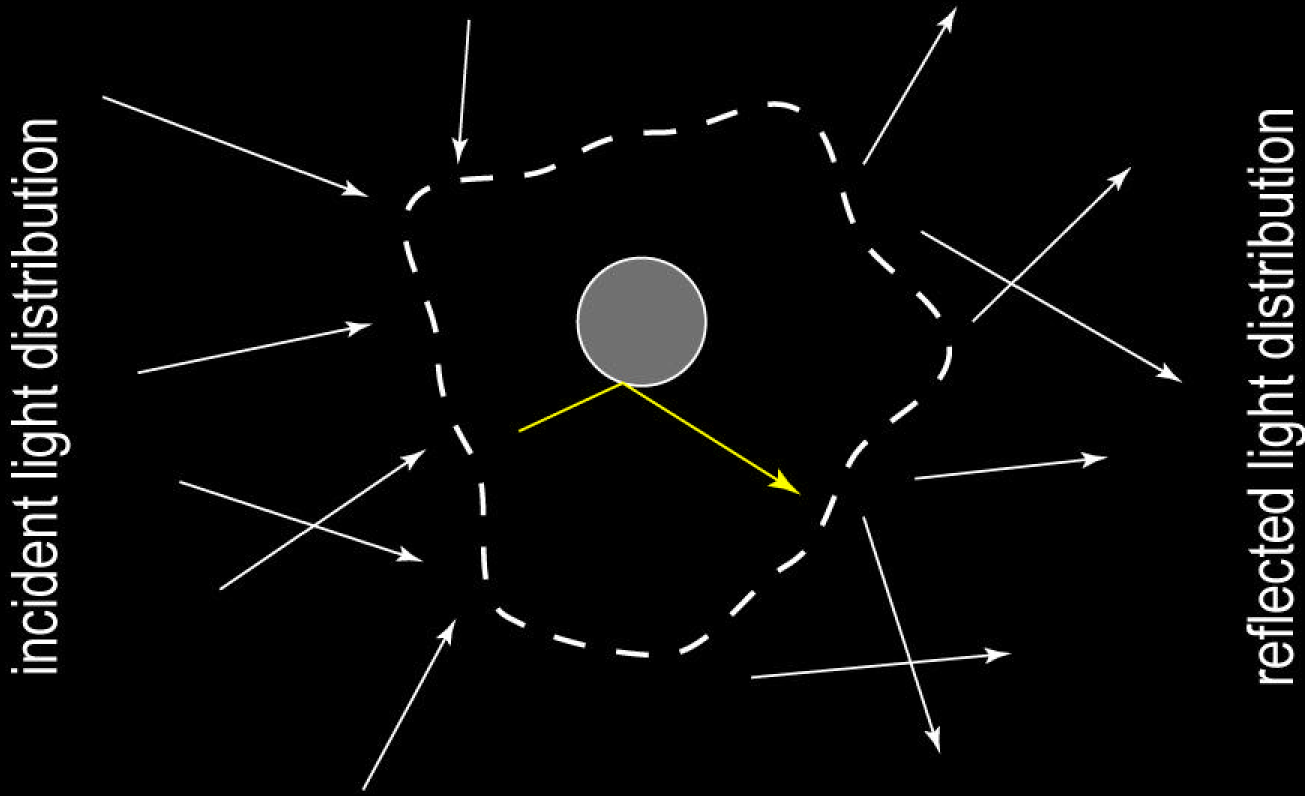
Volume scattering



Most general form of model:

volume scattering as a function of position

Geometry

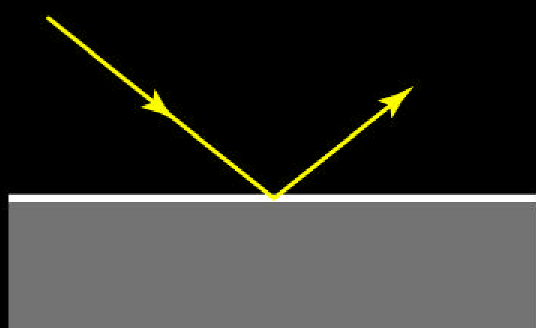


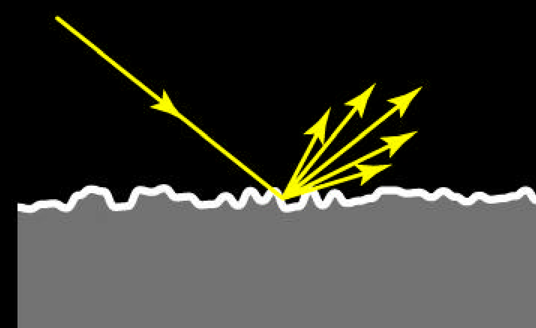
For opaque and transparent surfaces, you can model just the interfaces between materials

Materials

conductor

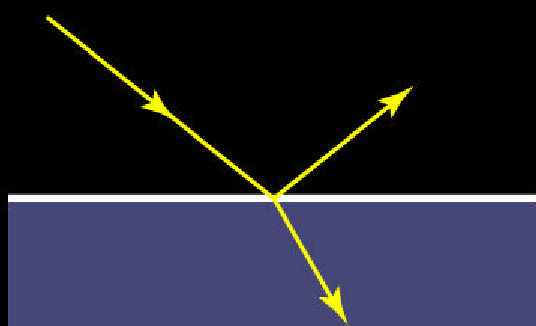
conductor plus microgeometry

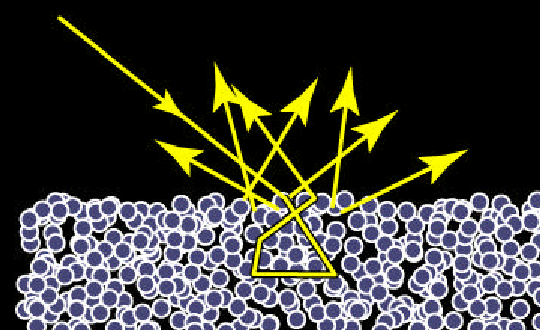




insulator

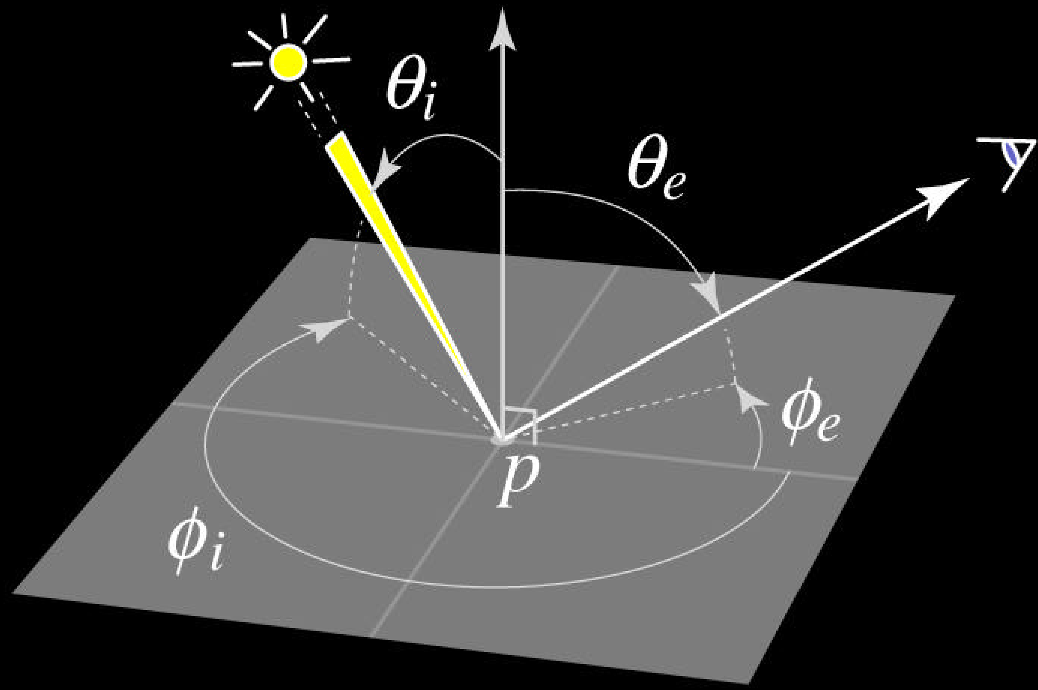
insulator plus microgeometry





BRDF

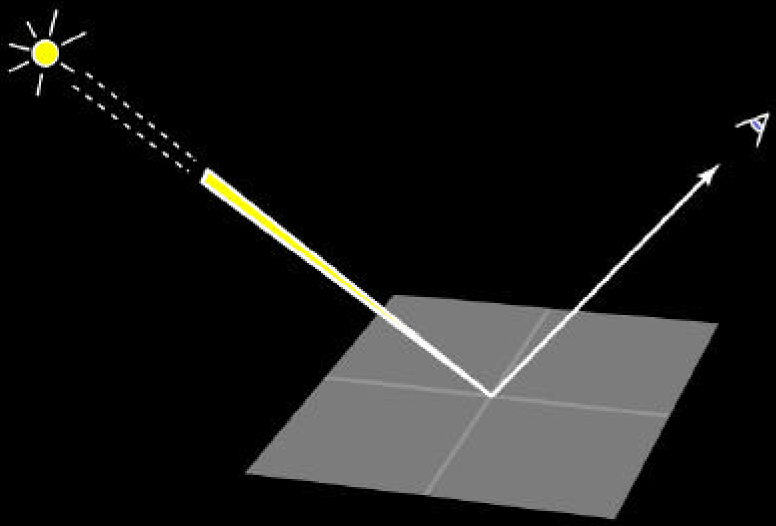
$$f_r(p, \theta_i, \phi_i, \theta_e, \phi_e)$$

