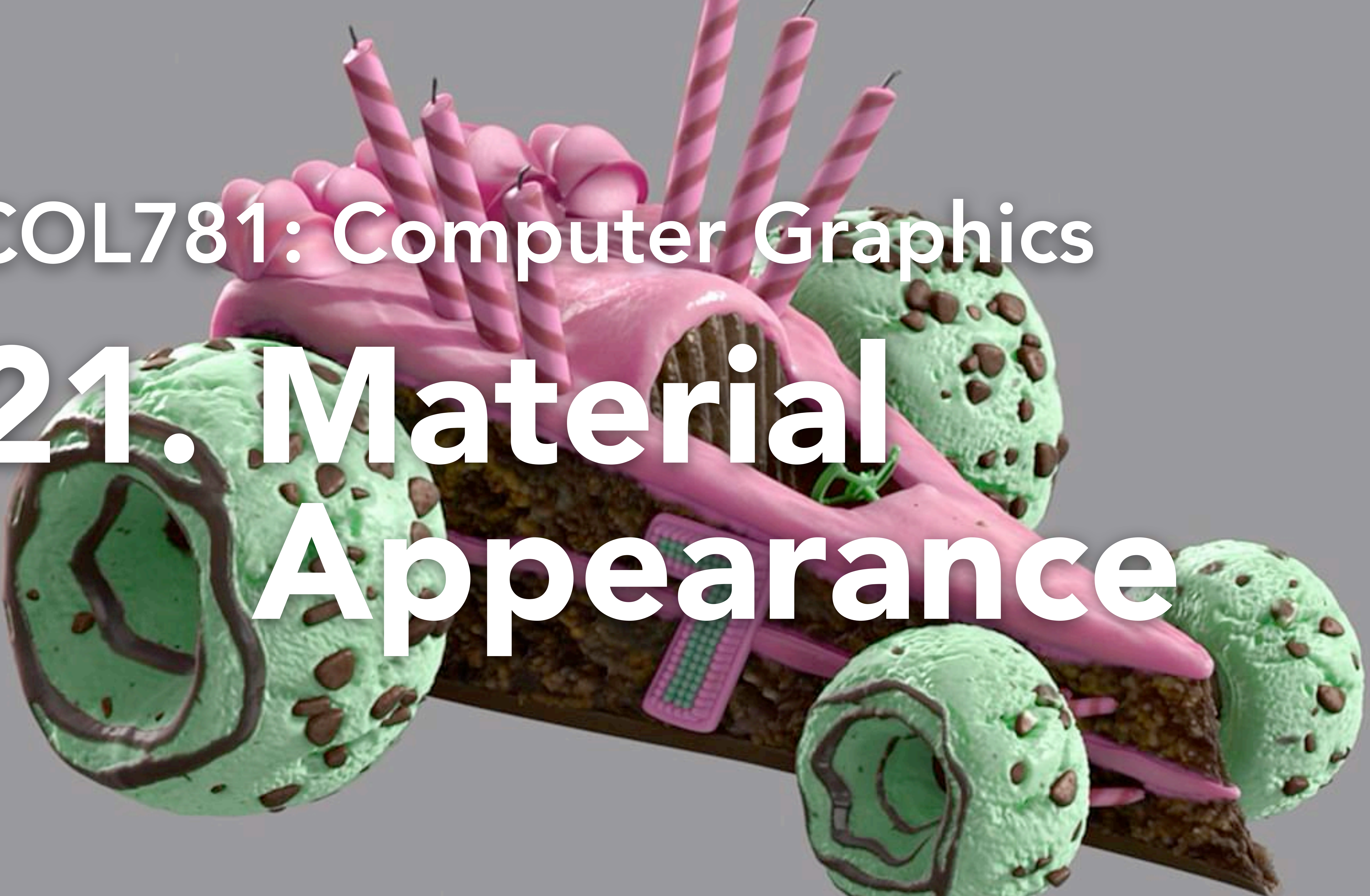
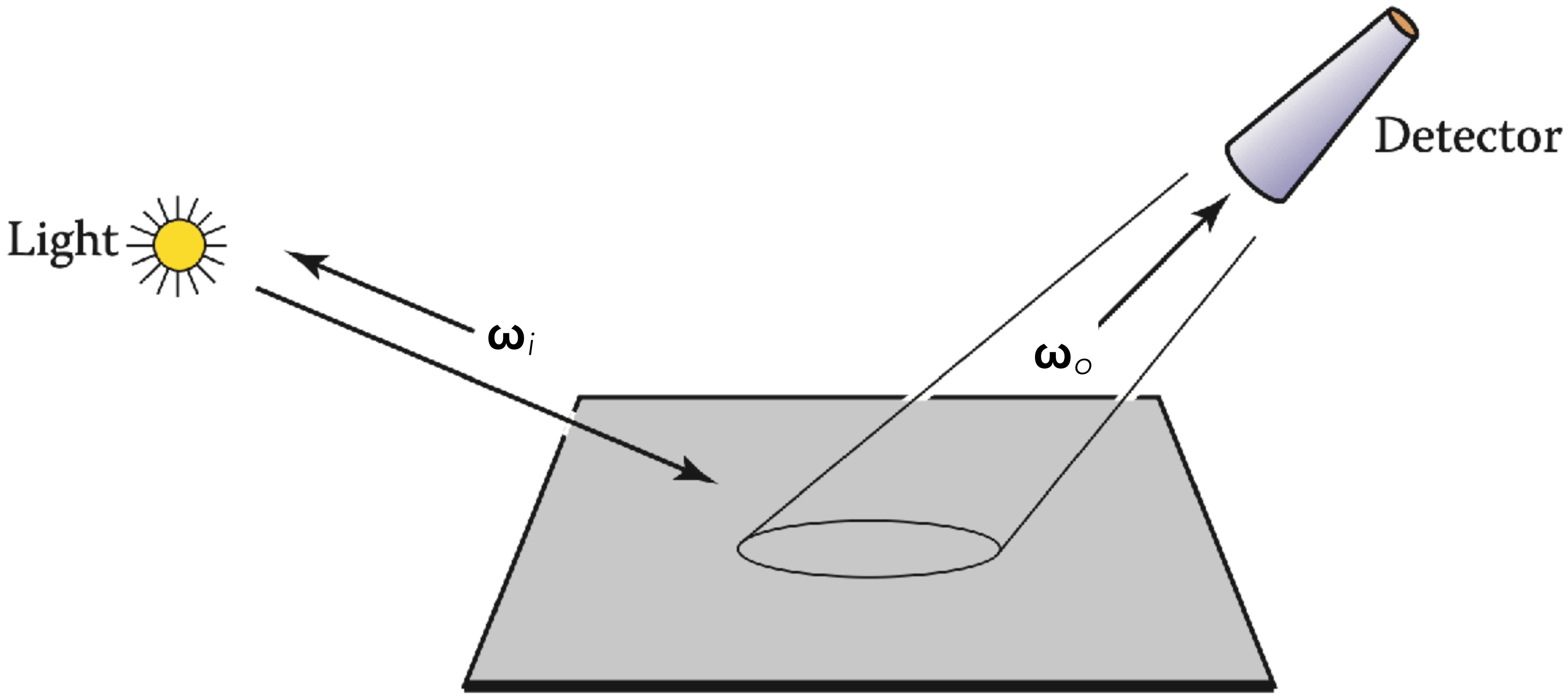
COL781: Computer Graphics

21. Material Appearance



Disney

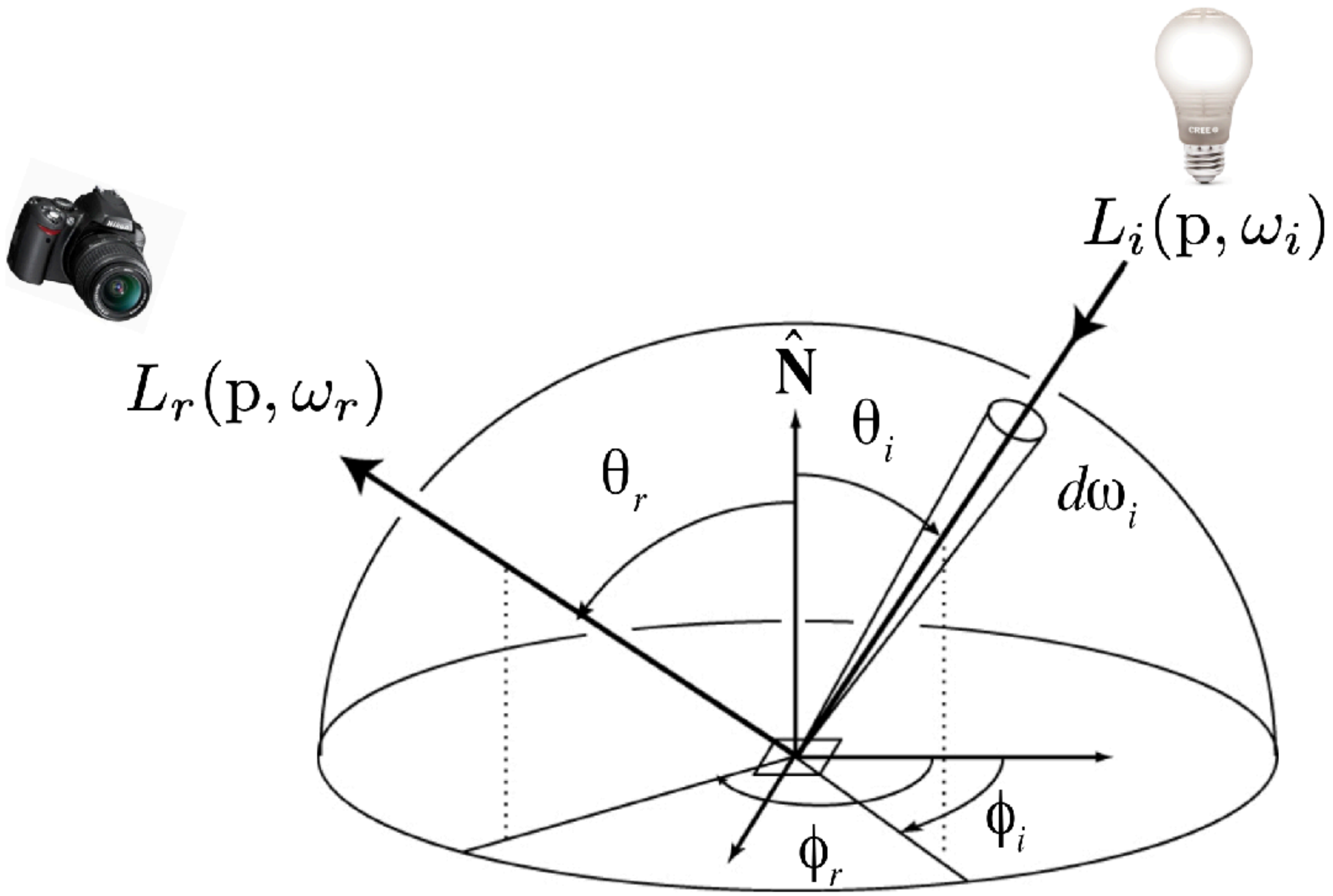
Recap: the BRDF



Bidirectional
Reflectance
Distribution
Function

Fundamentals of Computer Graphics

$$f_r(\boldsymbol{\omega}_i \rightarrow \boldsymbol{\omega}_o) = L_o(\mathbf{x}, \boldsymbol{\omega}_o)/E(\mathbf{x})$$



$$L_r(\mathbf{x}, \boldsymbol{\omega}_r) = \int_{H^2} f_r(\boldsymbol{\omega}_i \to \boldsymbol{\omega}_r)\, L_i(\mathbf{x}, \boldsymbol{\omega}_i) \cos(\theta_i)\, \mathrm{d}\boldsymbol{\omega}_i$$

Diffuse

Plastic

Red semi-gloss paint

Ford “Mystic Lacquer” paint

Mirror

Gold

Lambertian (diffuse) material

Simplest possible model: BRDF is a constant!

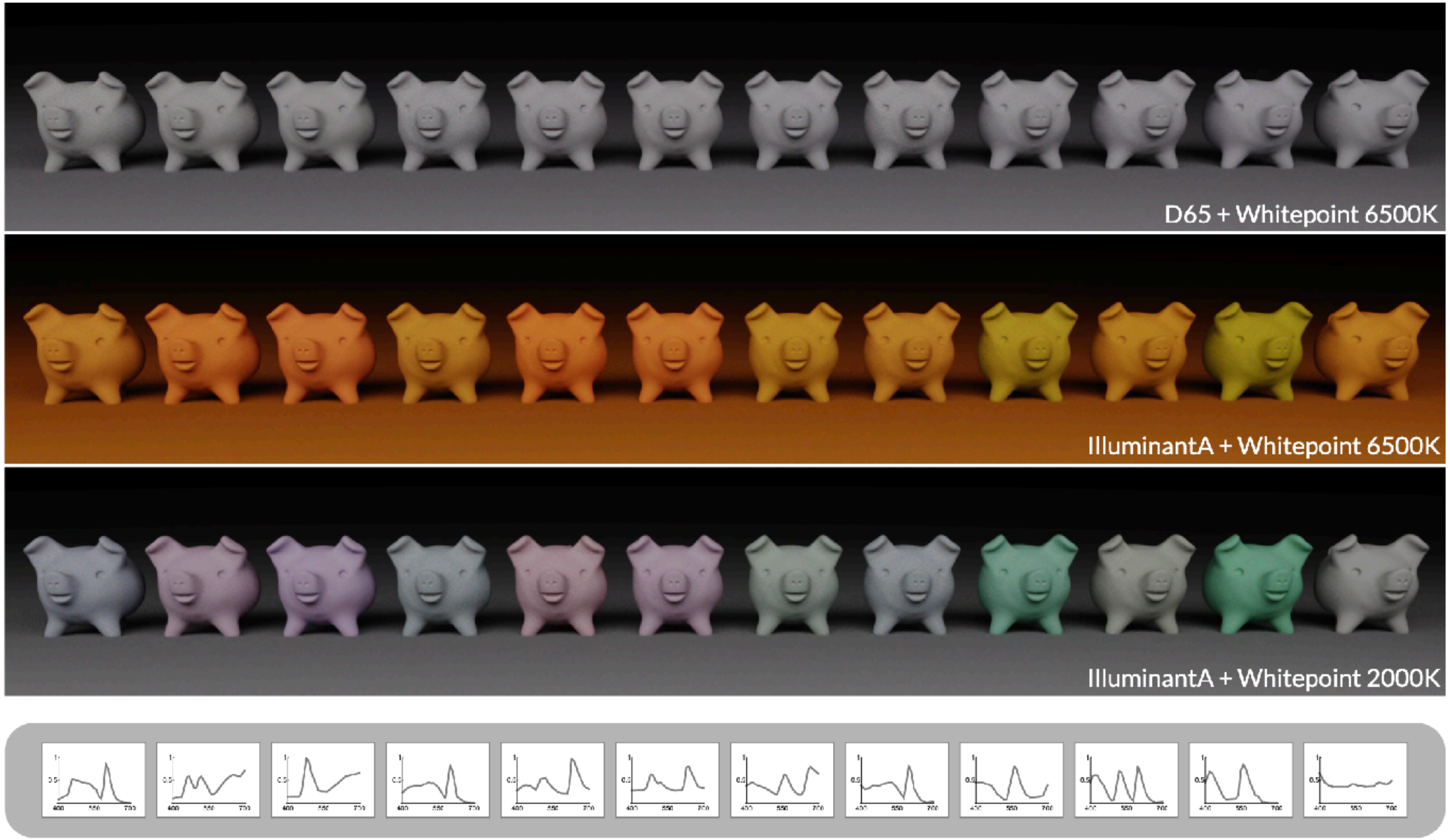
$$L_o(\boldsymbol{\omega}_o) = \int_{H^2} f_r \, L_i(\boldsymbol{\omega}_i) \cos(\theta_i) \, d\boldsymbol{\omega}_i$$

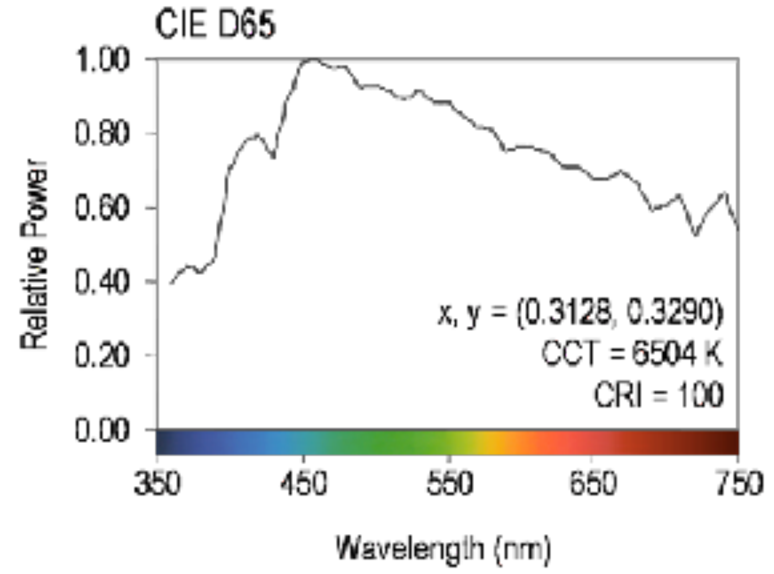
$$= f_r \, E_i$$

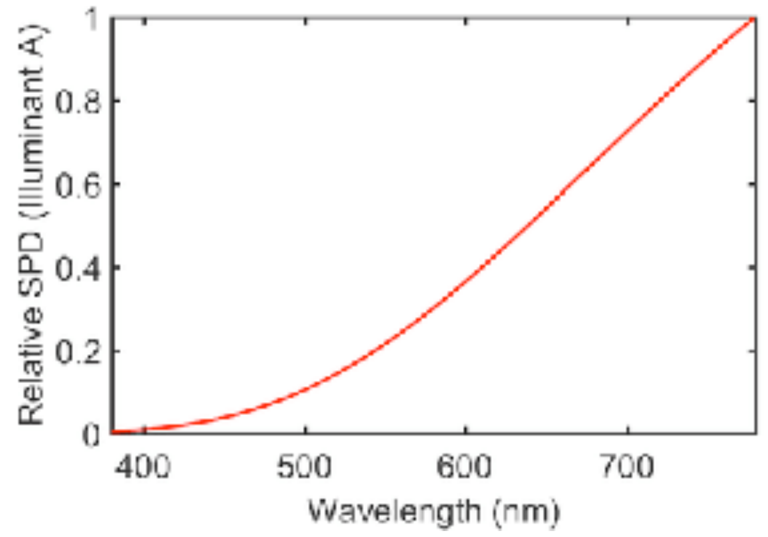
To conserve energy, $f_r = \rho/\pi$ where **albedo** ρ is ≤ 1