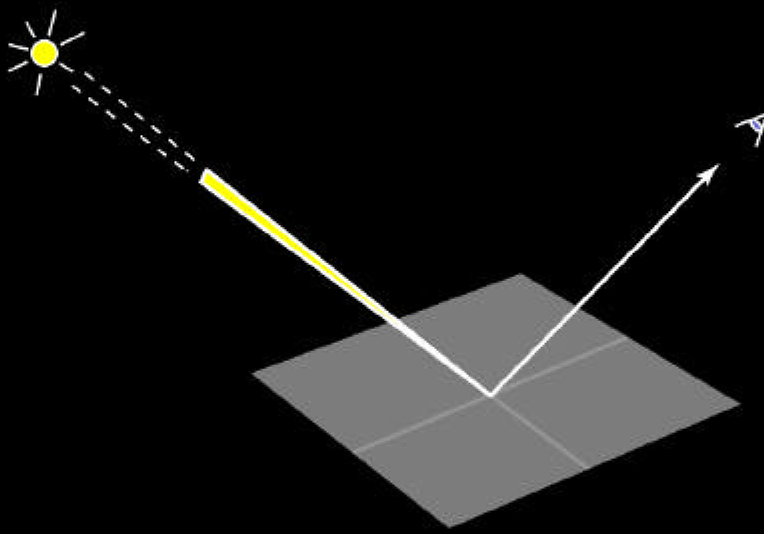


Bidirectional **R**eflectance **D**istribution **F**unction

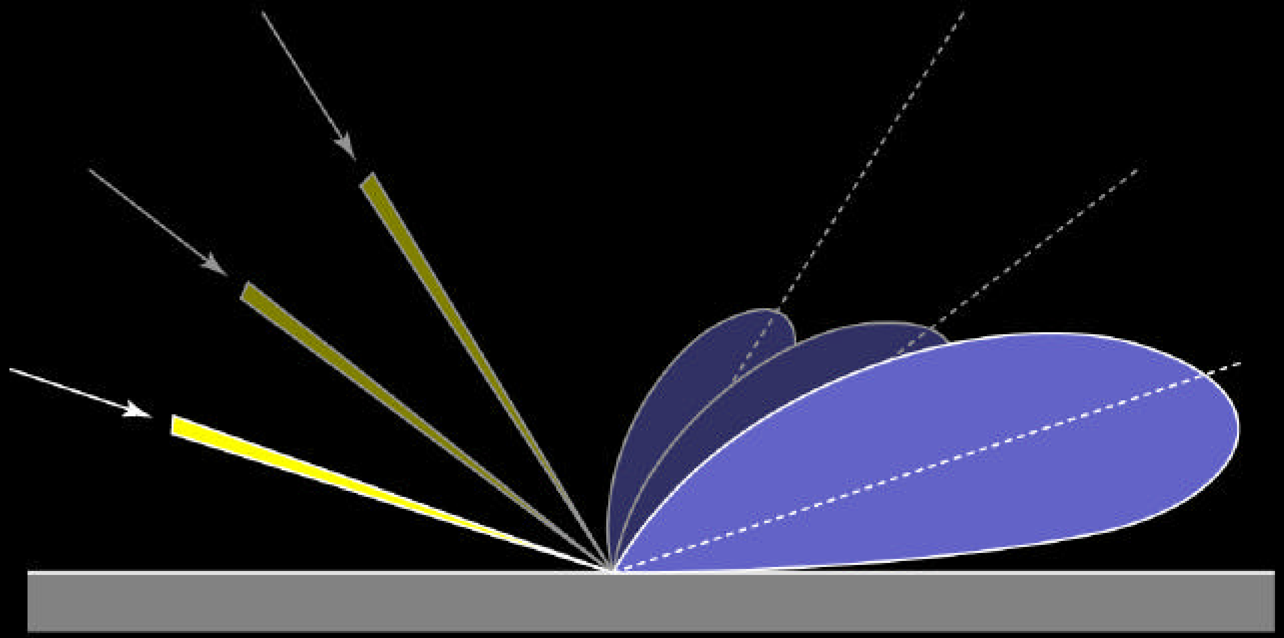
Reciprocity; energy conservation

Isotropy

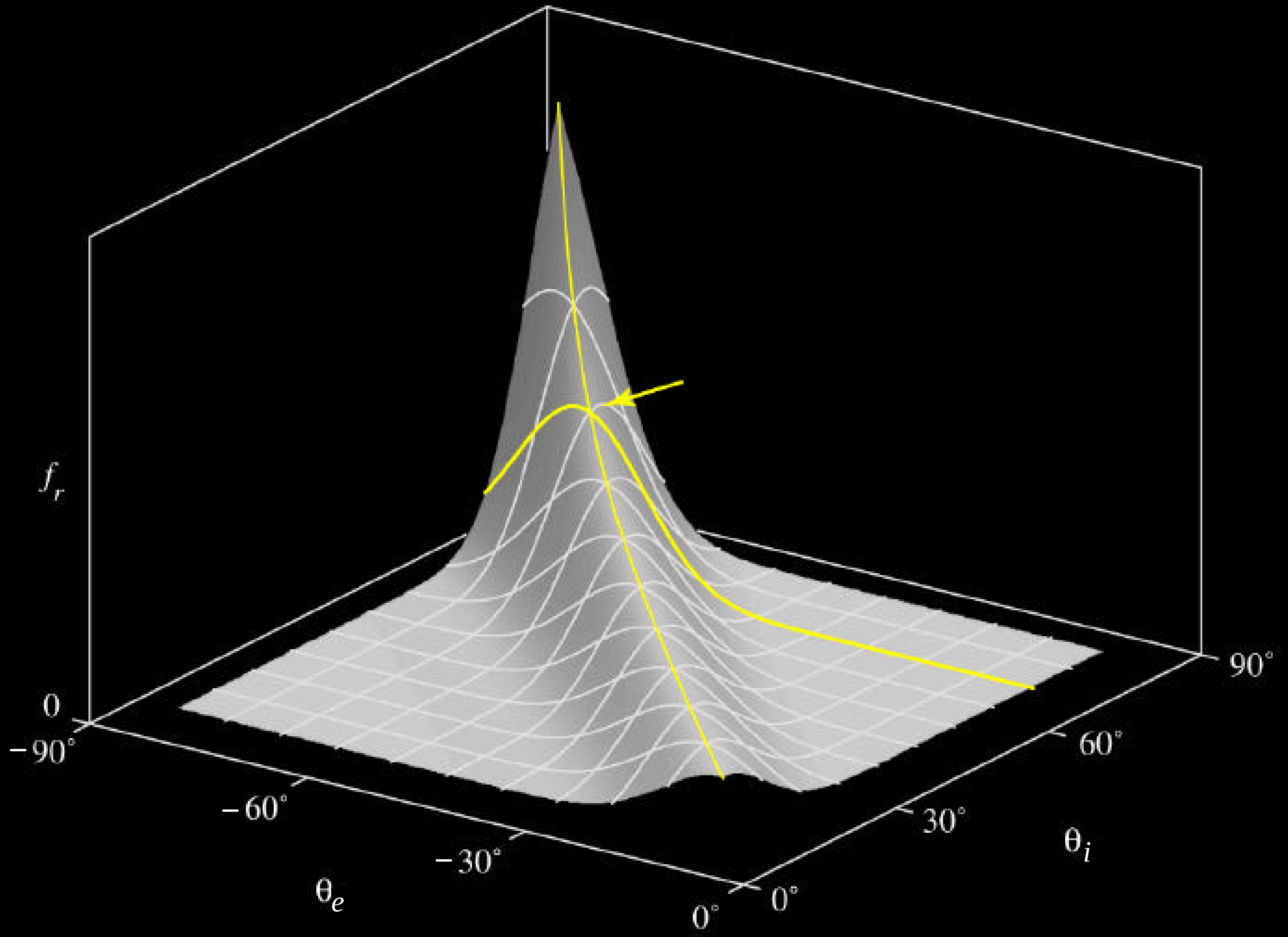




Off-specular Reflection

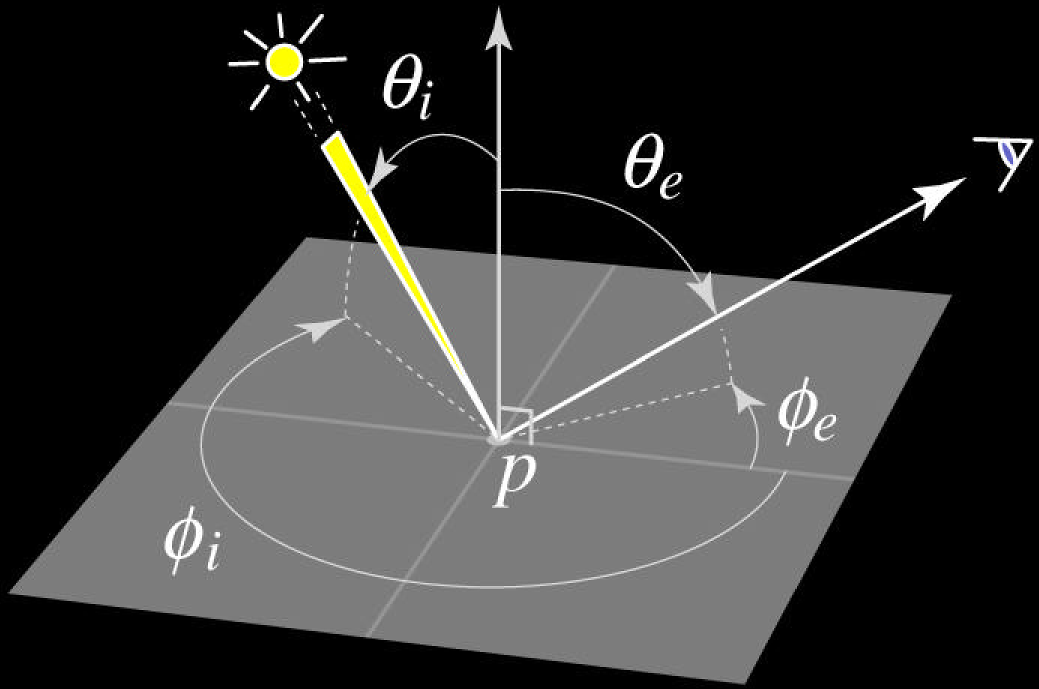


Off-specular Reflection



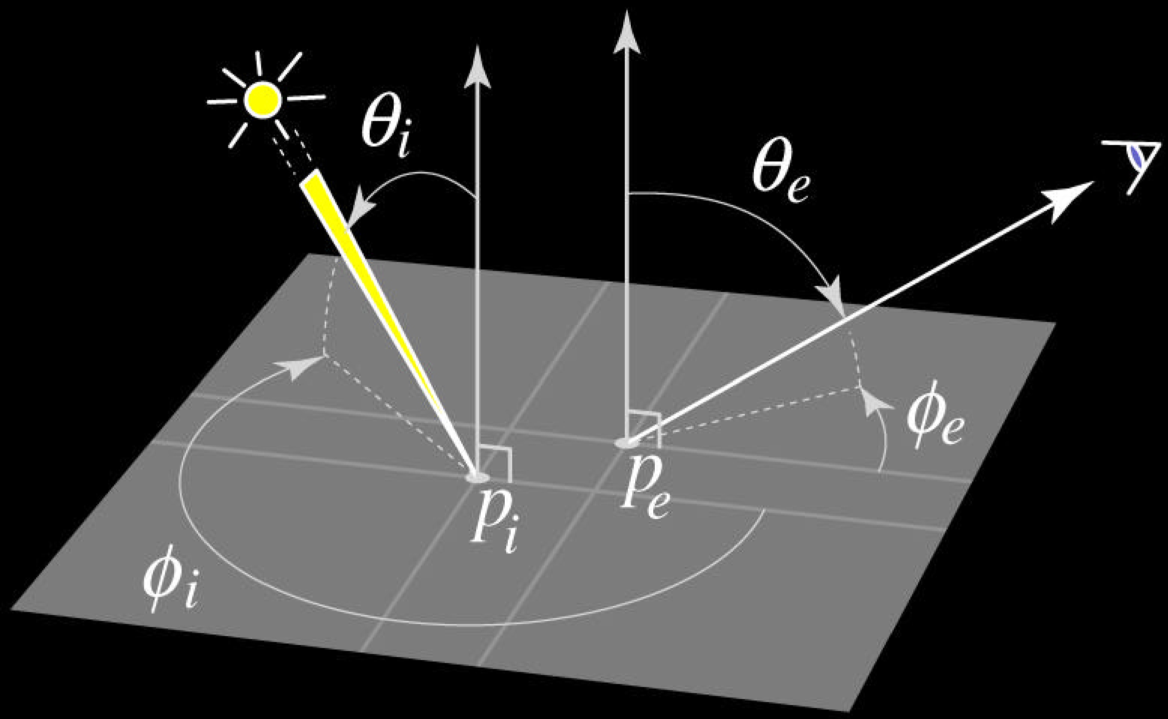
BRDF

$$f_r(p, \theta_i, \phi_i, \theta_e, \phi_e)$$



BSSRDF

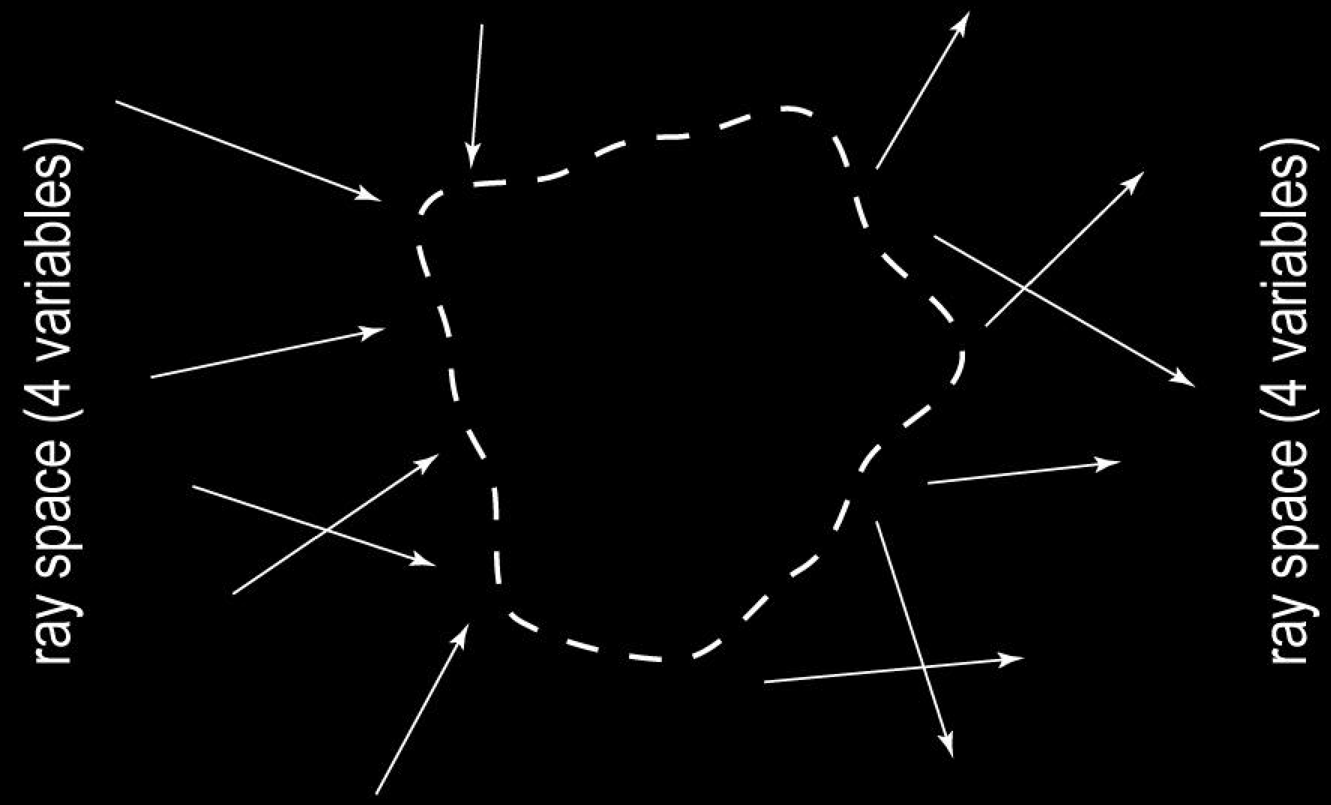
$$S(p_i, \theta_i, \phi_i, p_e, \theta_e, \phi_e)$$



Bidirectional **S**urface **S**cattering **R**eflectance **D**istribution **F**unction

Representing Appearance

Scattering Function



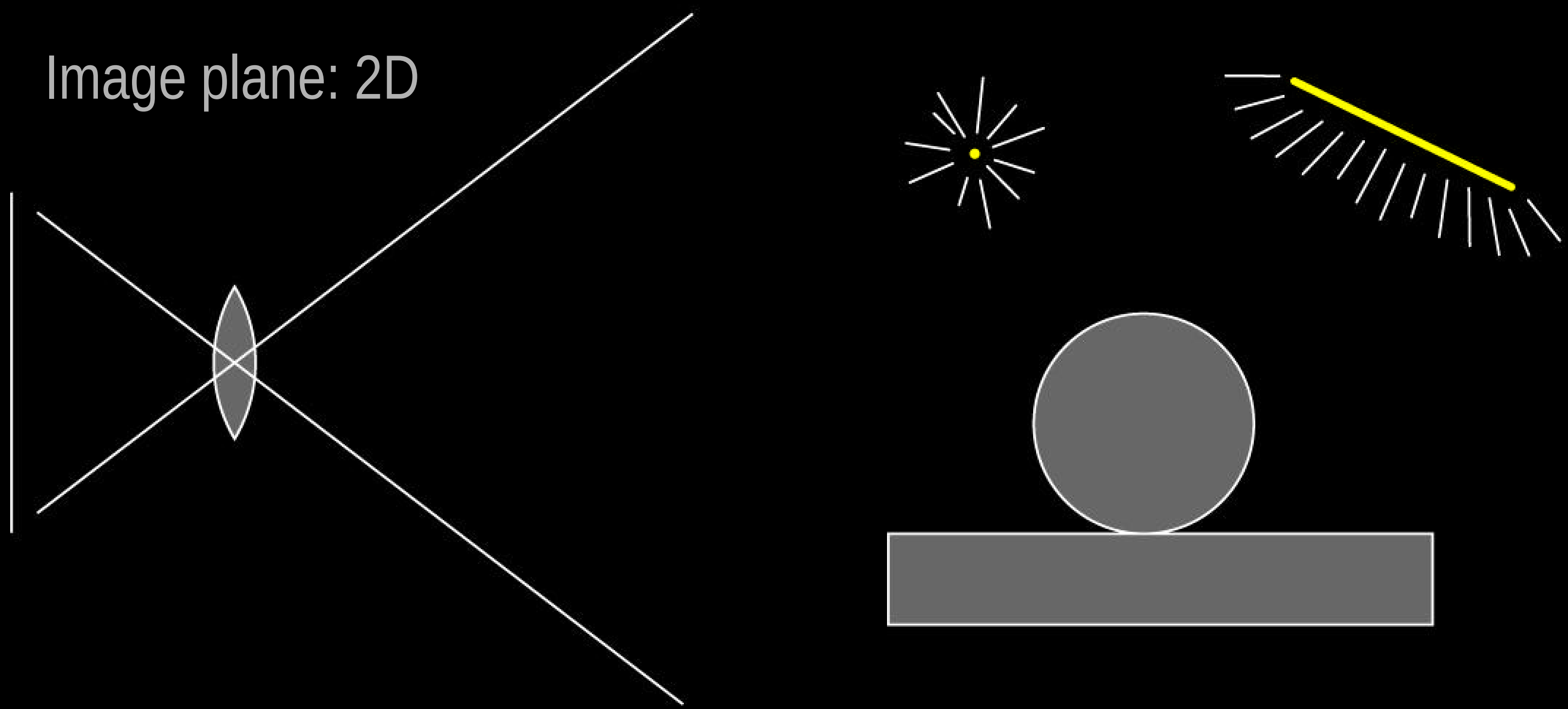
Operator transforms 4D function to 4D function

Linear, so represent with 8D function

Representing Scattering

- 8D is generally too much to treat generally
- Two solutions:
  - **Restrictions:** treat the function generally but constrain it to a lower-dimensional domain
  - **Assumptions:** Keep the whole domain but use models to simplify the representation

Restrict to 2D: Photograph



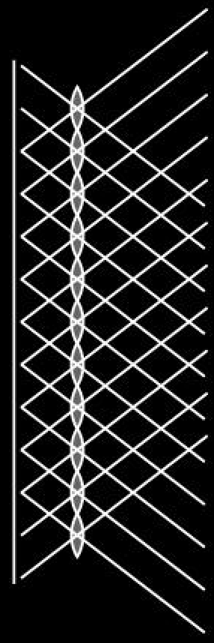
Fixed viewpoint: -2D

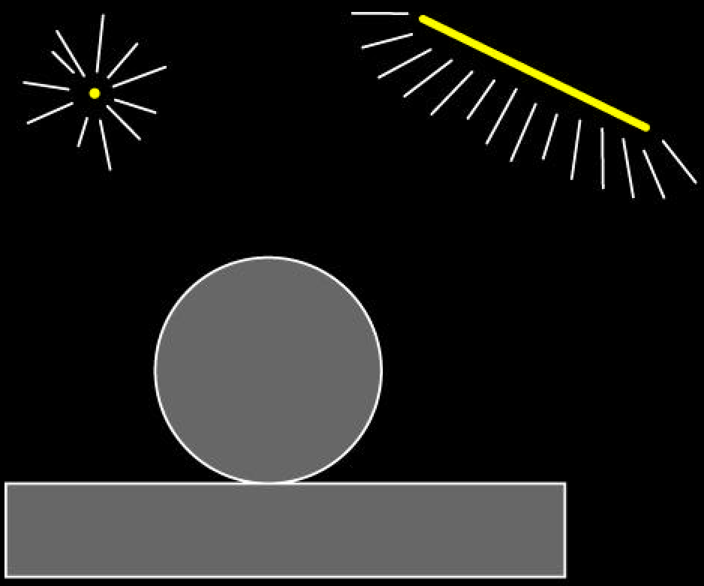
Fixed incident distribution: -4D

Restrict to 4D: Light field

Image plane: 2D

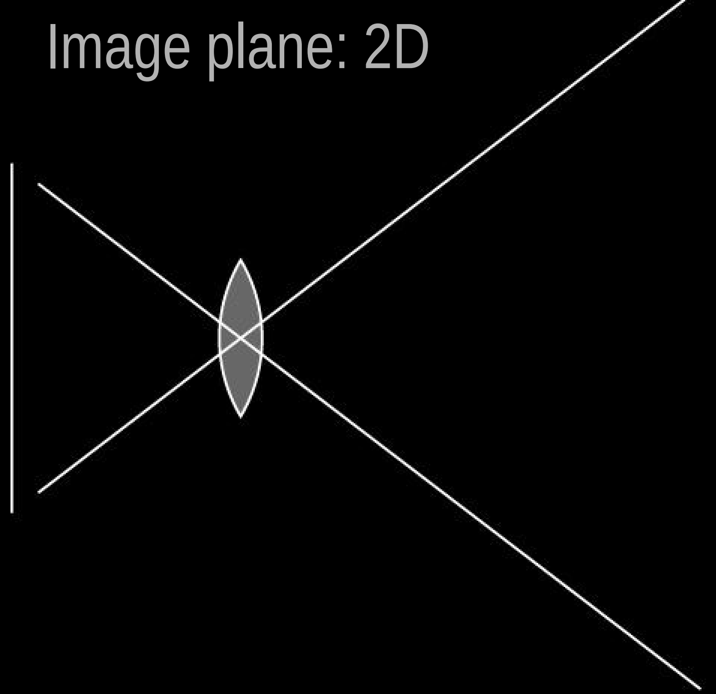
Viewpoint: 2D

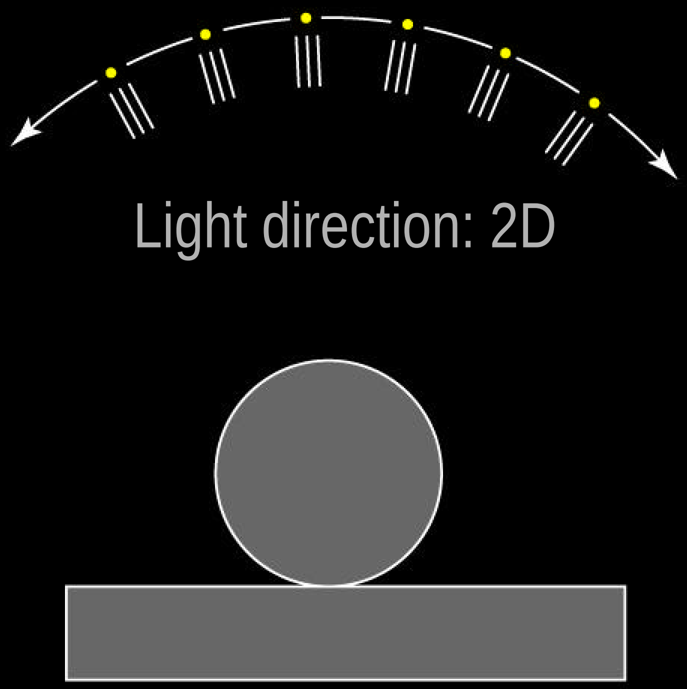




Fixed incident distribution: -4D

Restrict to 4D: Light stage et al.