Why? For constant radiance L, total flux density = $L\,\pi$

In principle, we should specify the spectral albedo…

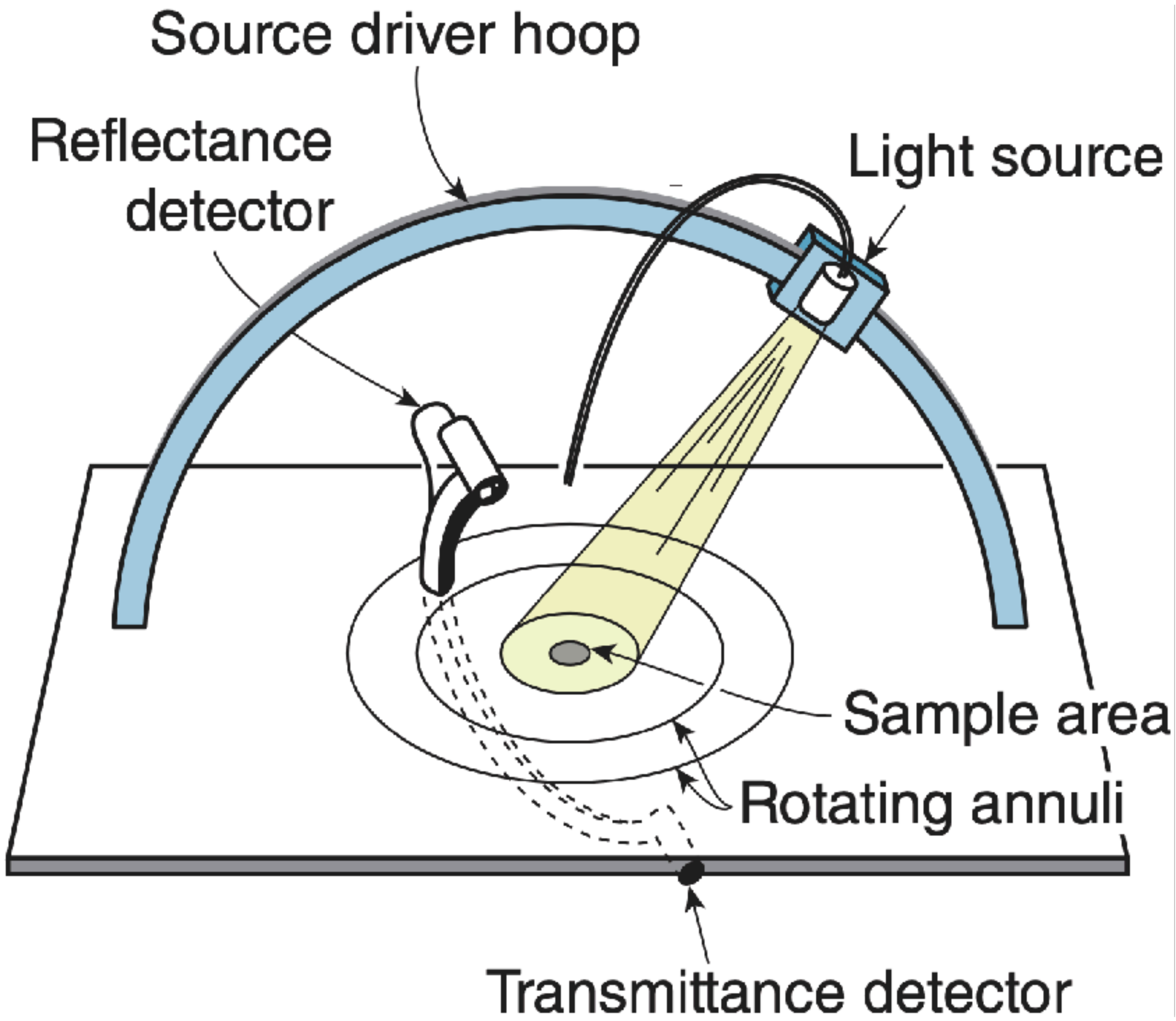






Andrea Weidlich

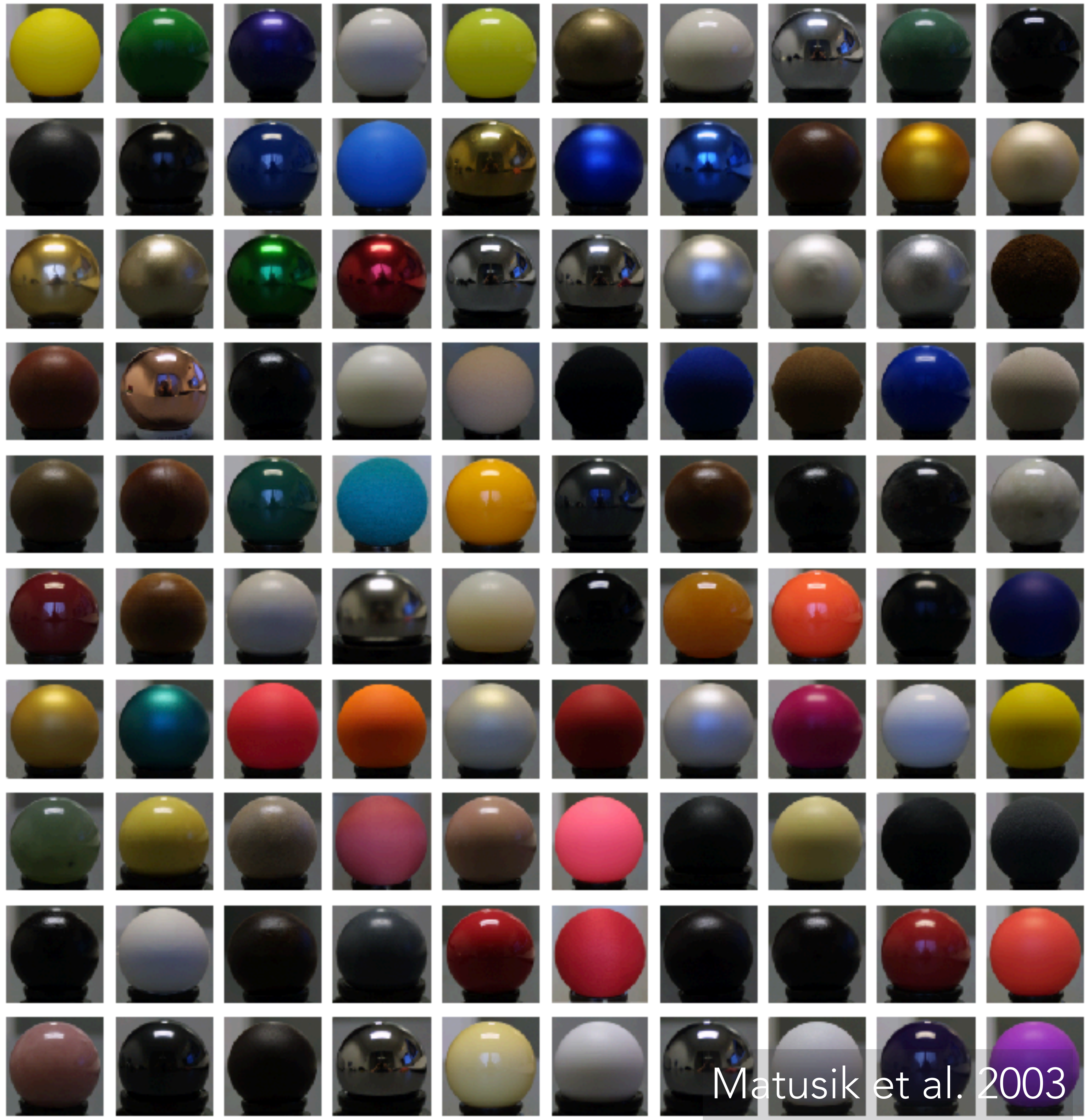
BRDF acquisition: Gonioreflectometer

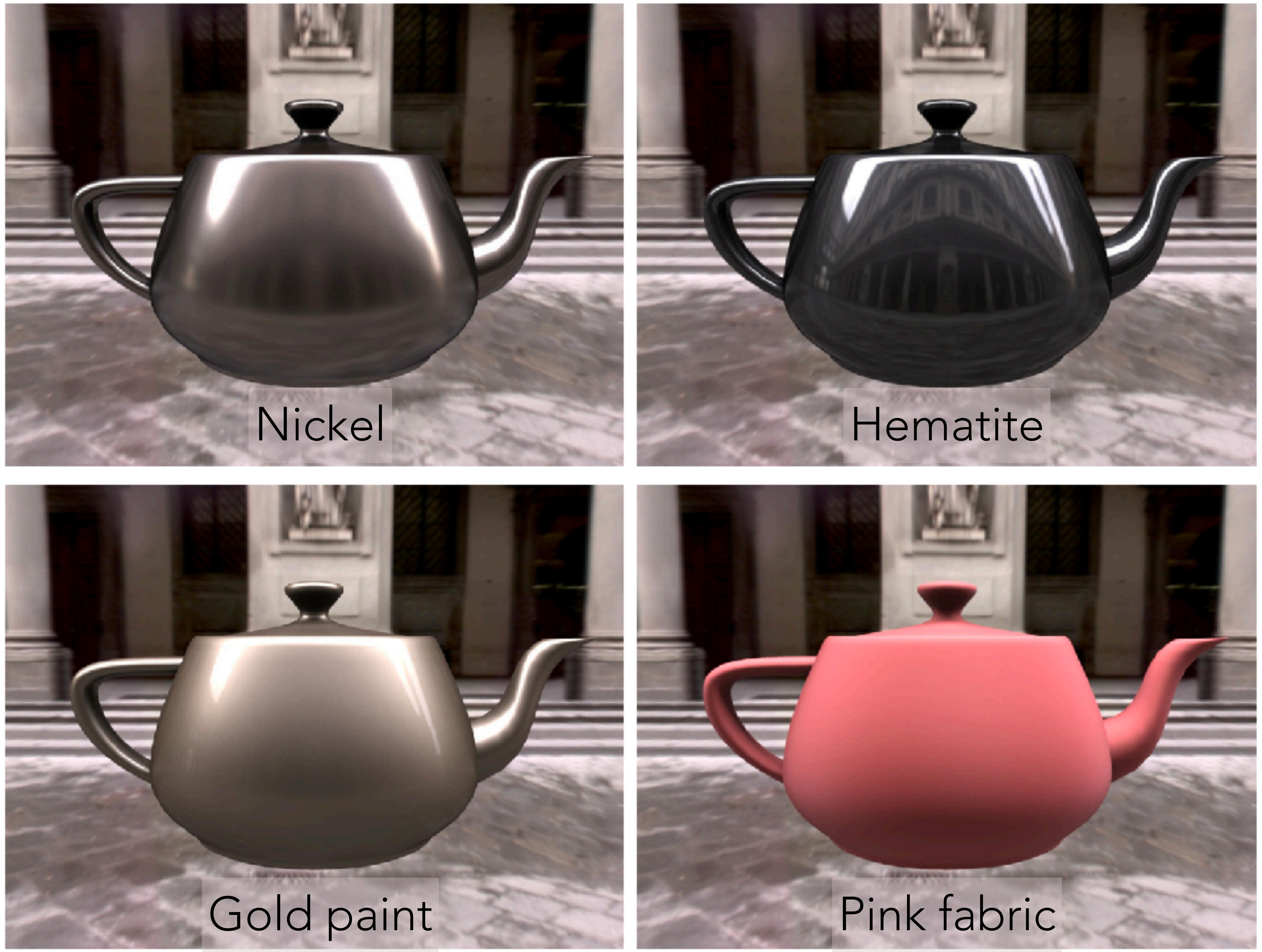


Computer Graphics: Principles and Practice