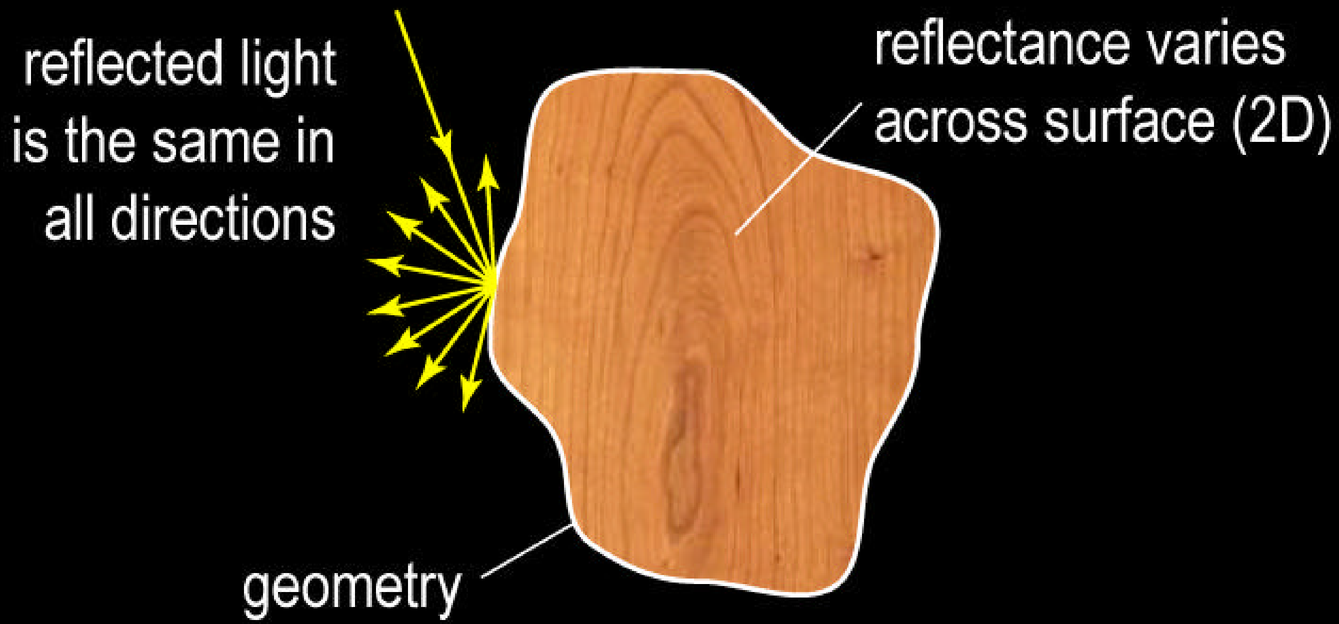




Fixed viewpoint: -2D

Parallel incident distribution: -2D

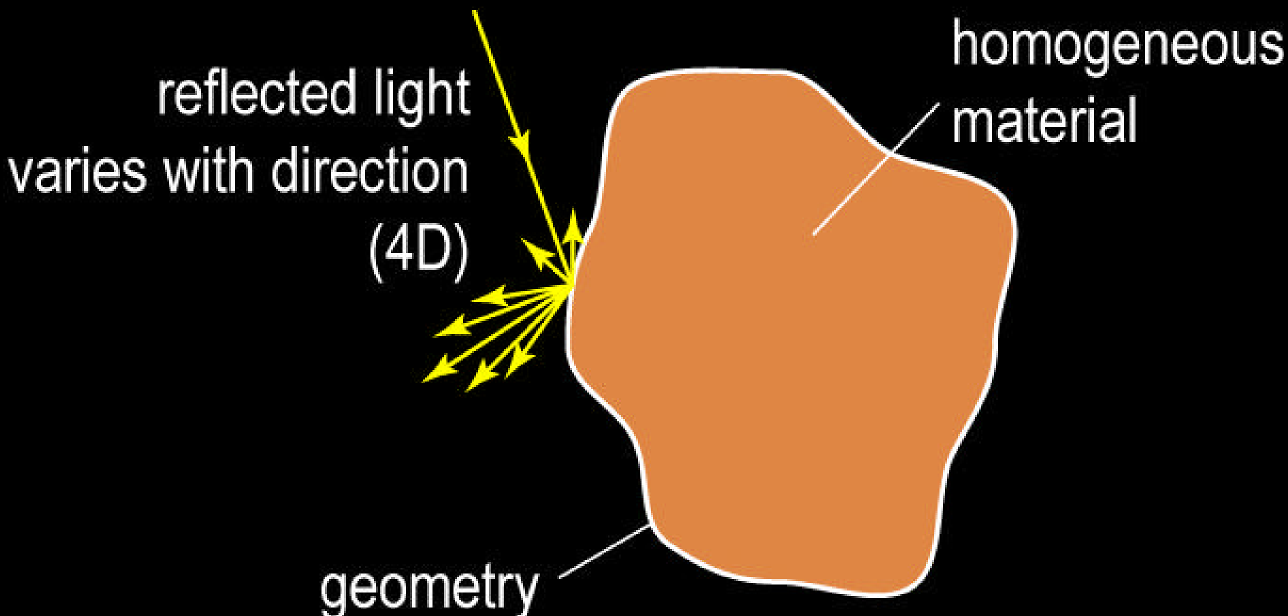
2D Assumption: Texture map



Single scattering: -1D; surface scattering: -1D

Diffuse reflection: -4D

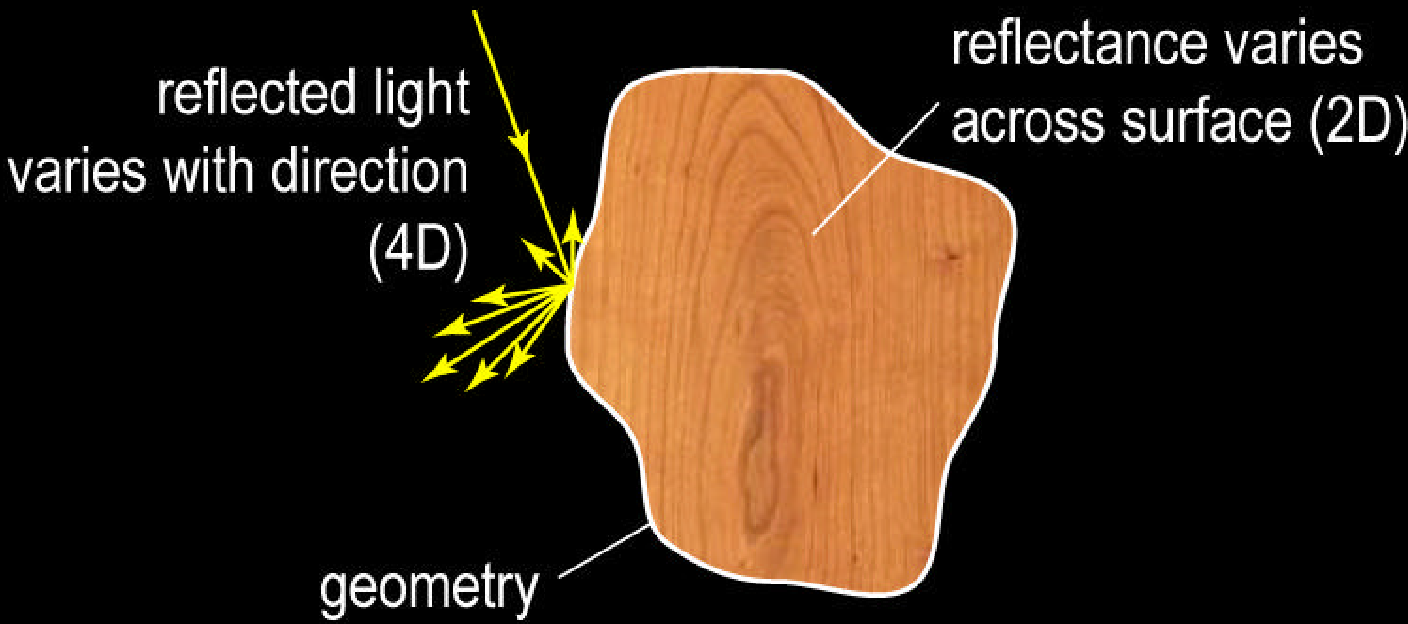
4D Assumption: BRDF



Single scattering: -1D; surface scattering: -1D

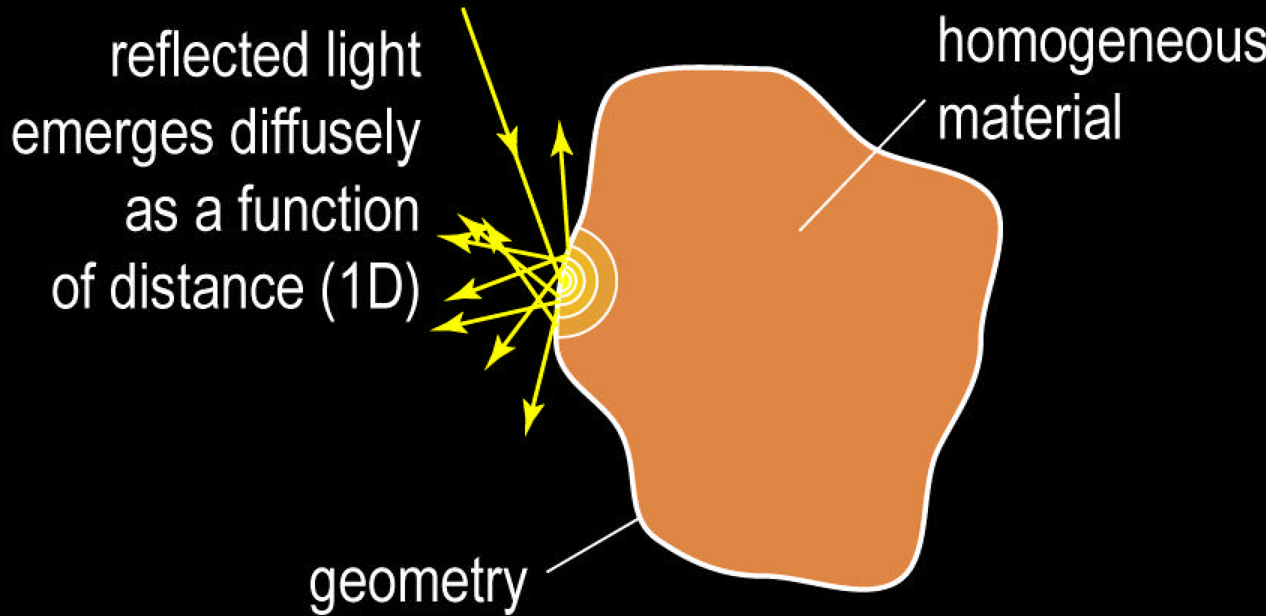
Homogeneous material: -2D

6D Assumption: Variable BRDF



Single scattering: -1D; surface scattering: -1D

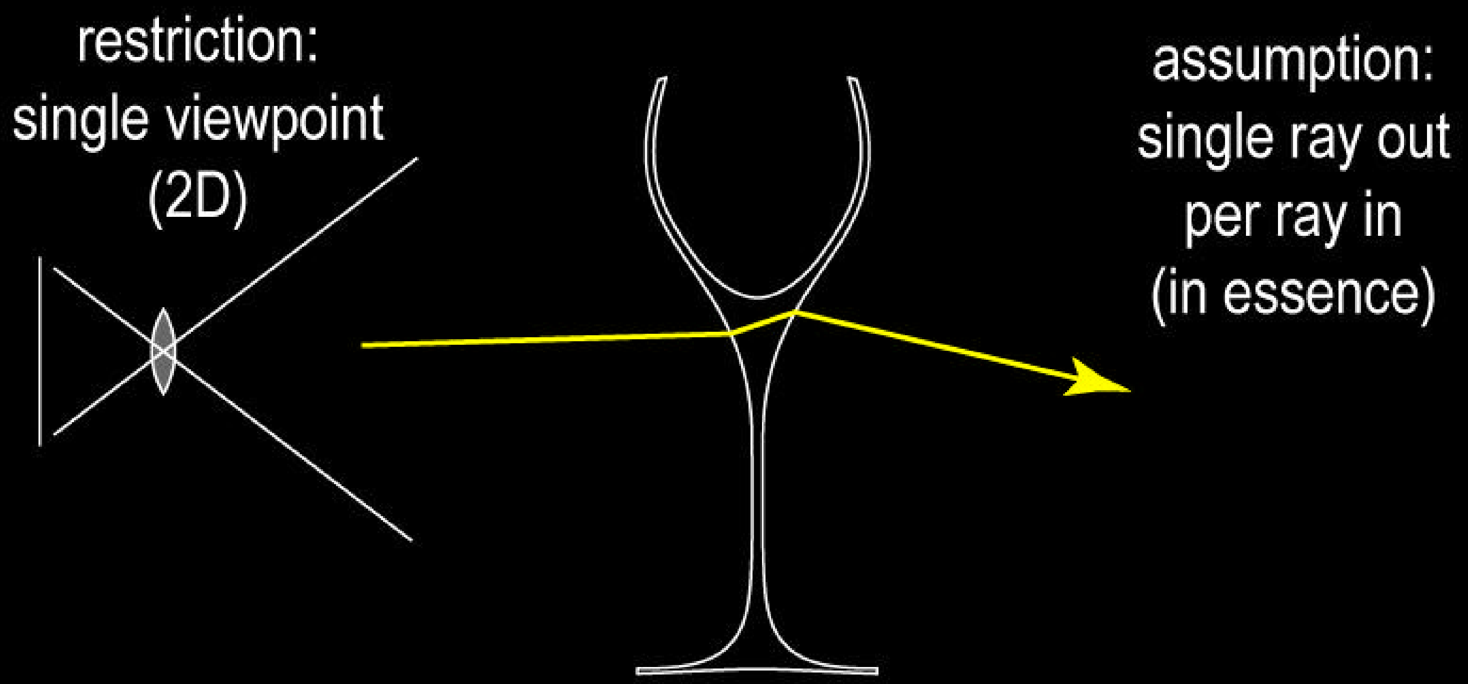
1D Assumption: Translucent



Homogeneous material: -2D

Diffuse reflection: -4D; isotropic material: -1D

2D: Environment matte



Fixed viewpoint: -2D [restriction]

Single ray transport: -4D [assumption]

Measuring Appearance

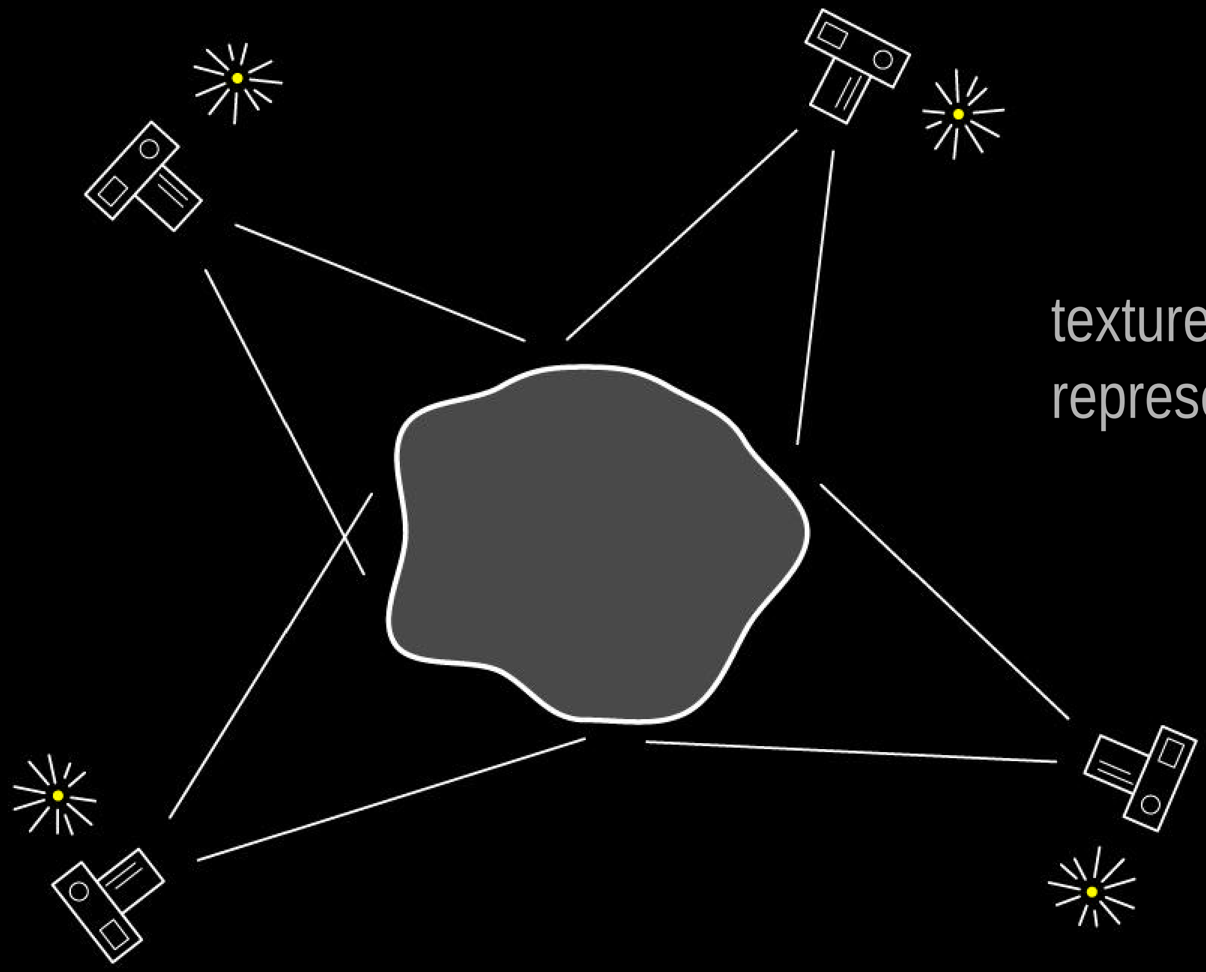
1. Diffuse texture maps
2. Homogeneous BRDFs
3. Translucent materials

Measuring texture maps

Techniques and results from:

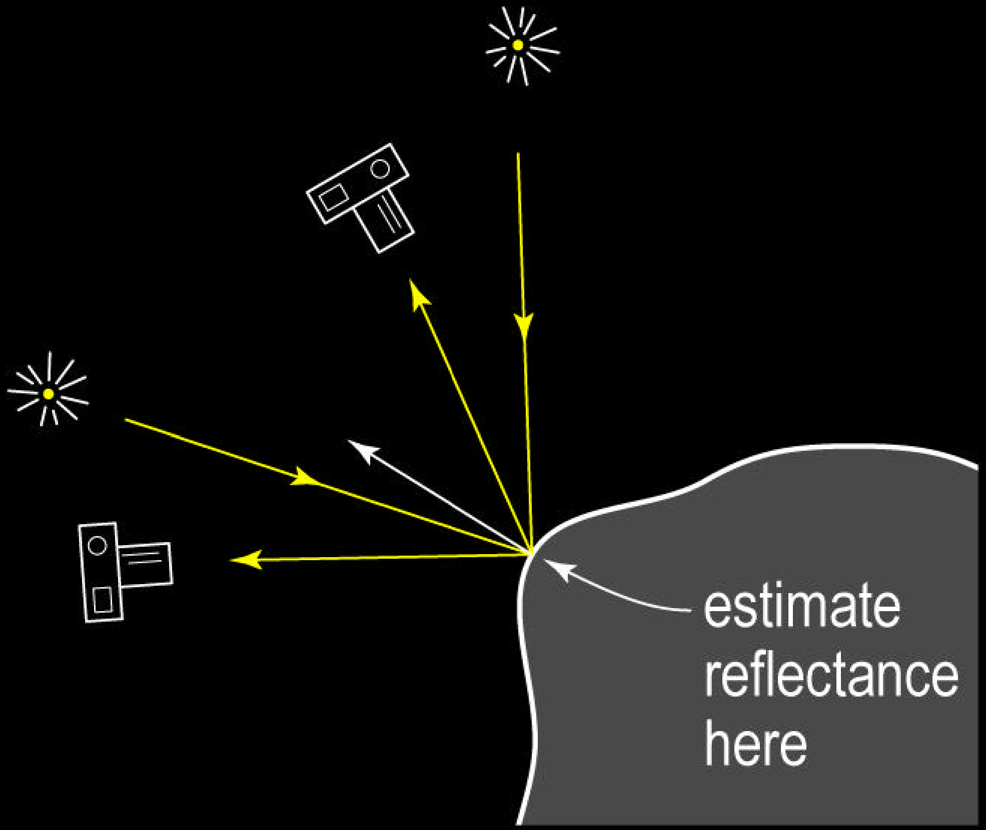
Stephen R. Marschner. "Inverse Rendering for Computer Graphics." Ph.D. Thesis, Cornell University, August 1998.

Measuring texture maps



texture map
representation…

Measuring texture maps

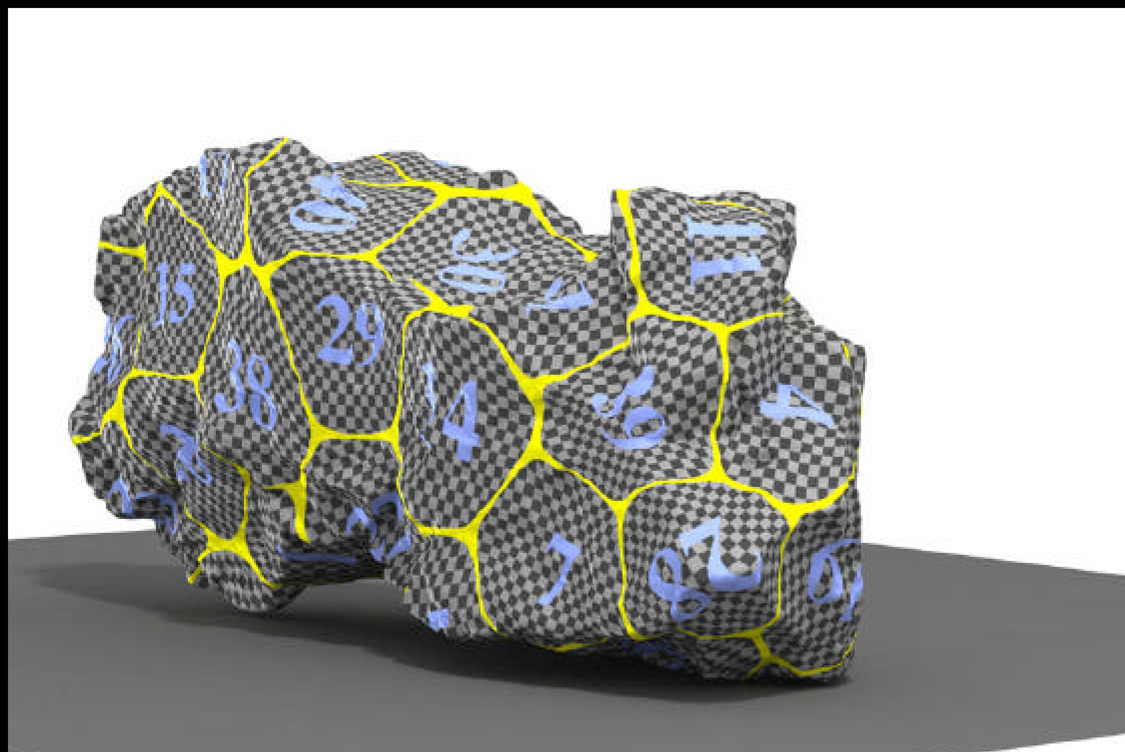


Each camera/source pair gives a BRDF estimate

Combine by averaging to get diffuse albedo

Rock: source photos

Rock: Texture maps



Rock: Textured model

Rock: Photo comparison

Measuring BRDFs

Techniques from:

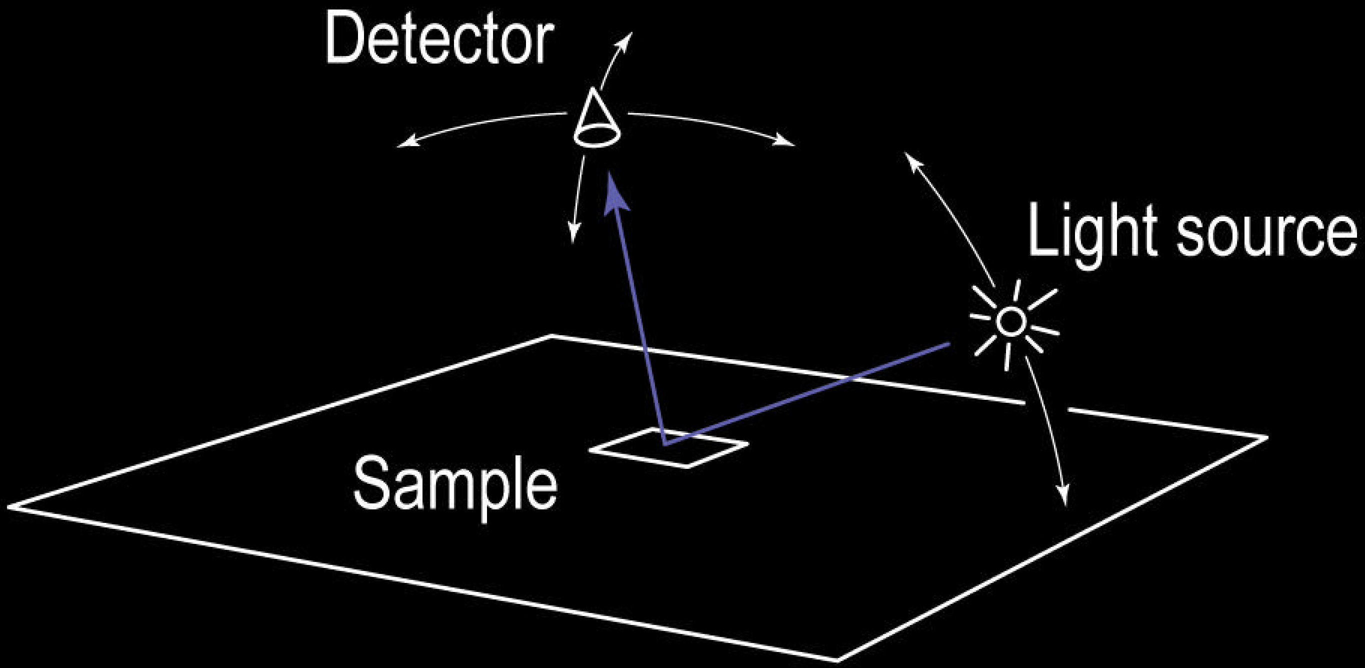
Stephen R. Marschner, Stephen H. Westin, Eric P. F. Lafortune, and Kenneth E. Torrance. "Image-based Measurement of the Bidirectional Reflectance Distribution Function." *Applied Optics*, vol. 39, no. 16 (2000).

Stephen R. Marschner, Stephen H. Westin, Eric P. F. Lafortune, Kenneth E. Torrance, and Donald P. Greenberg. "Image-based BRDF Measurement Including Human Skin." In proceedings of *10th Eurographics Workshop on Rendering*, pages 139-152, June 1999.