Matusik et al.'s acquisition setup for isotropic BRDFs

MERL BRDF database

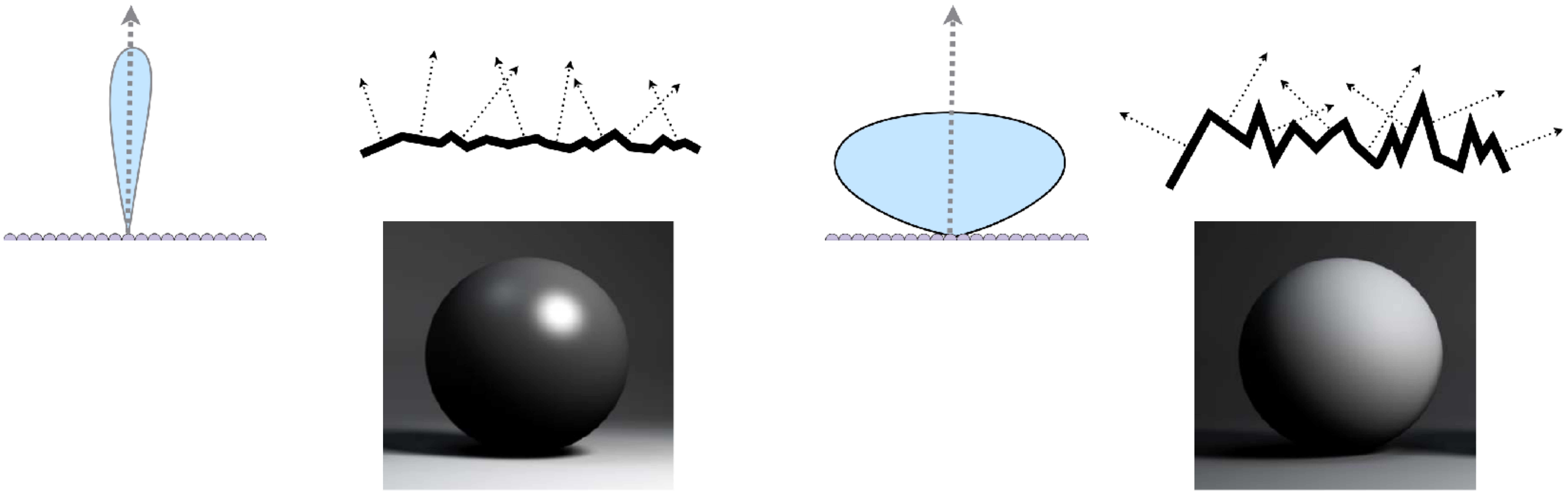


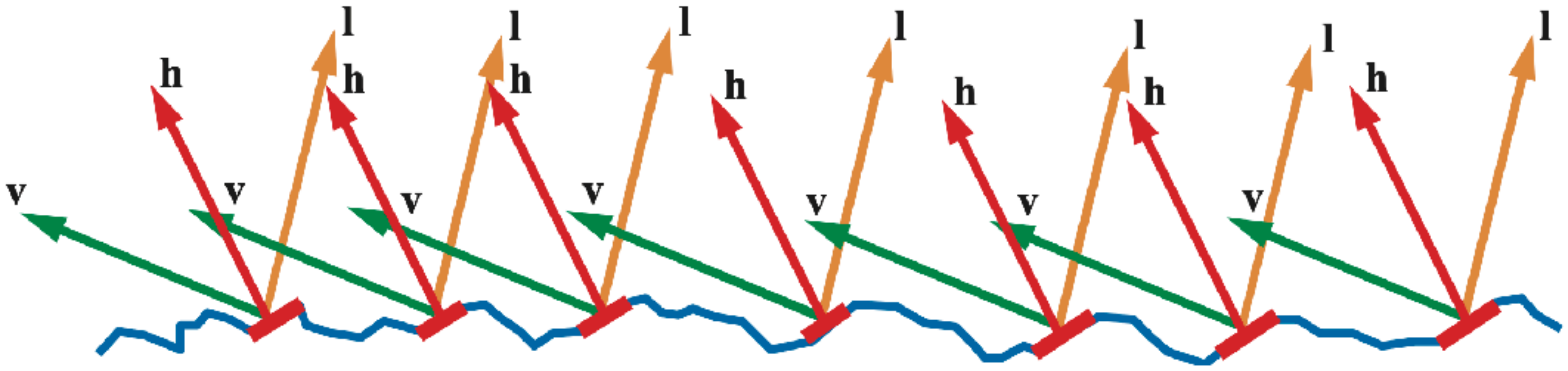


Microfacet models

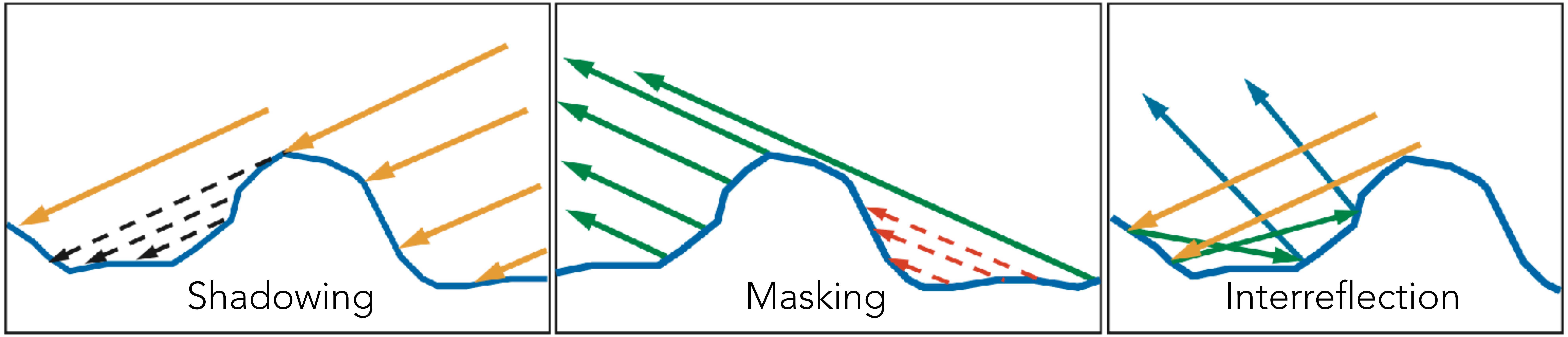
Assume rough surface is actually perfectly specular but bumpy at microscale

Made of small flat patches ("microfacets") with **normal distribution function** $D(\mathbf{h})$





$f_r(\boldsymbol{\ell} \to \mathbf{v}) = D(\mathbf{h})$? Not quite…



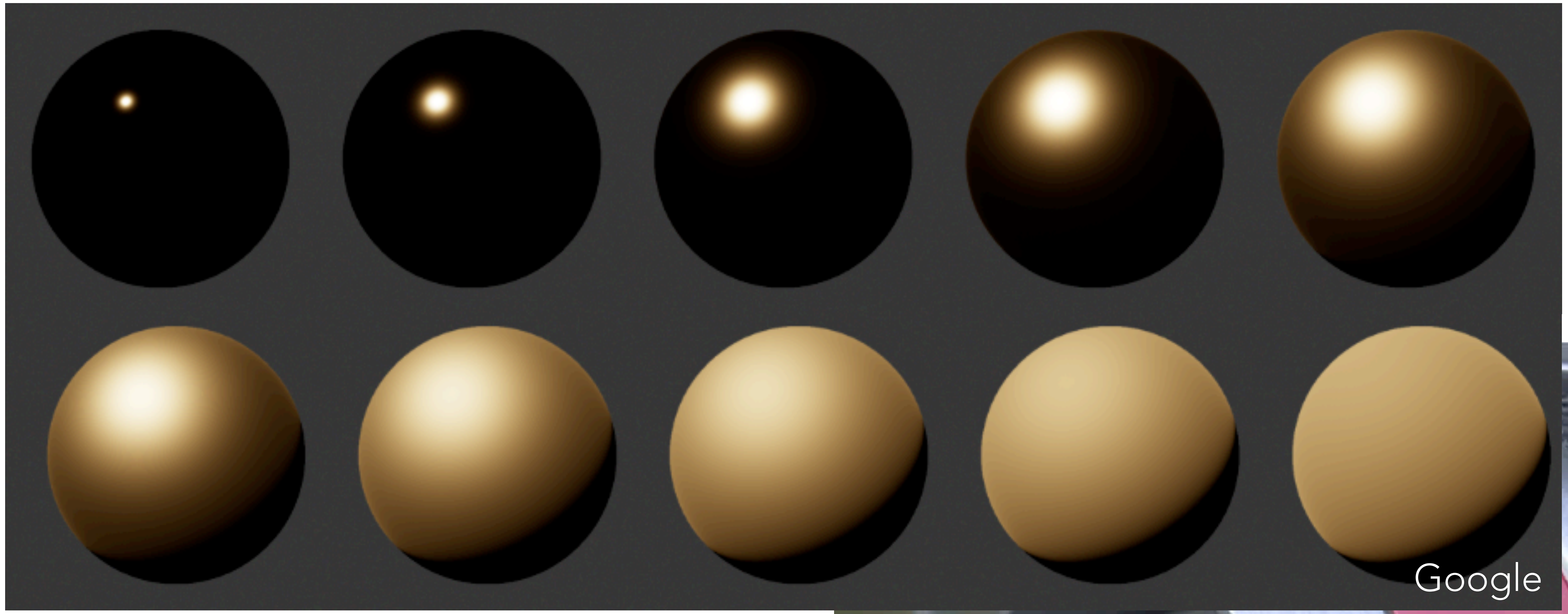
$$f_r(\boldsymbol{\ell} \to \mathbf{v}) = \frac{F(\mathbf{l}, \mathbf{v})G(\mathbf{l}, \mathbf{v}, \mathbf{h})D(\mathbf{h})}{4(\mathbf{n} \cdot \mathbf{l})(\mathbf{n} \cdot \mathbf{v})}$$

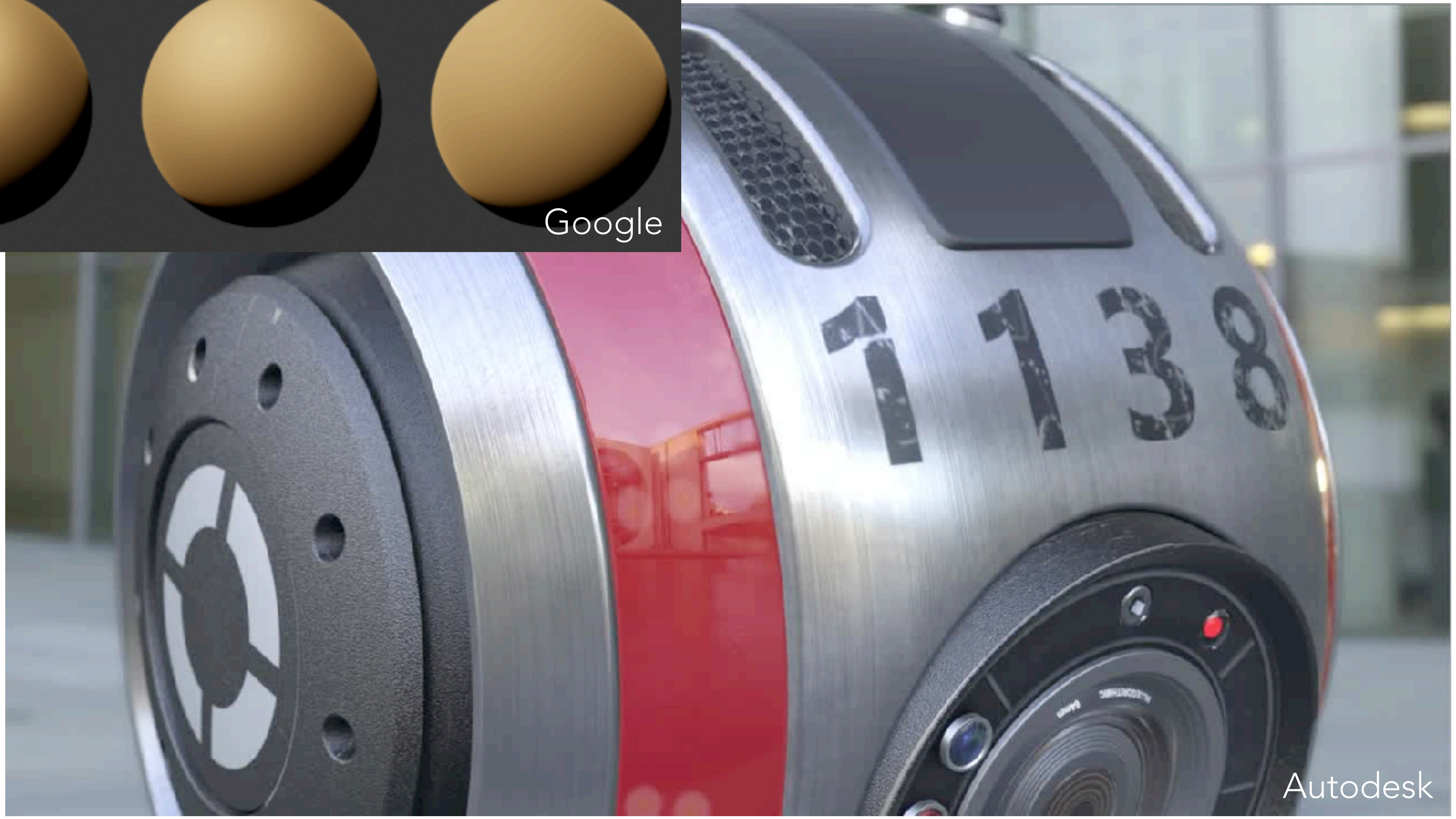
$$f_r(\boldsymbol{\ell} \to \mathbf{v}) = \frac{F(\mathbf{l}, \mathbf{v})G(\mathbf{l}, \mathbf{v}, \mathbf{h})D(\mathbf{h})}{4(\mathbf{n} \cdot \mathbf{l})(\mathbf{n} \cdot \mathbf{v})}$$

- $F(\boldsymbol{\ell}, \mathbf{v}) \leq 1$: **Fresnel term**
  - To be discussed
- $G(\boldsymbol{\ell}, \mathbf{v}, \mathbf{h}) \leq 1$: **Geometry term**
  - Probability that microfacet with normal $\mathbf{h}$ is visible from both $\boldsymbol{\ell}$ and $\mathbf{v}$
  - Accounts for shadowing and masking (interreflections ignored)
- $D(\mathbf{h})$: Normal distribution function