Face results from:

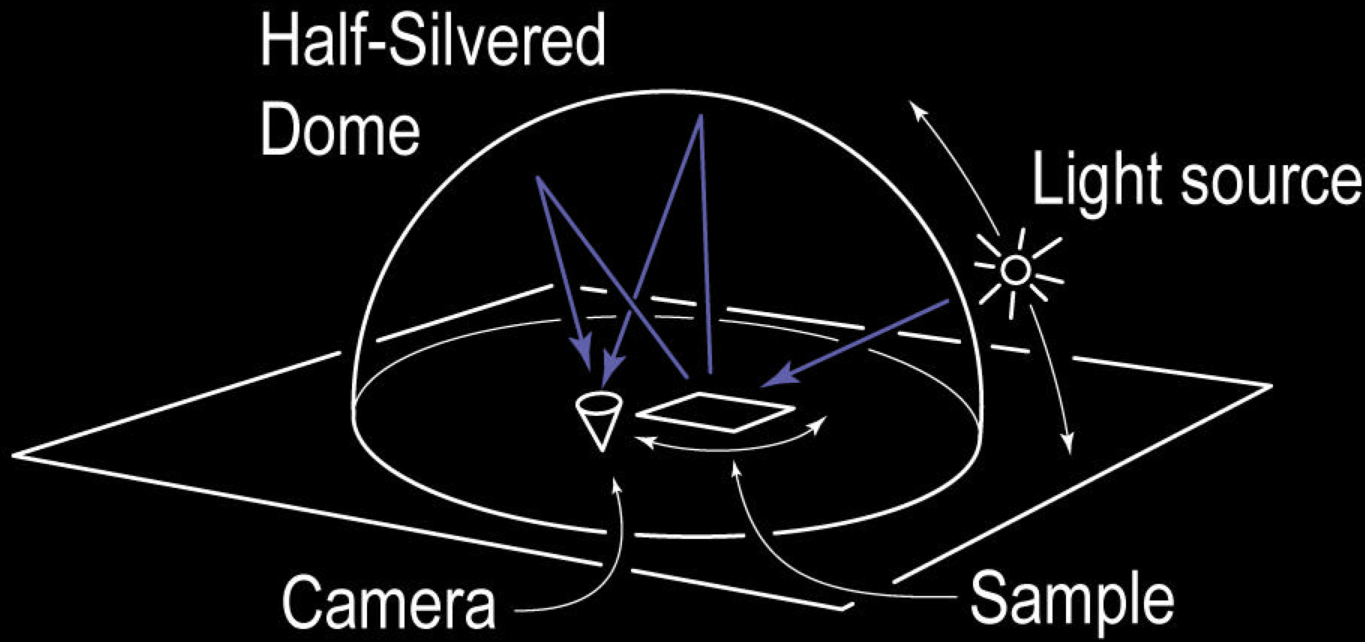
Stephen R. Marschner, Brian Guenter, and Sashi Raghupathy. "Modeling and Rendering for Realistic Facial Animation." In proceedings of *11th Eurographics Workshop on Rendering*, June 2000.

Traditional



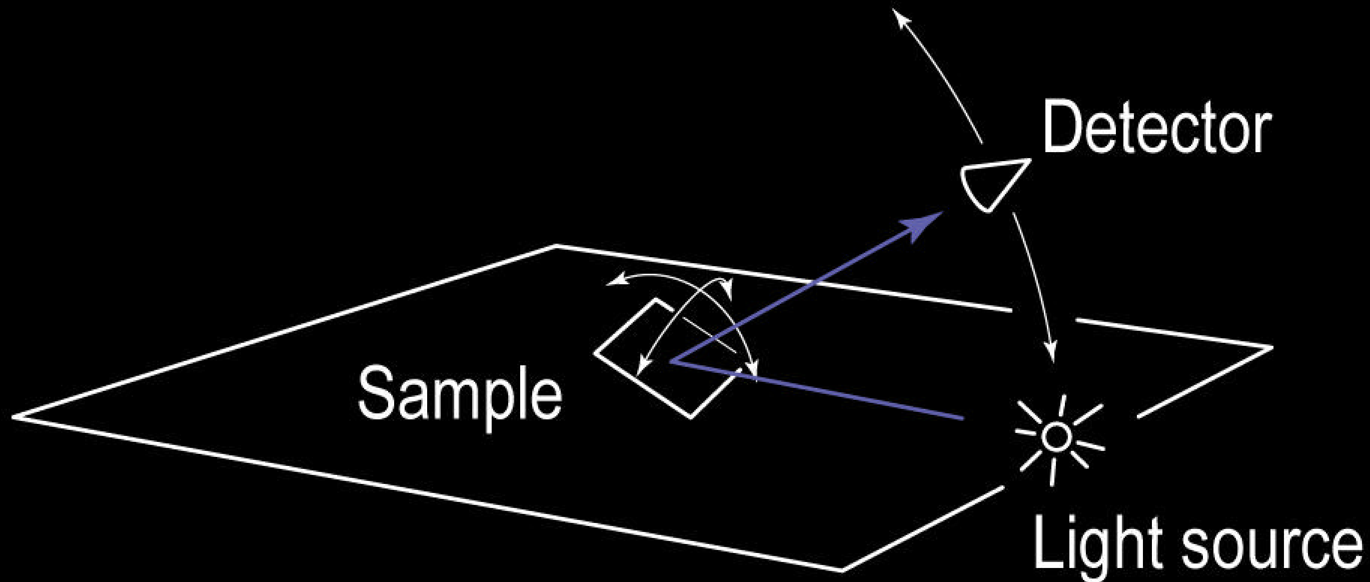
3 DOF: 2 detector, 1 source
Samples arranged on any desired grid

Image-based: Ward



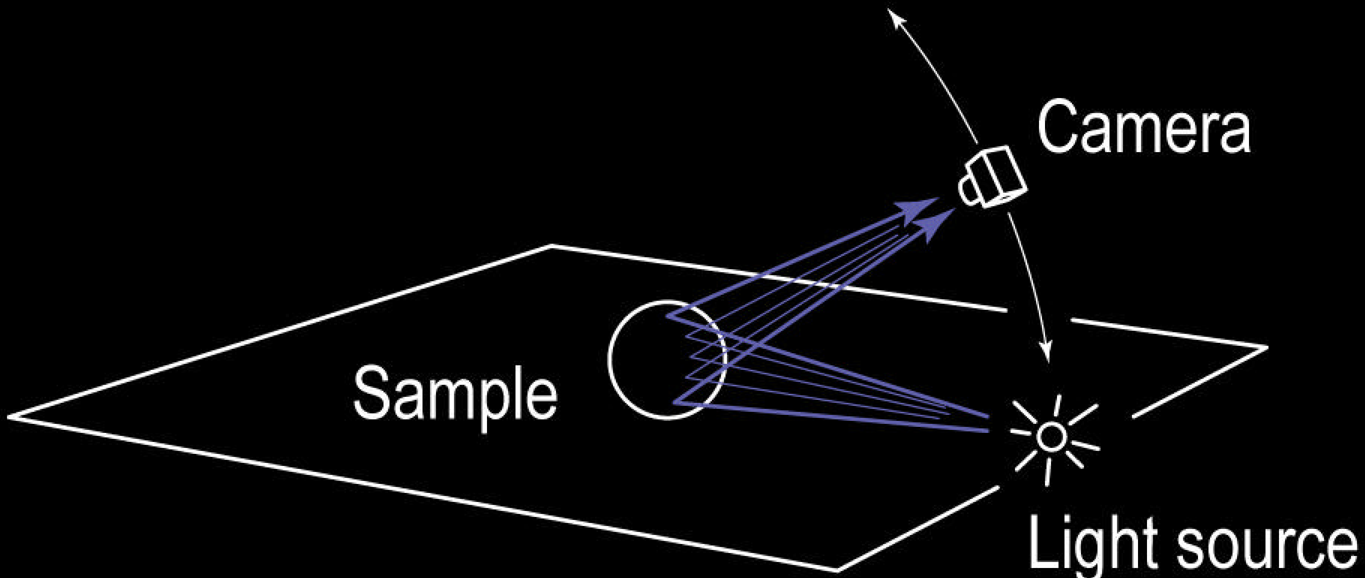
3 DOF: 2 detector, 1 source (+1 sample)
Exitant directions fixed by optics; incident directions chosen

Traditional



3 DOF: 2 sample, 1 detector
Samples arranged on any desired grid

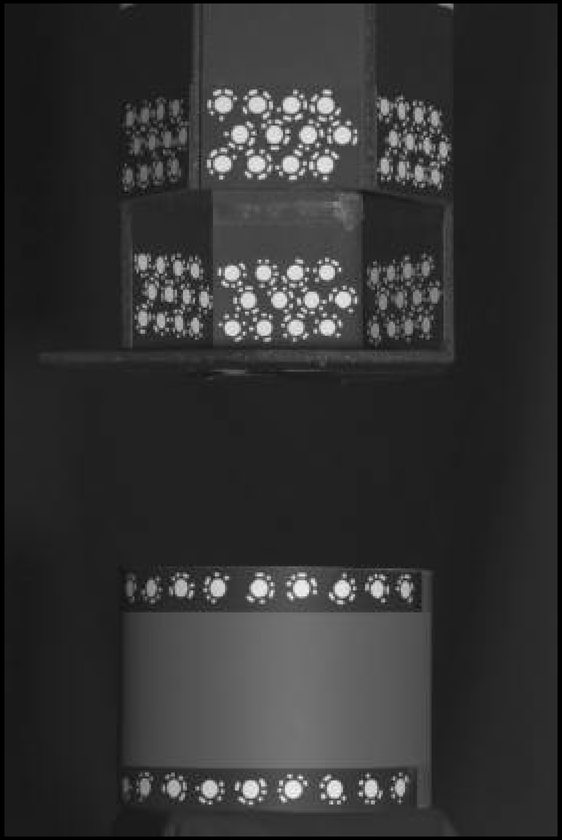
Image-based



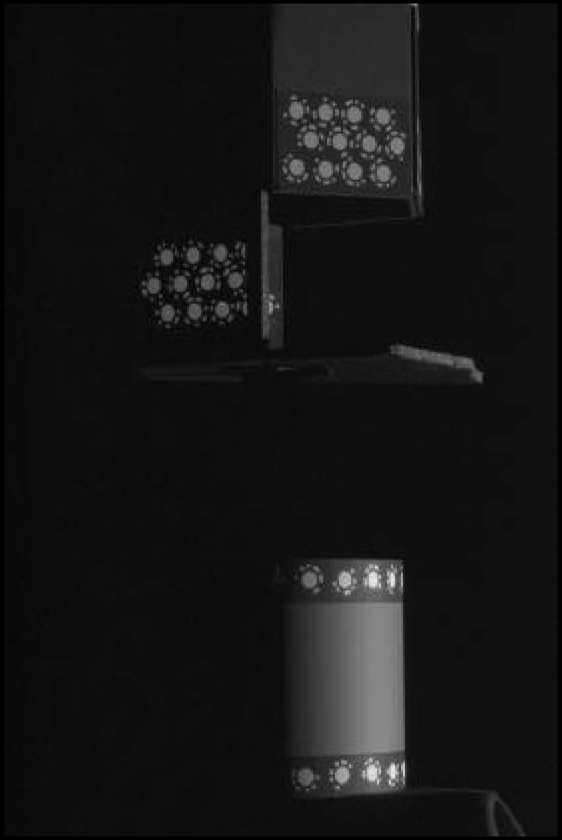
3 DOF: 2 image, 1 camera

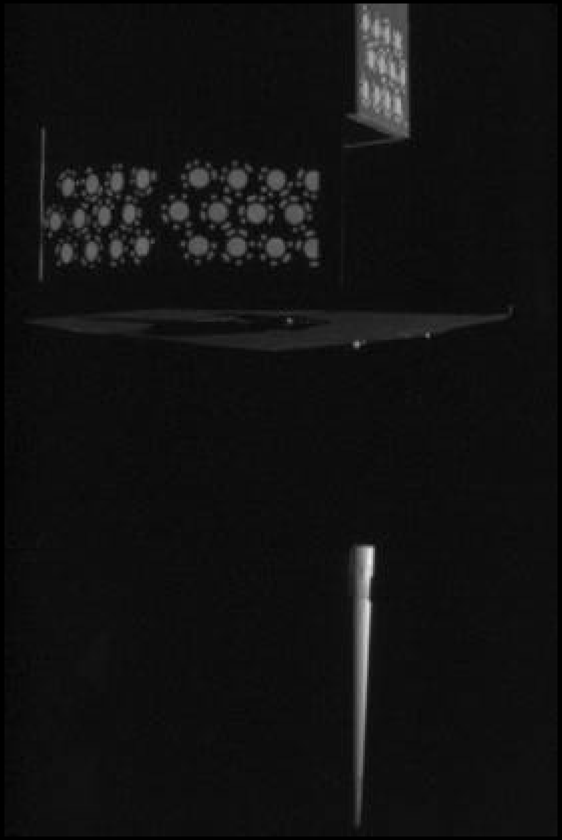
Samples arranged on 2D sheets in 3D parameter space