All these terms have
various analytical models…

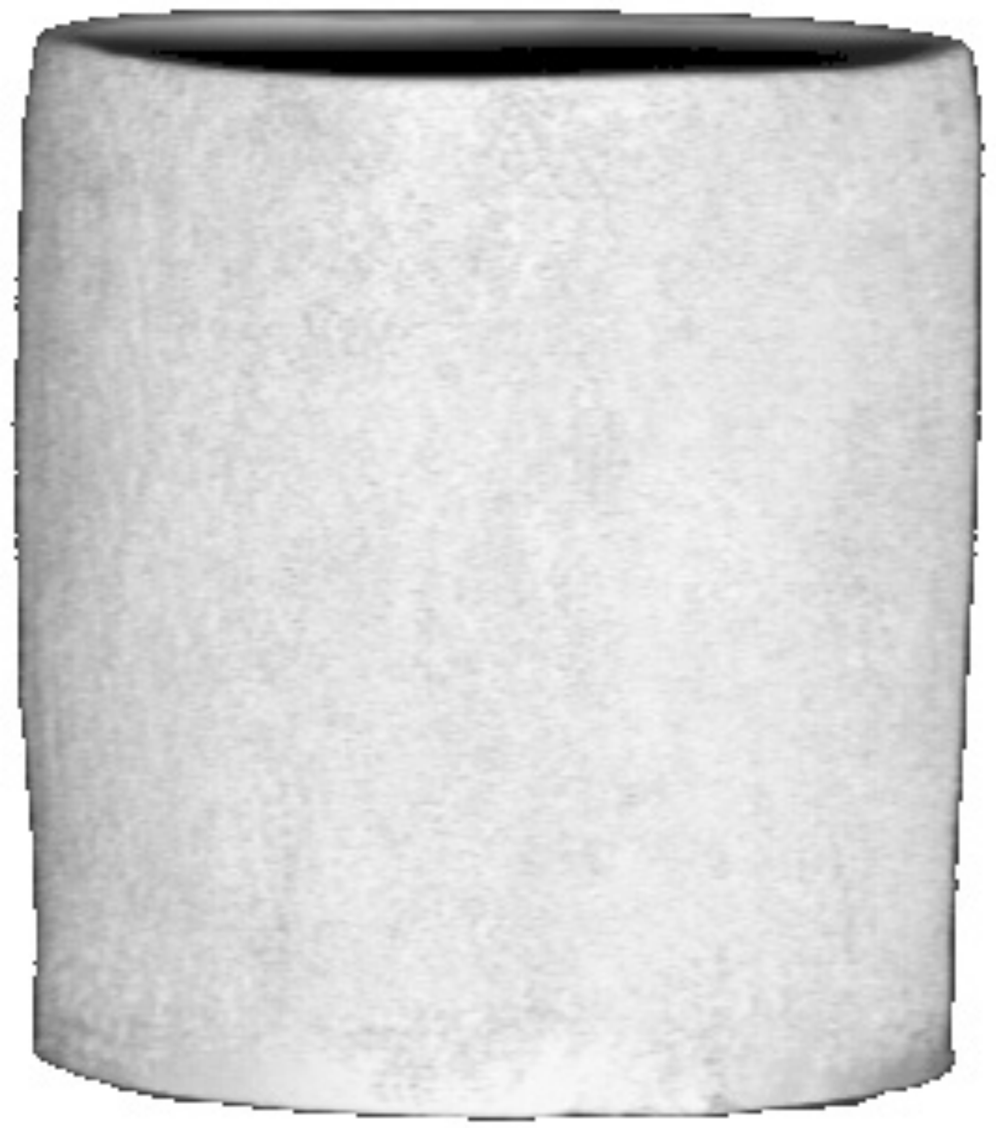
Wojciech Matusik


Google

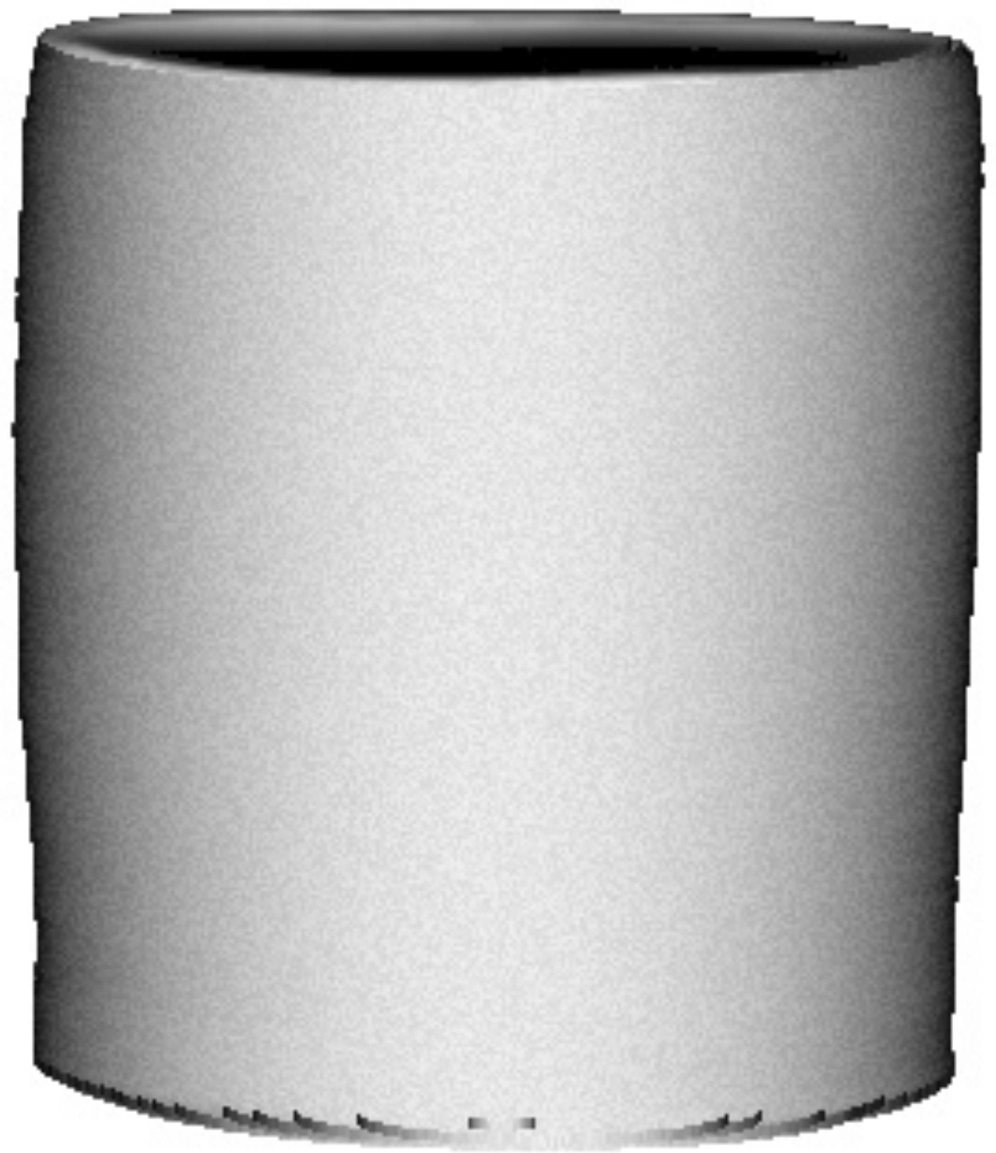

1138
Autodesk

What if the microfacets are diffuse instead of specular?

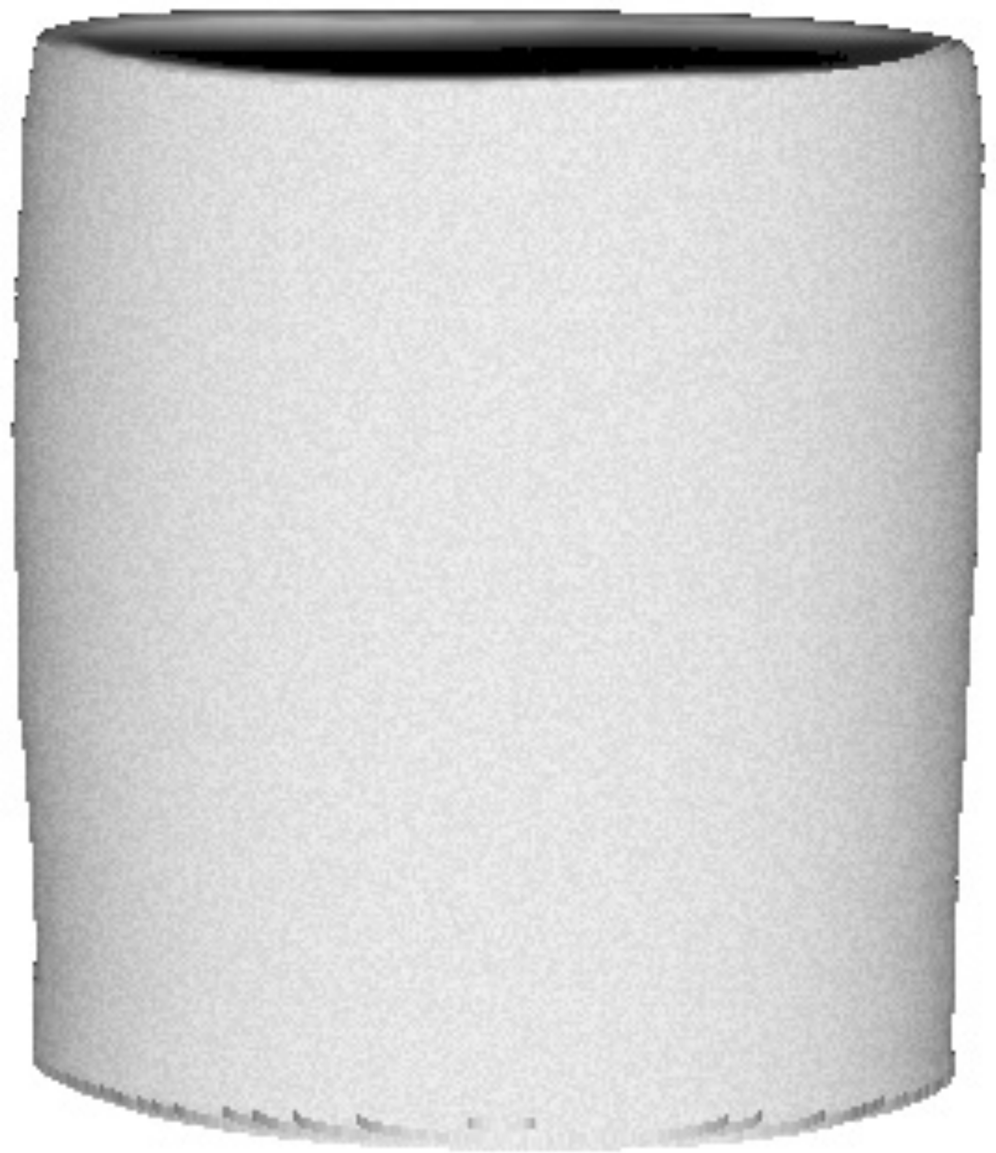
Oren-Nayar model for rough diffuse surfaces