Results: paint

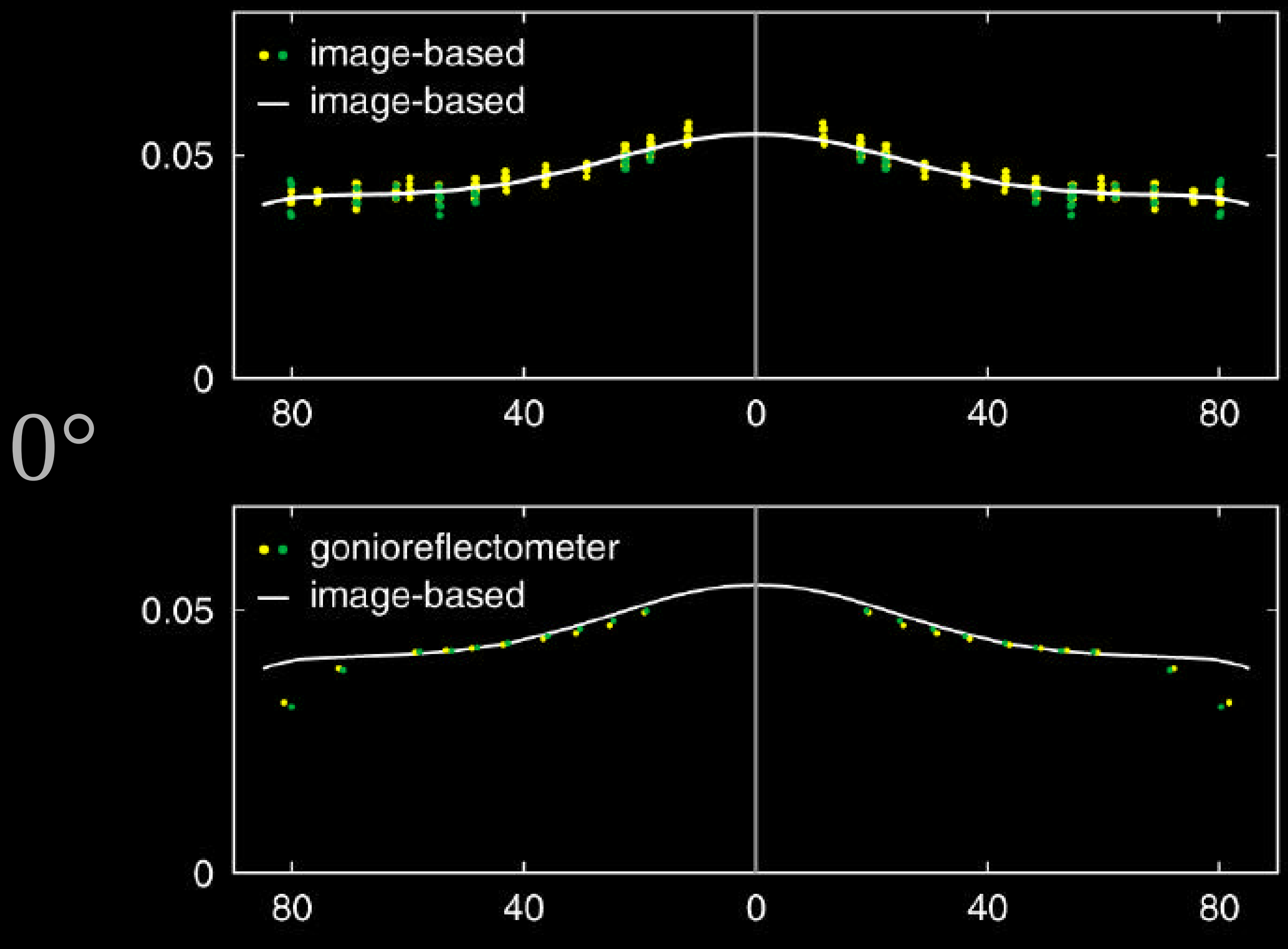


Results: paint



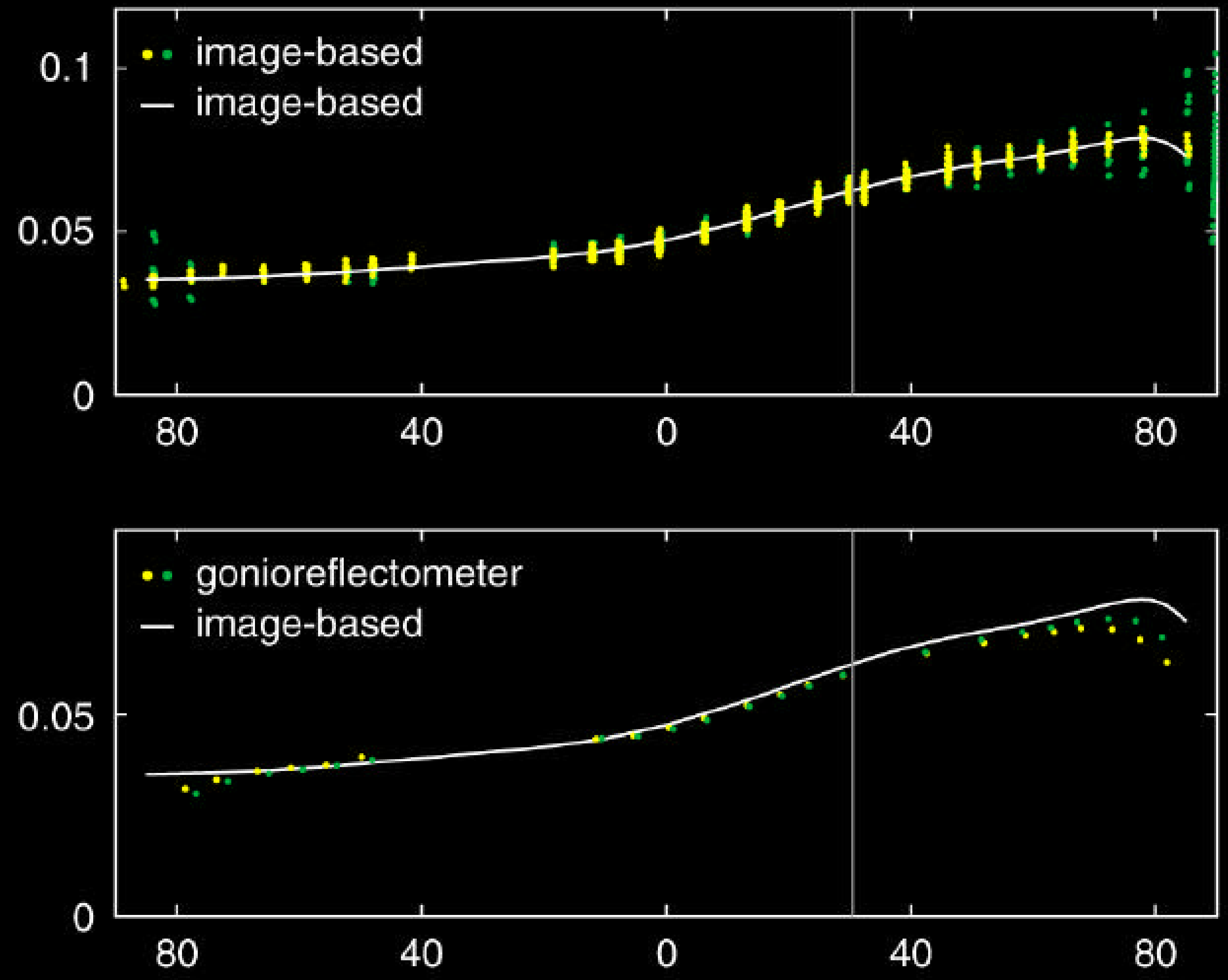


Results: paint



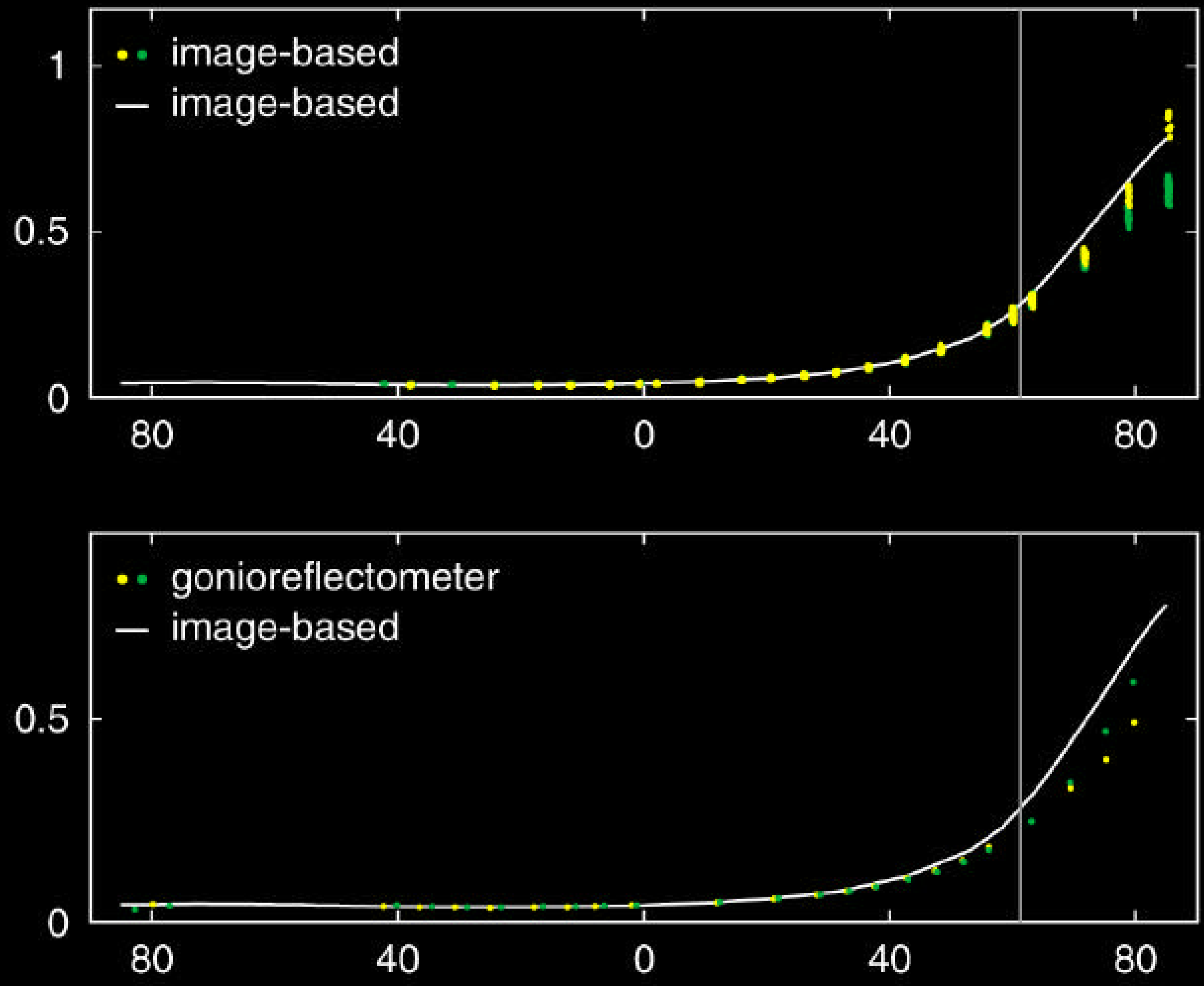
Results: paint

30°



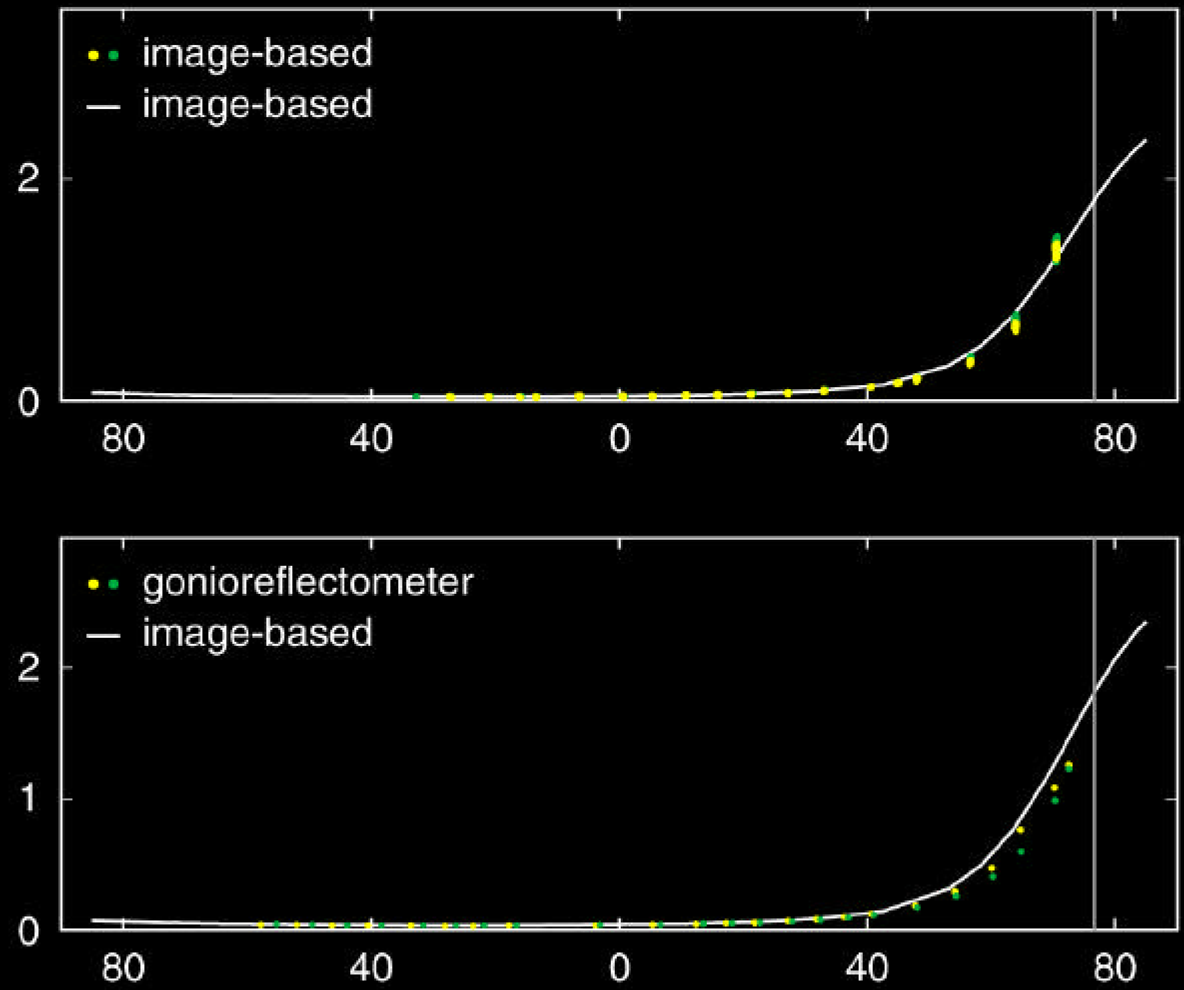
Results: paint

60°

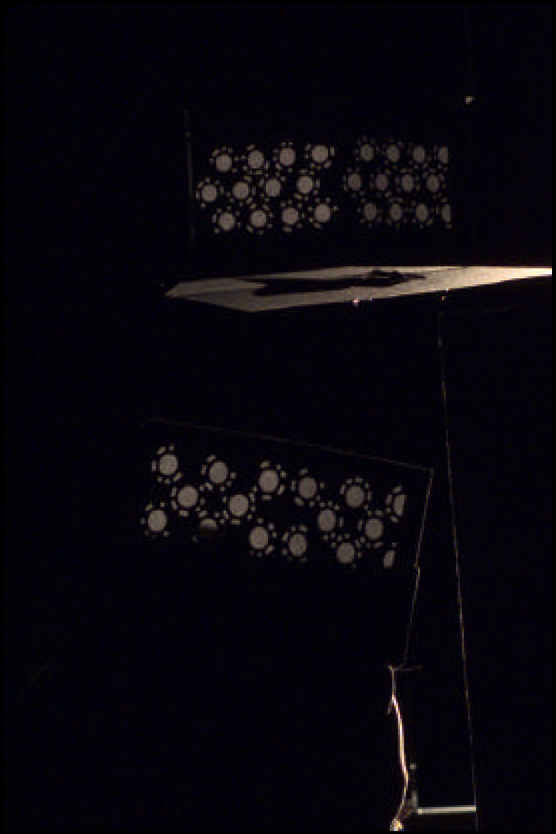


Results: paint

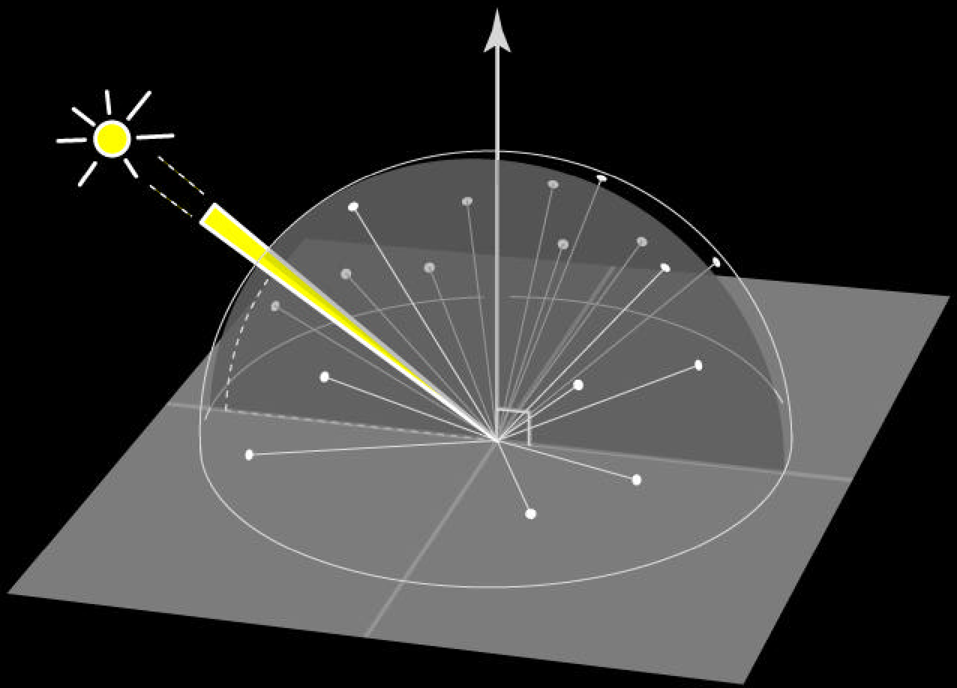
75°



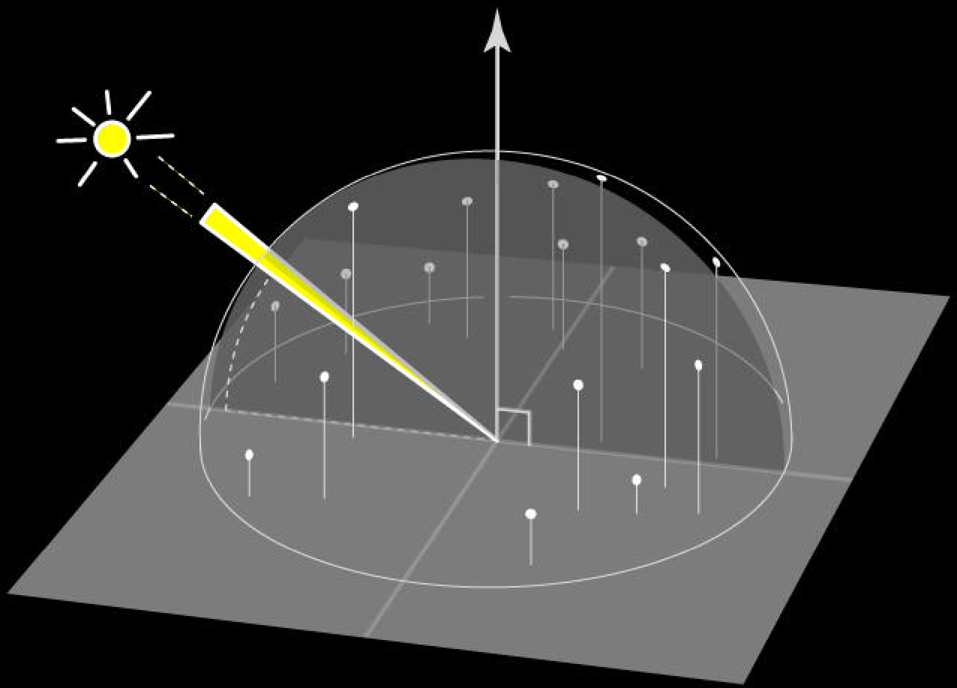
Results: skin



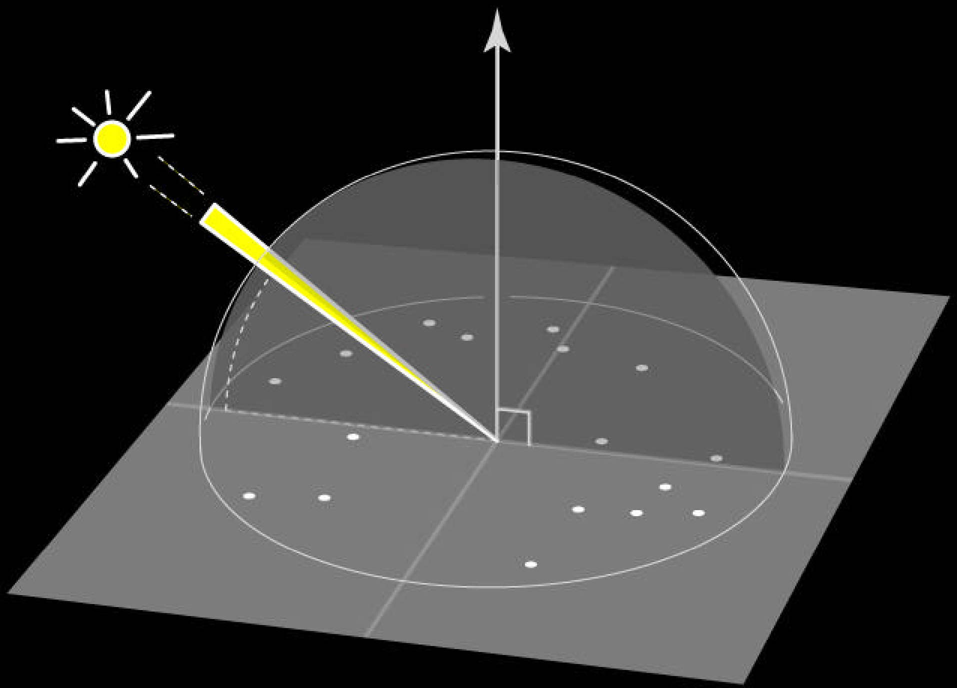
Domain Coverage



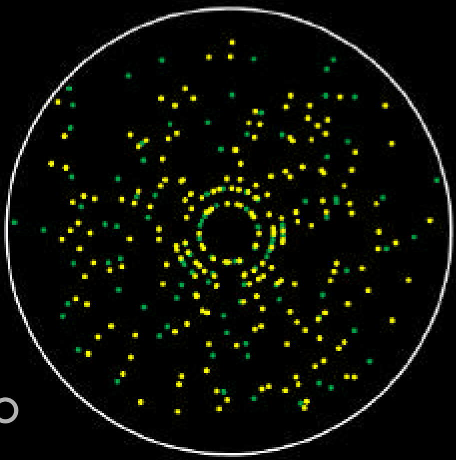
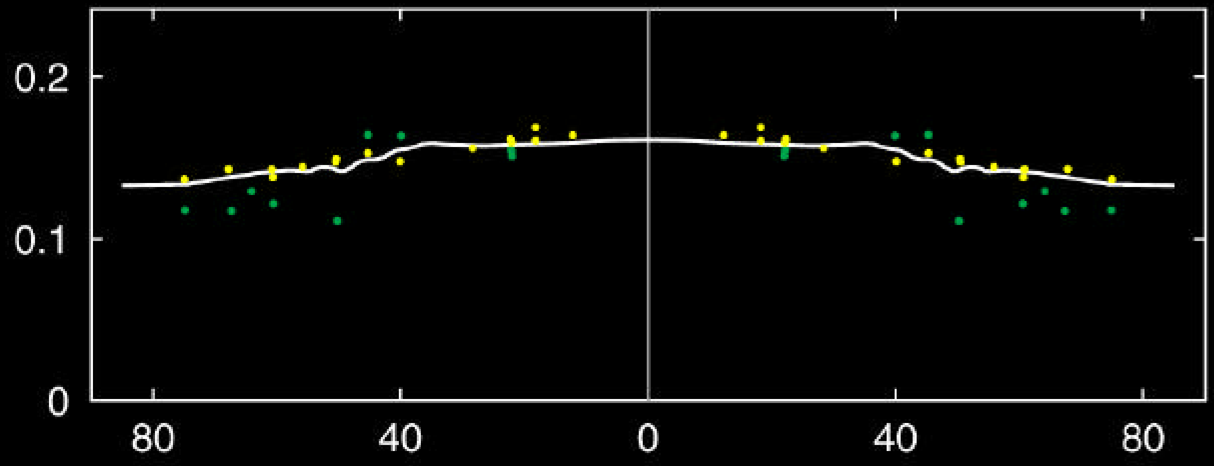
Domain Coverage

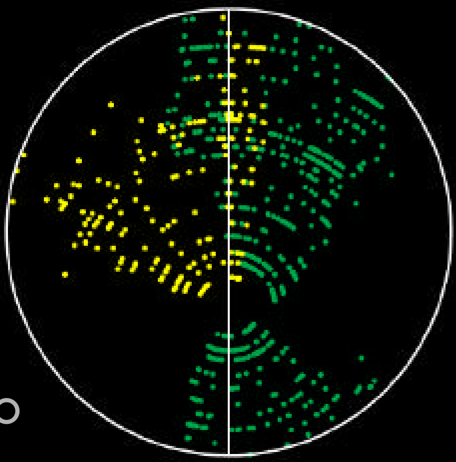
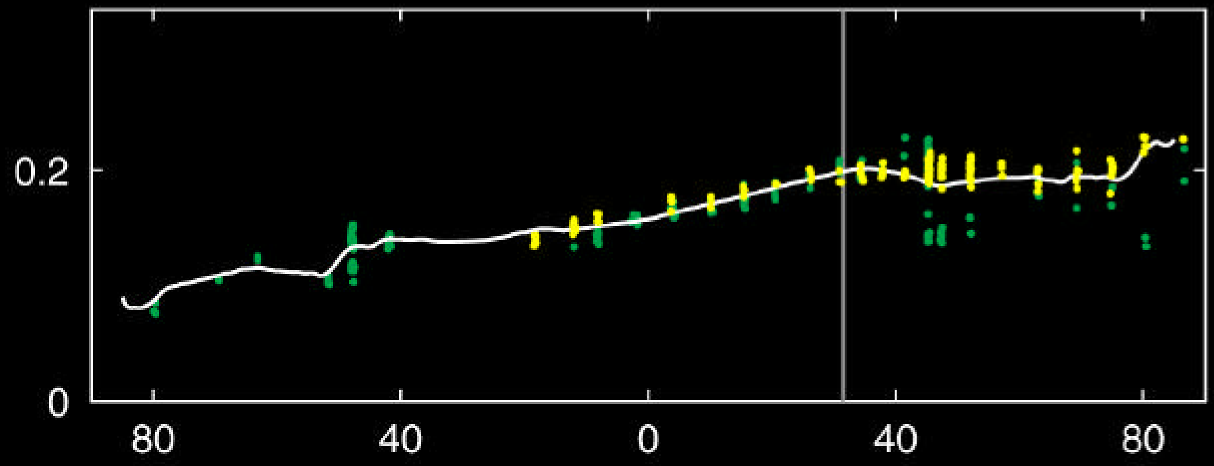


Domain Coverage

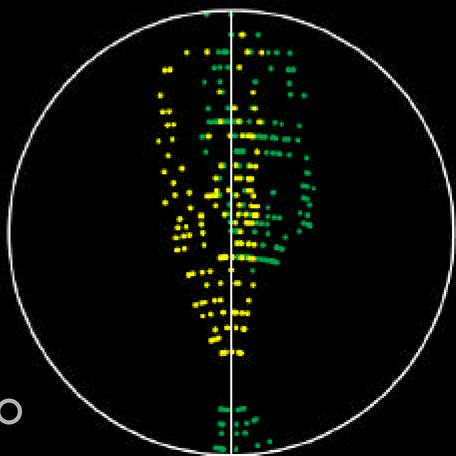


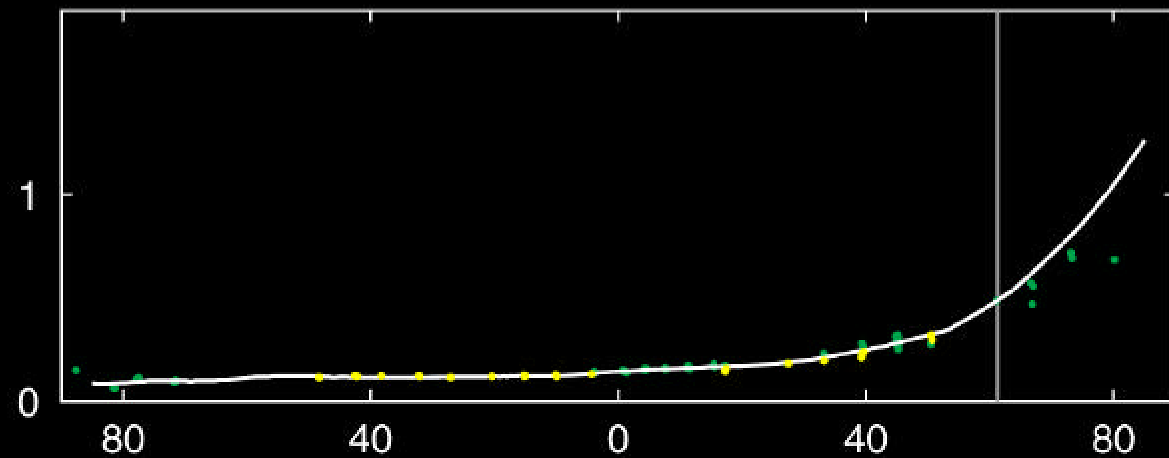
Results: skin


0°


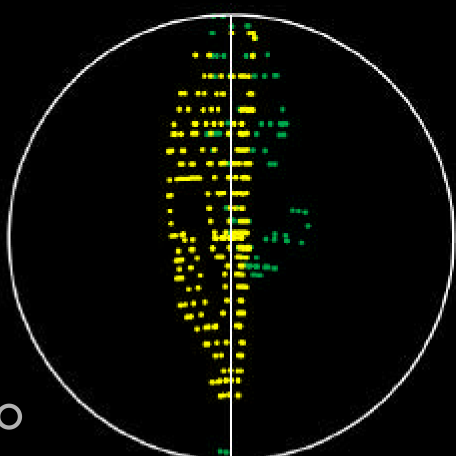

30°


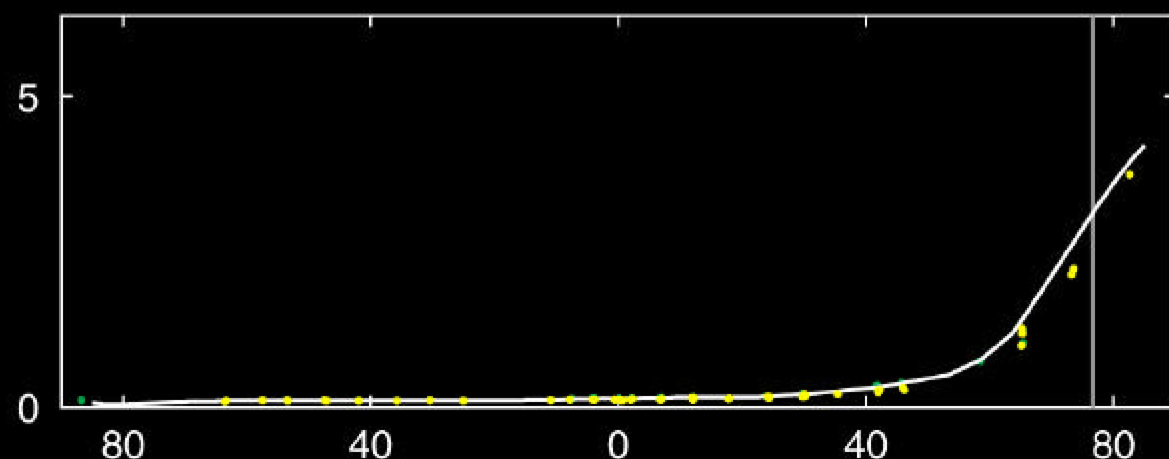
Results: skin





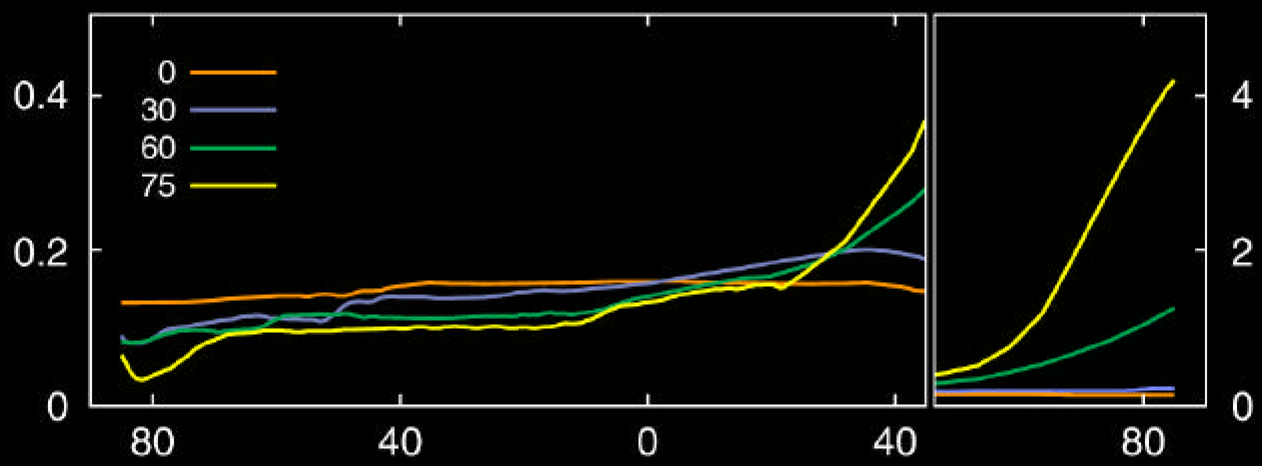
60°





75°

Results: skin



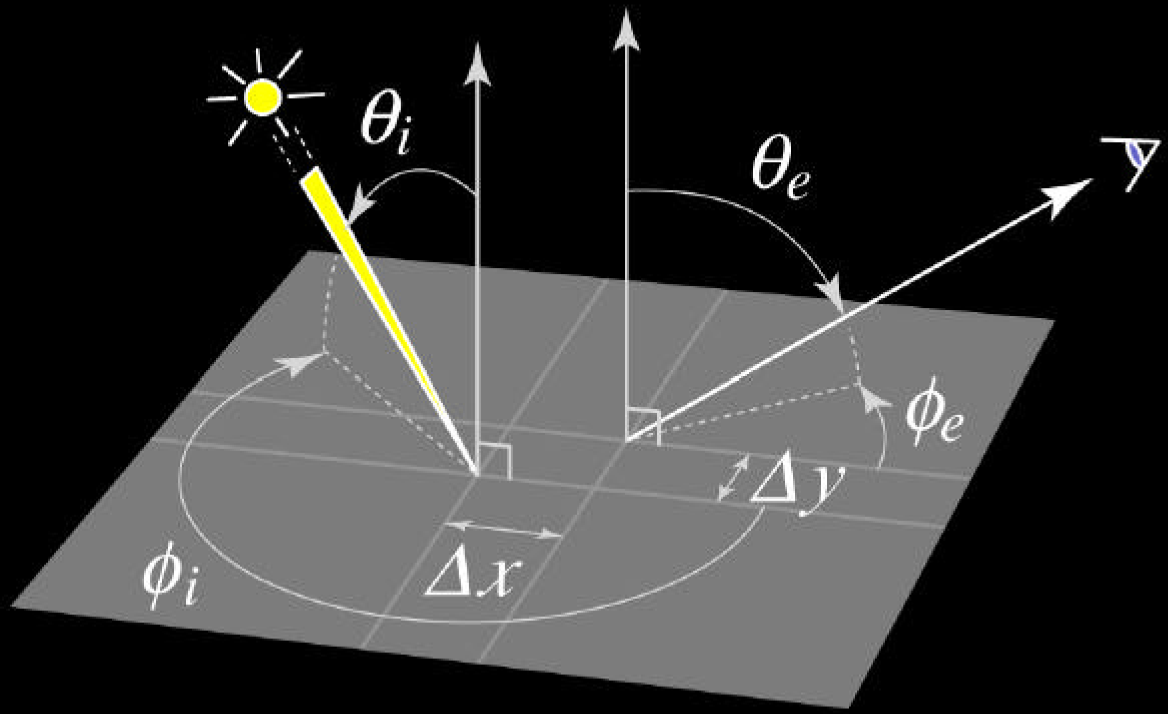
Face model

Measuring Translucency

Techniques and results from:

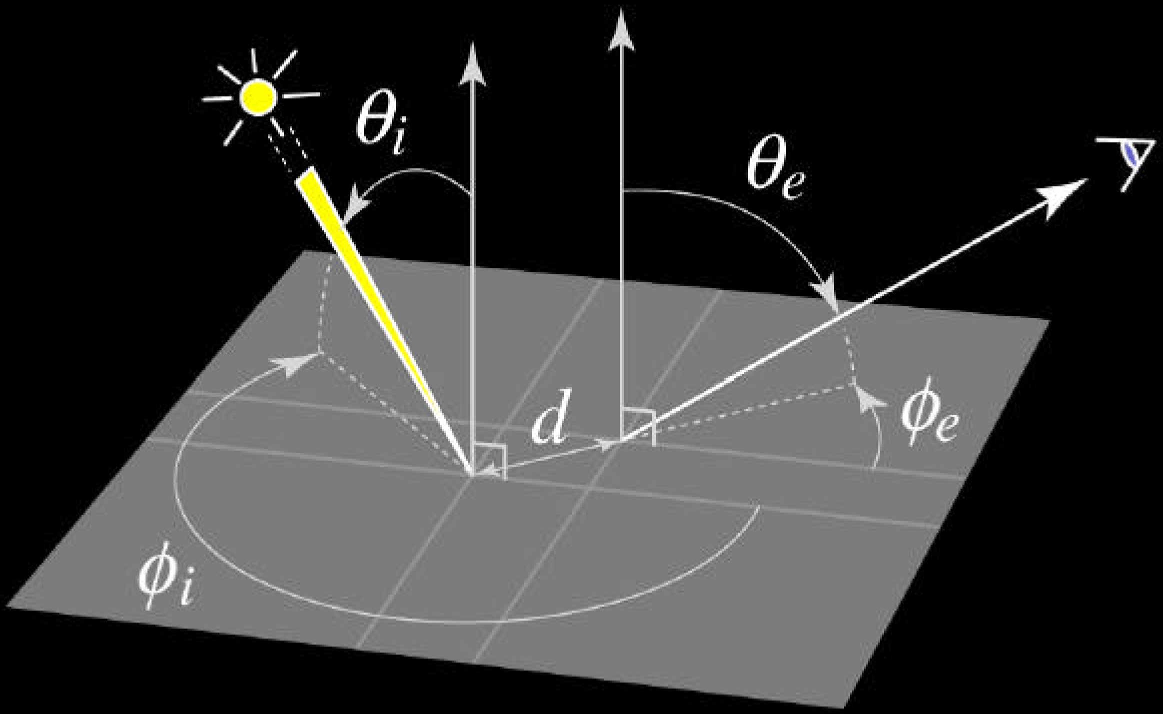
Henrik Wann Jensen, Stephen R. Marschner, Marc Levoy, and Pat Hanrahan. "A Practical Model for Subsurface Light Transport." In proceedings of *SIGGRAPH 2001*, August 2001.

BSSRDF



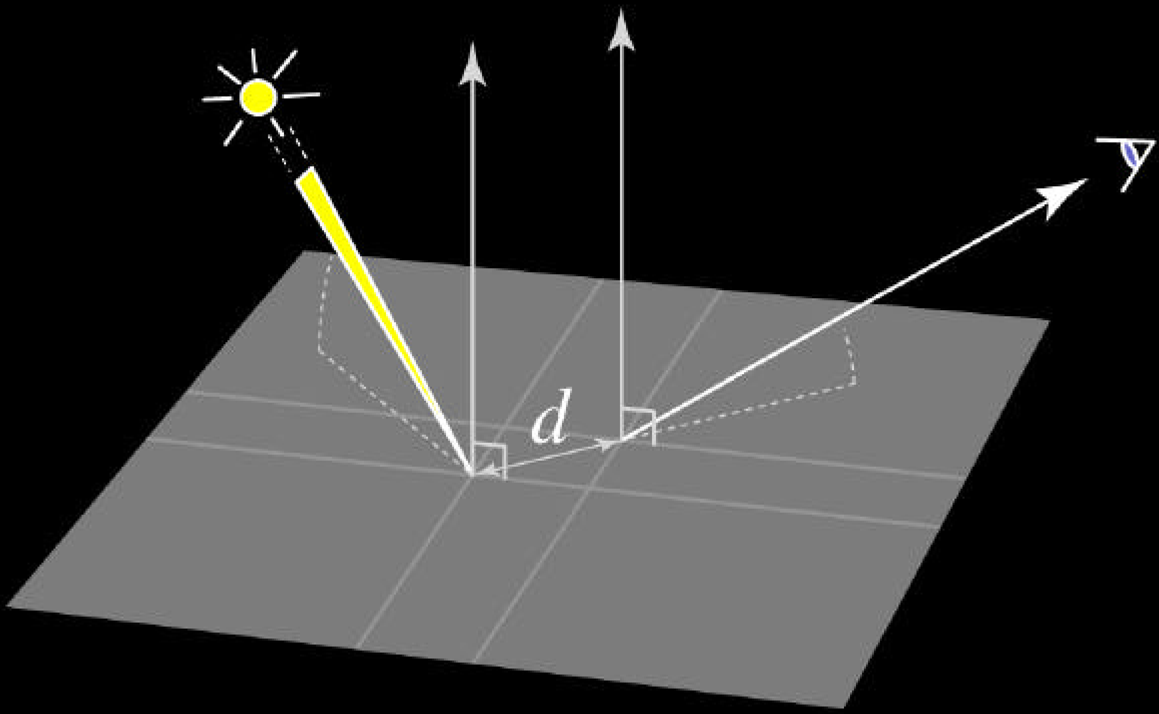
$$S(\theta_i, \phi_i, \theta_e, \phi_e, \Delta x, \Delta y)$$

BSSRDF: isotropic



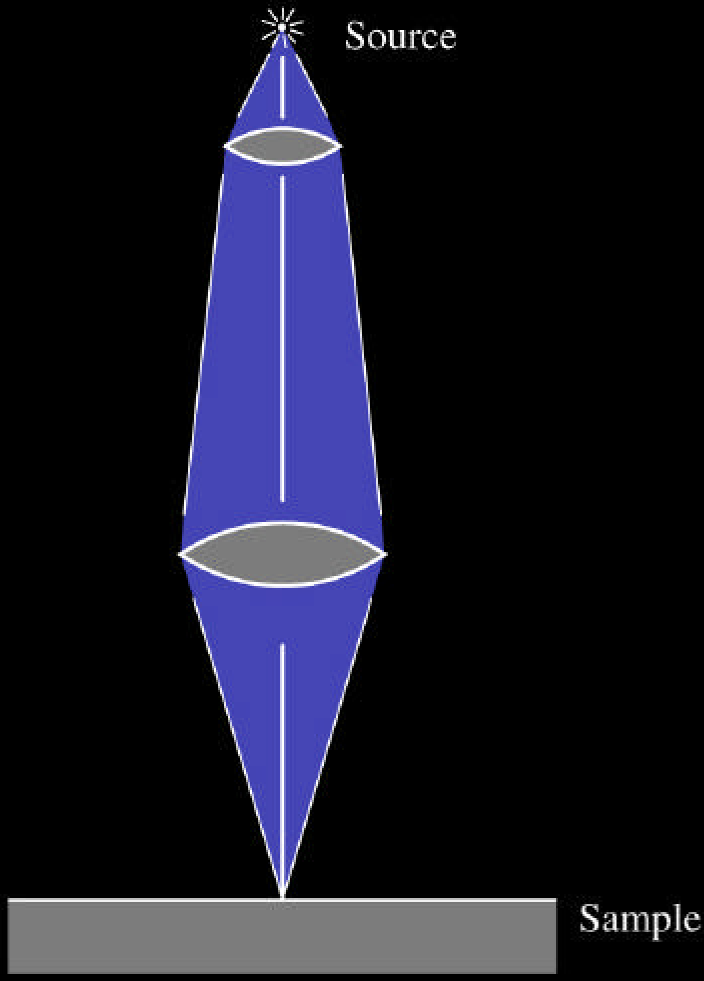
$$S(\theta_i, \phi_i, \theta_e, \phi_e, d)$$

BSSRDF: Lambertian

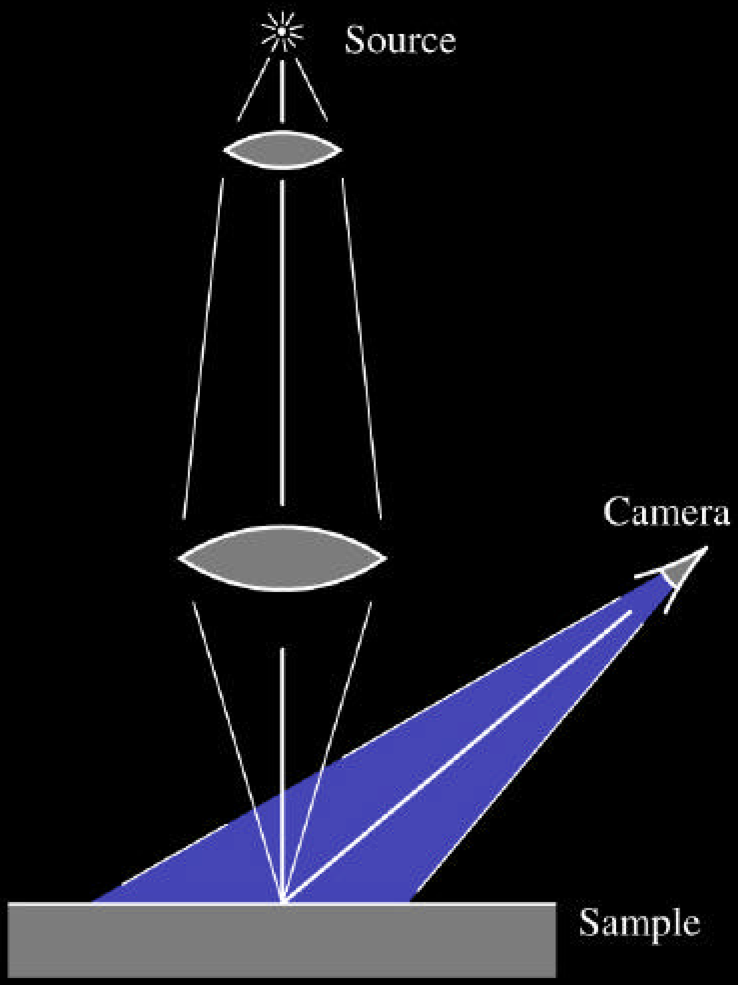


$R_d(d)$

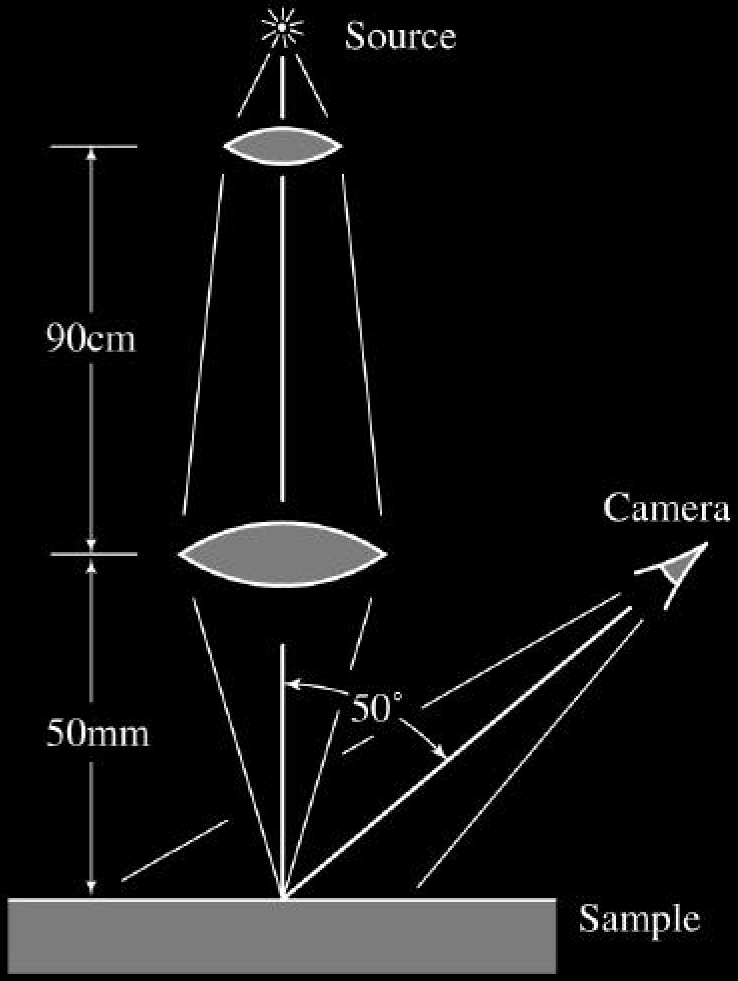
Scattering measurement



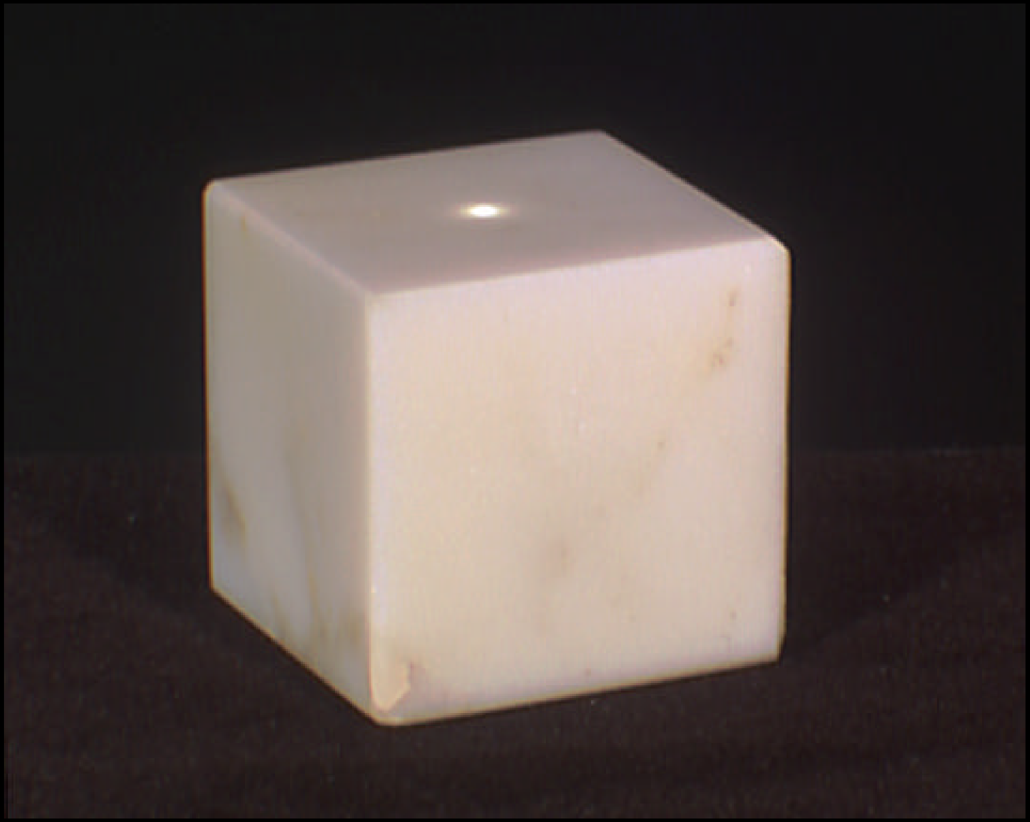
Scattering measurement



Scattering measurement



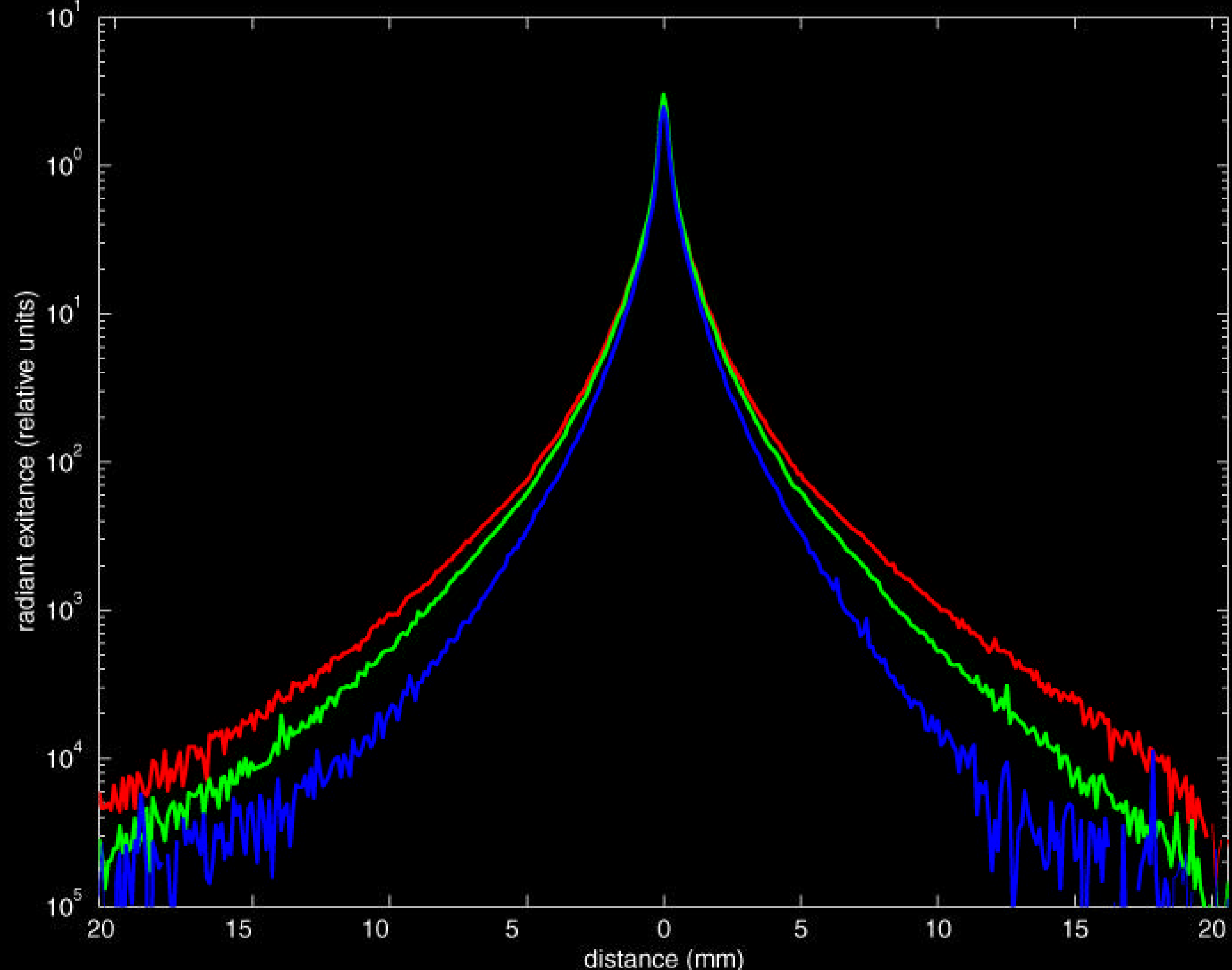
Marble sample



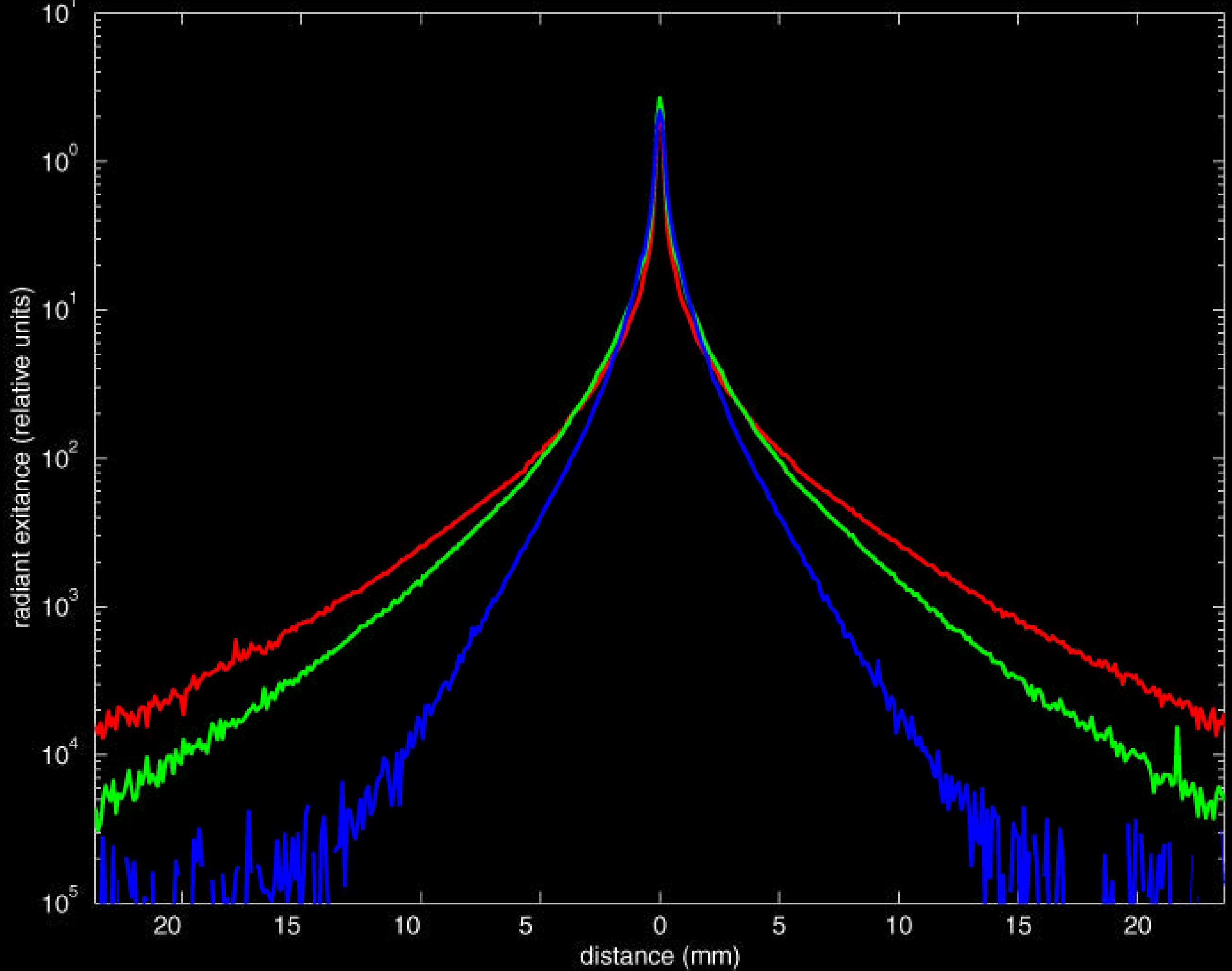
HDR photograph

(log scaled image)

Marble

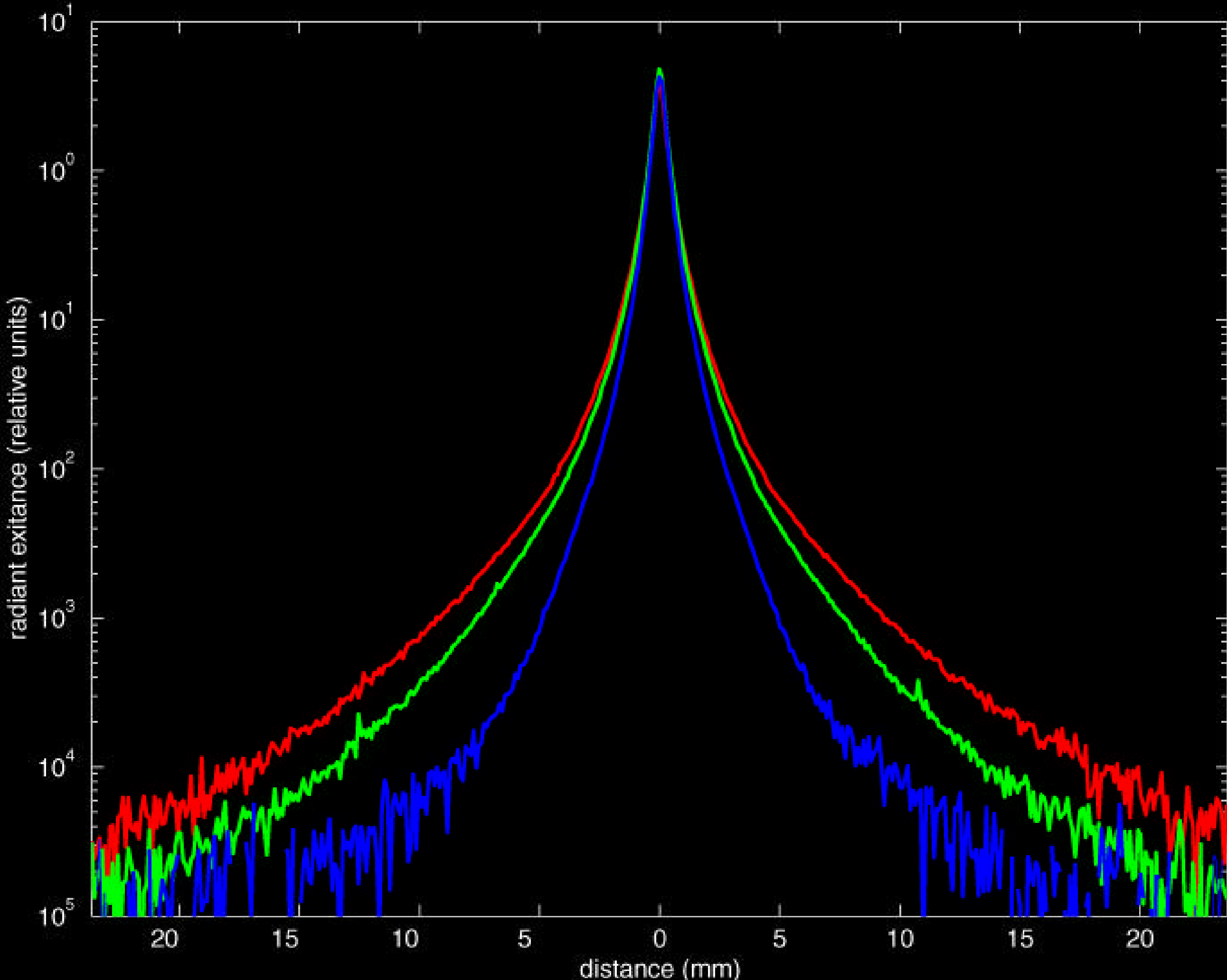

radiant exitance (relative units)
10^{1}
10^{0}
10^{1}
10^{2}
10^{3}
10^{4}
10^{5}
20
15
10
5
0
5
10
15
20
distance (mm)

Skim milk



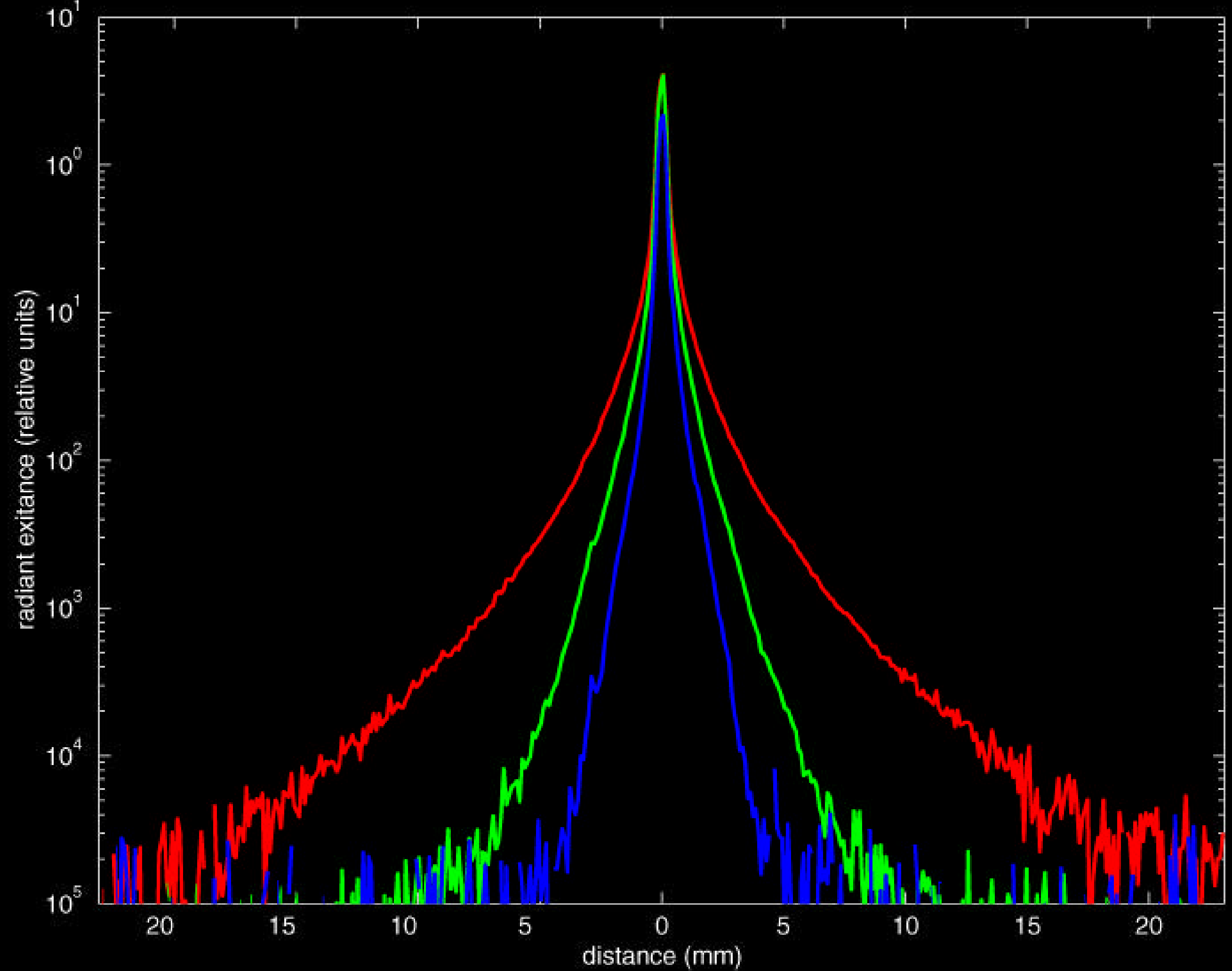
radiant exitance (relative units)
10^{1}
10^{0}
10^{1}
10^{2}
10^{3}
10^{4}
10^{5}
20 15 10 5 0 5 10 15 20
distance (mm)

Whole milk



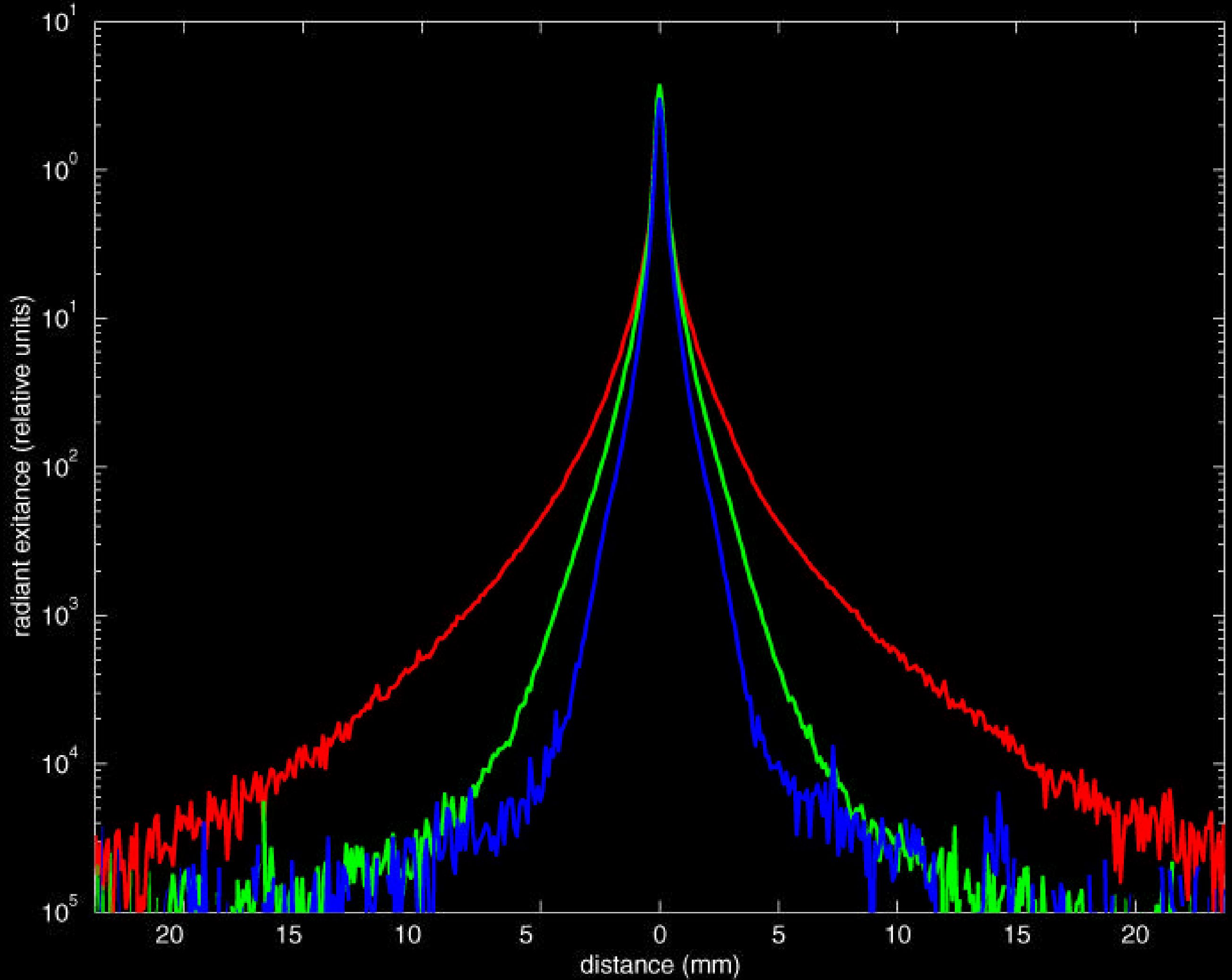
10^1
10^0
10^1
10^2
10^3
10^4
10^5
radiant exitance (relative units)
20
15
10
5
0
5
10
15
20
distance (mm)

Skin #1



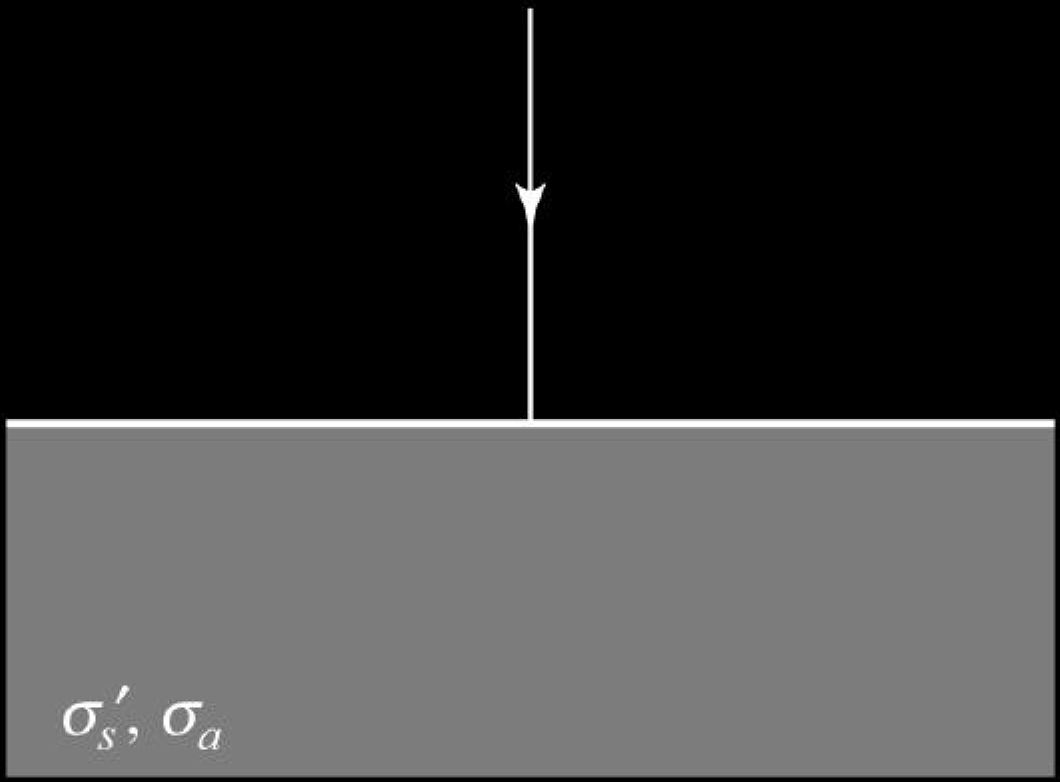
radiant exitance (relative units)
distance (mm)
10^1
10^0
10^1
10^2
10^3
10^4
10^5
20
15
10
5
0
5
10
15
20

Skin #2

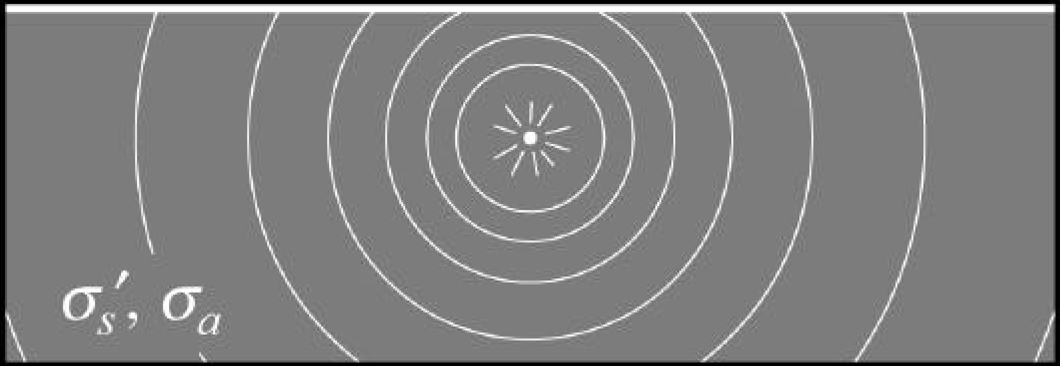


radiant exitance (relative units)
10^{1}
10^{0}
10^{1}
10^{2}
10^{3}
10^{4}
10^{5}
20
15
10
5
0
5
10
15
20
distance (mm)

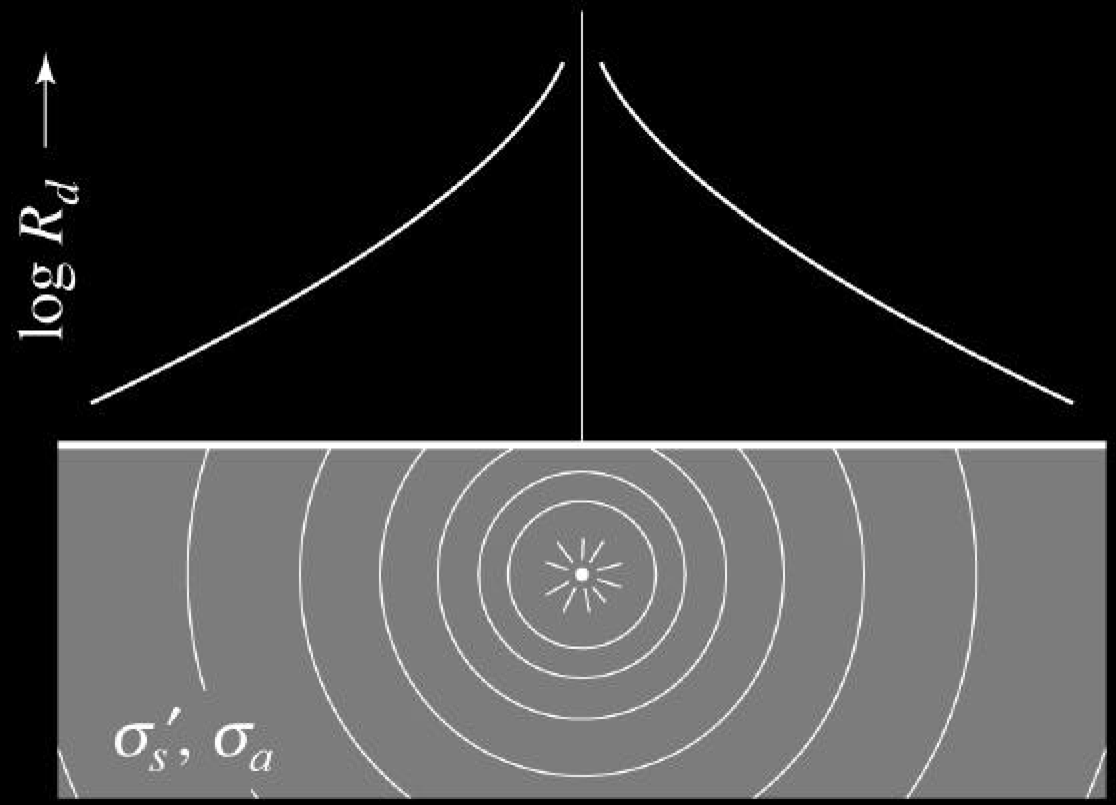
Diffusion approximation



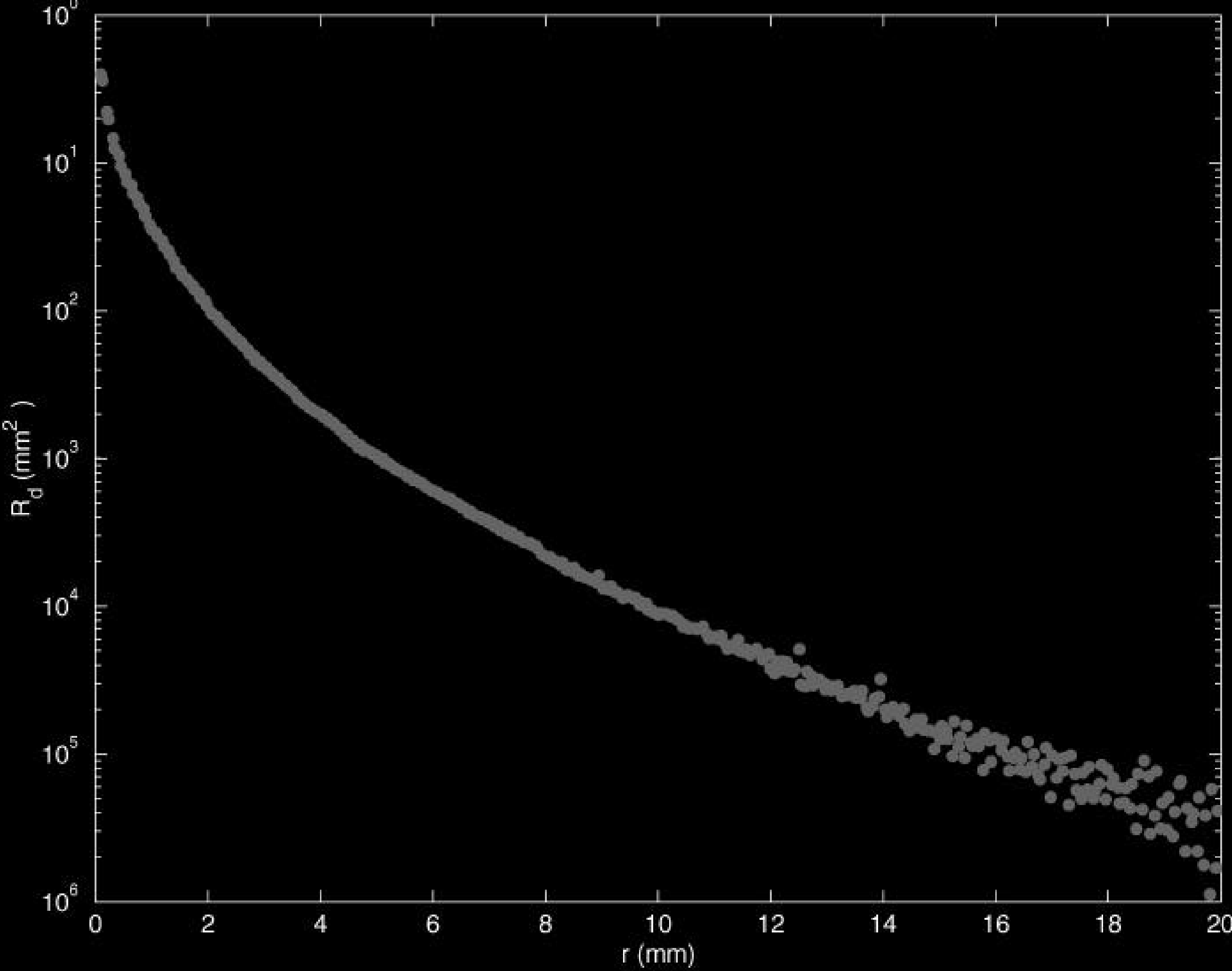
Diffusion approximation



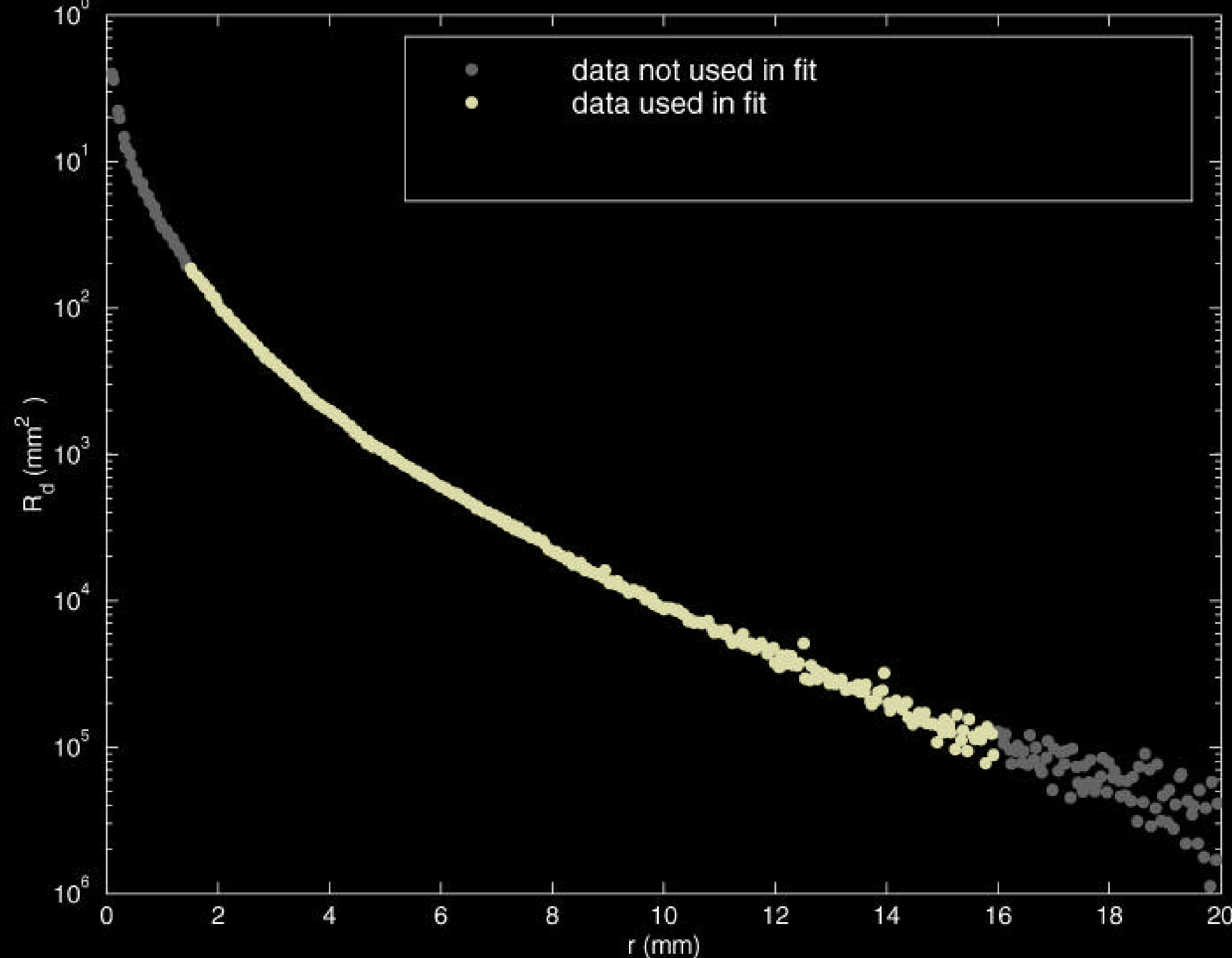
Diffusion approximation



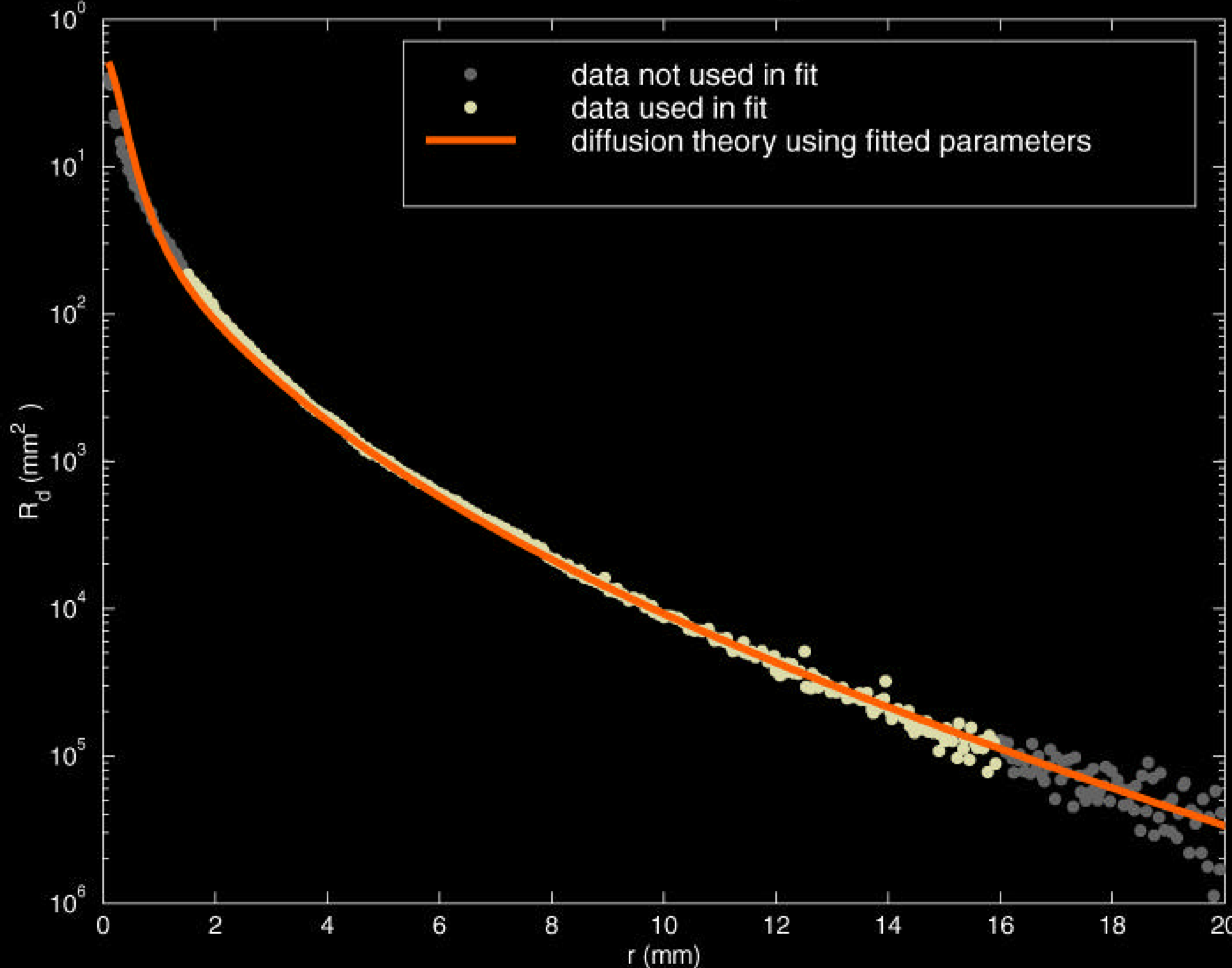
Marble data fitting



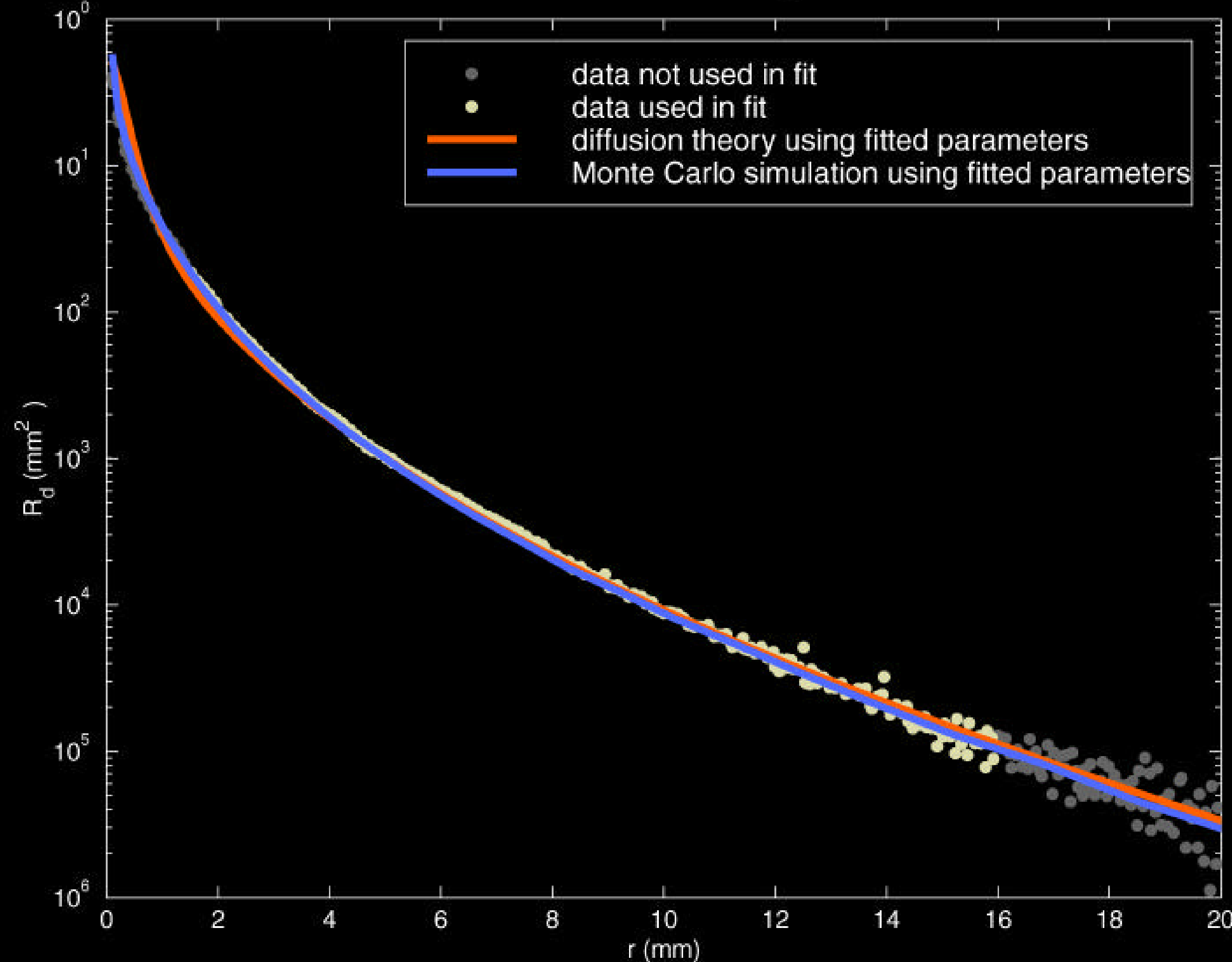
Marble data fitting



Marble data fitting



Marble data fitting



Diffuse “milk”

Skim milk

Whole milk

Opaque face

Translucent face