Photograph

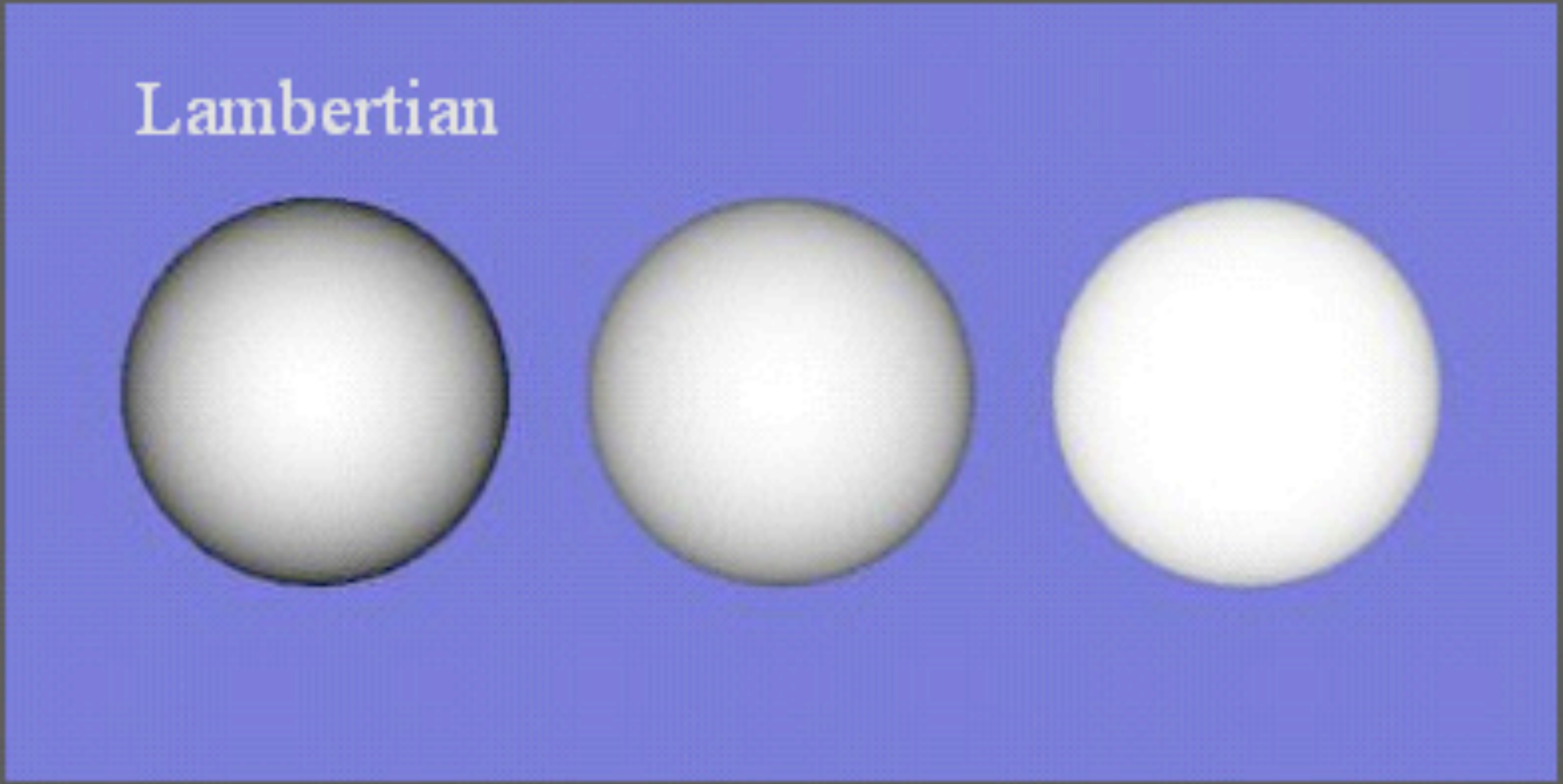


Lambertian



Oren-Nayar

Roughness →

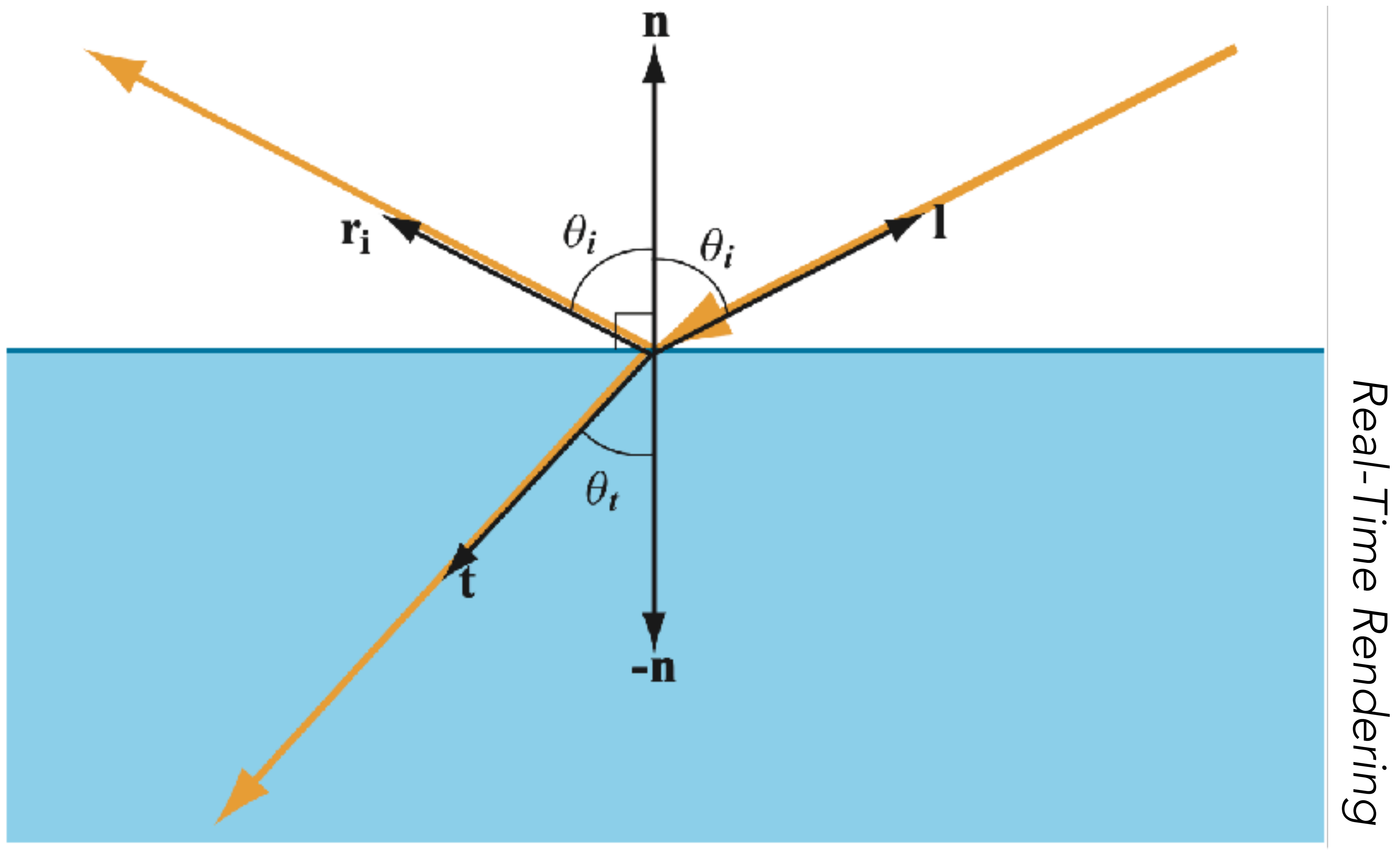


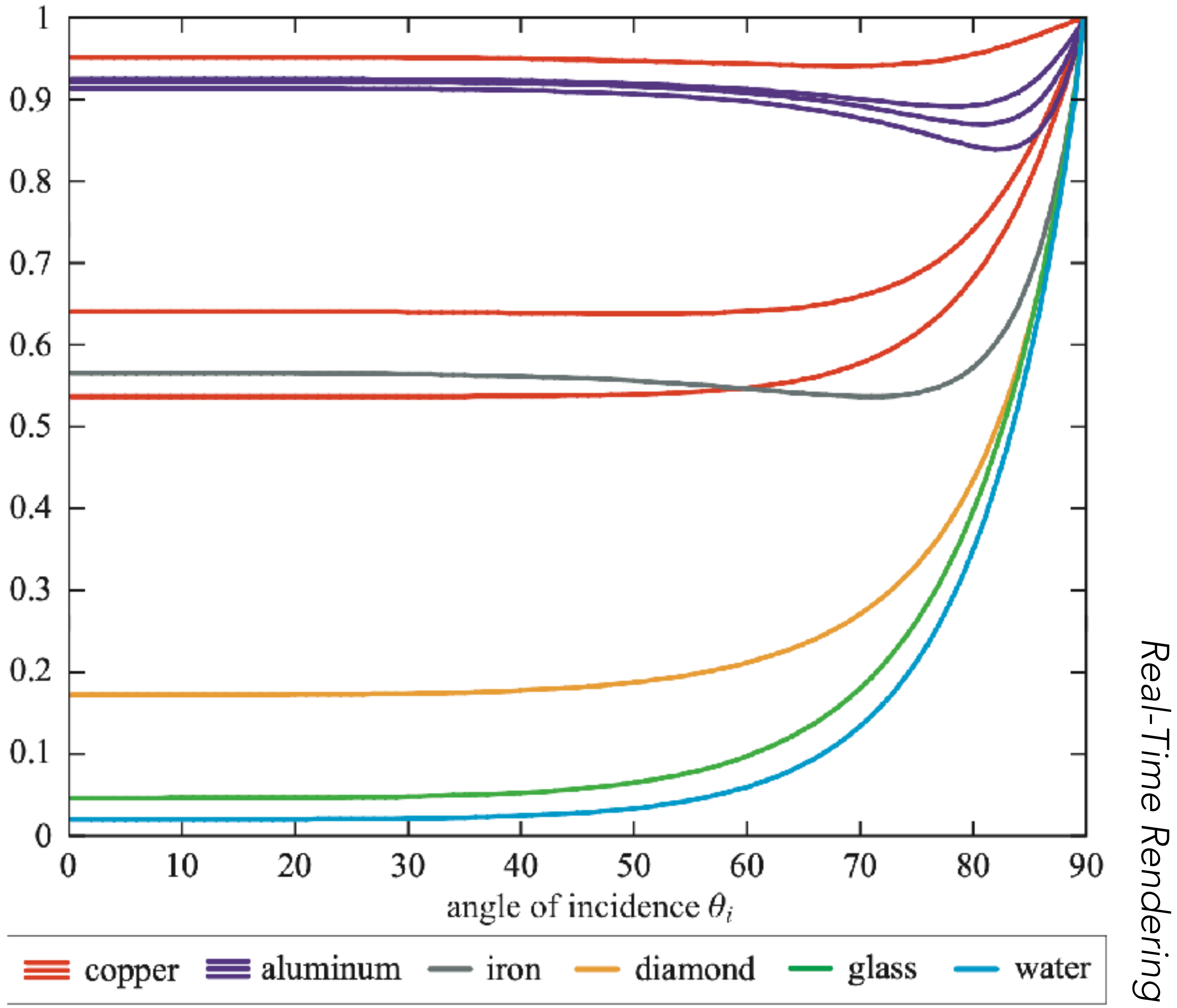
Rendered Spheres

Image of Full Moon

Oren and Nayar

Fresnel reflectance



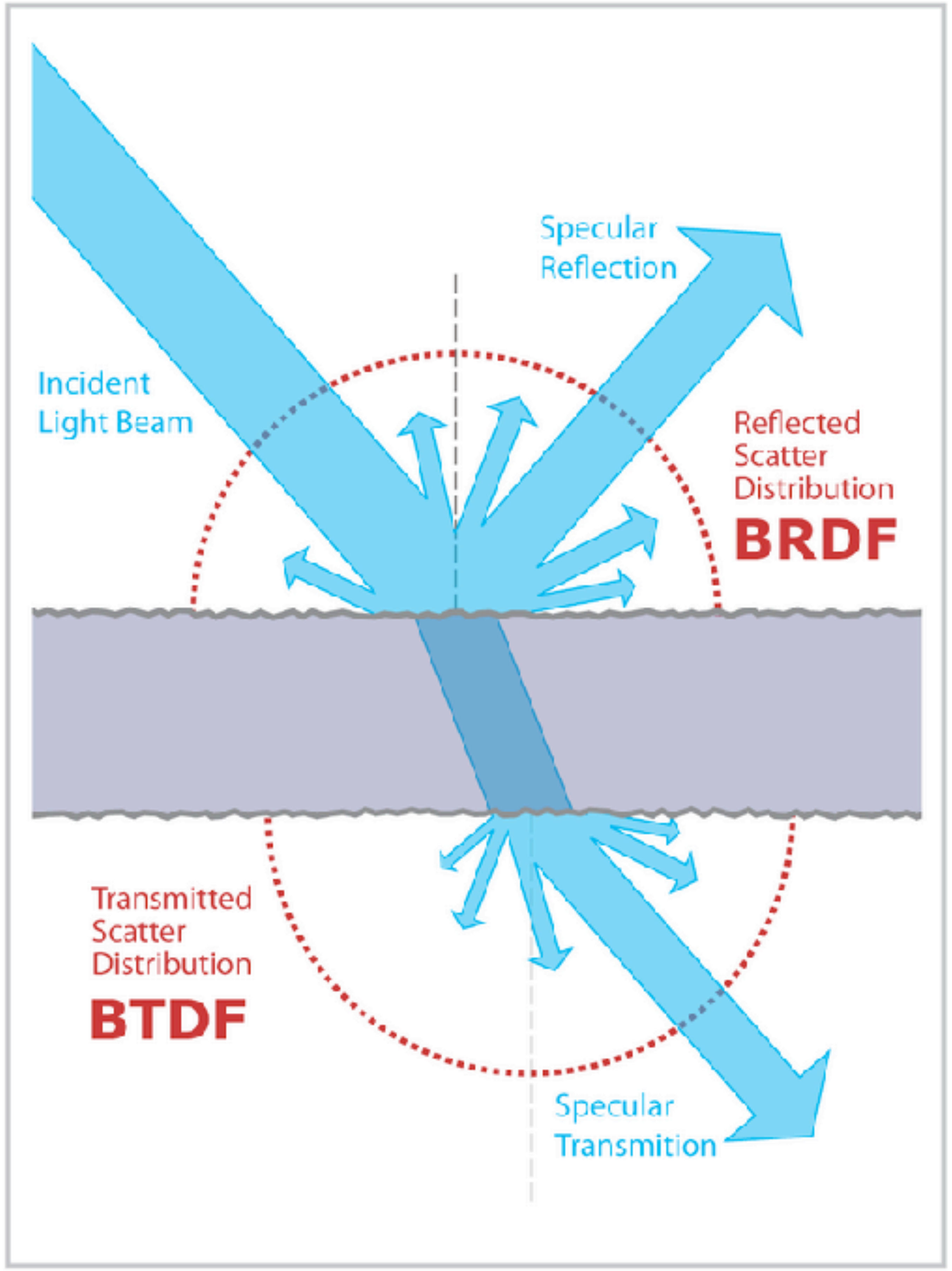


Schlick’s approximation:

$$F(\boldsymbol{\ell}, \mathbf{n}) = F_0 + (1 - F_0)(1 - (\boldsymbol{\ell} \cdot \mathbf{n}))^5$$

Lafortune et al. 1997


Without Fresnel
With Fresnel
Keenan Crane


Specular
Reflection
Incident
Light Beam
Reflected
Scatter
Distribution
BRDF
Transmitted
Scatter
Distribution
BTDF
Specular
Transmition

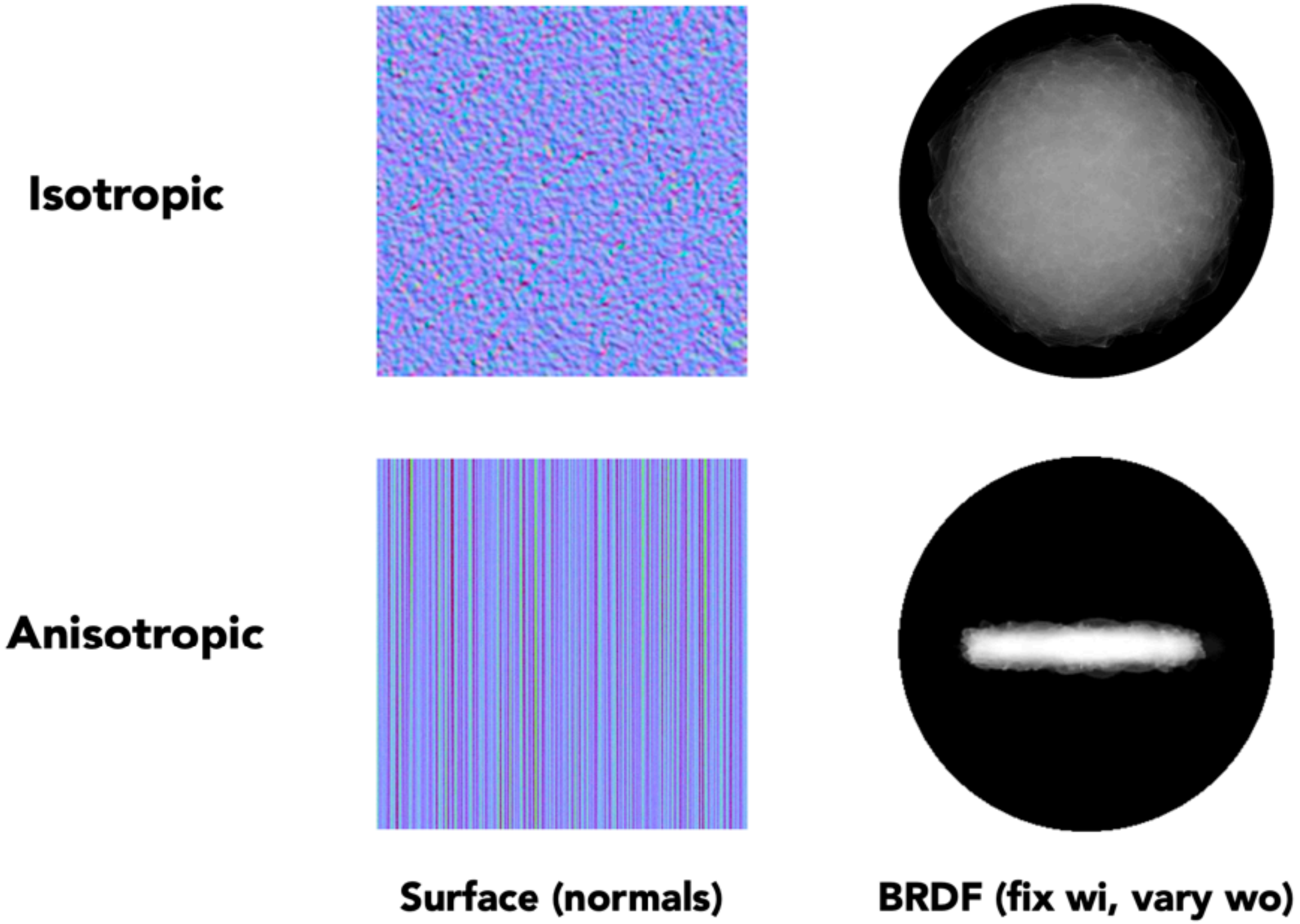

Walter et al. 2007

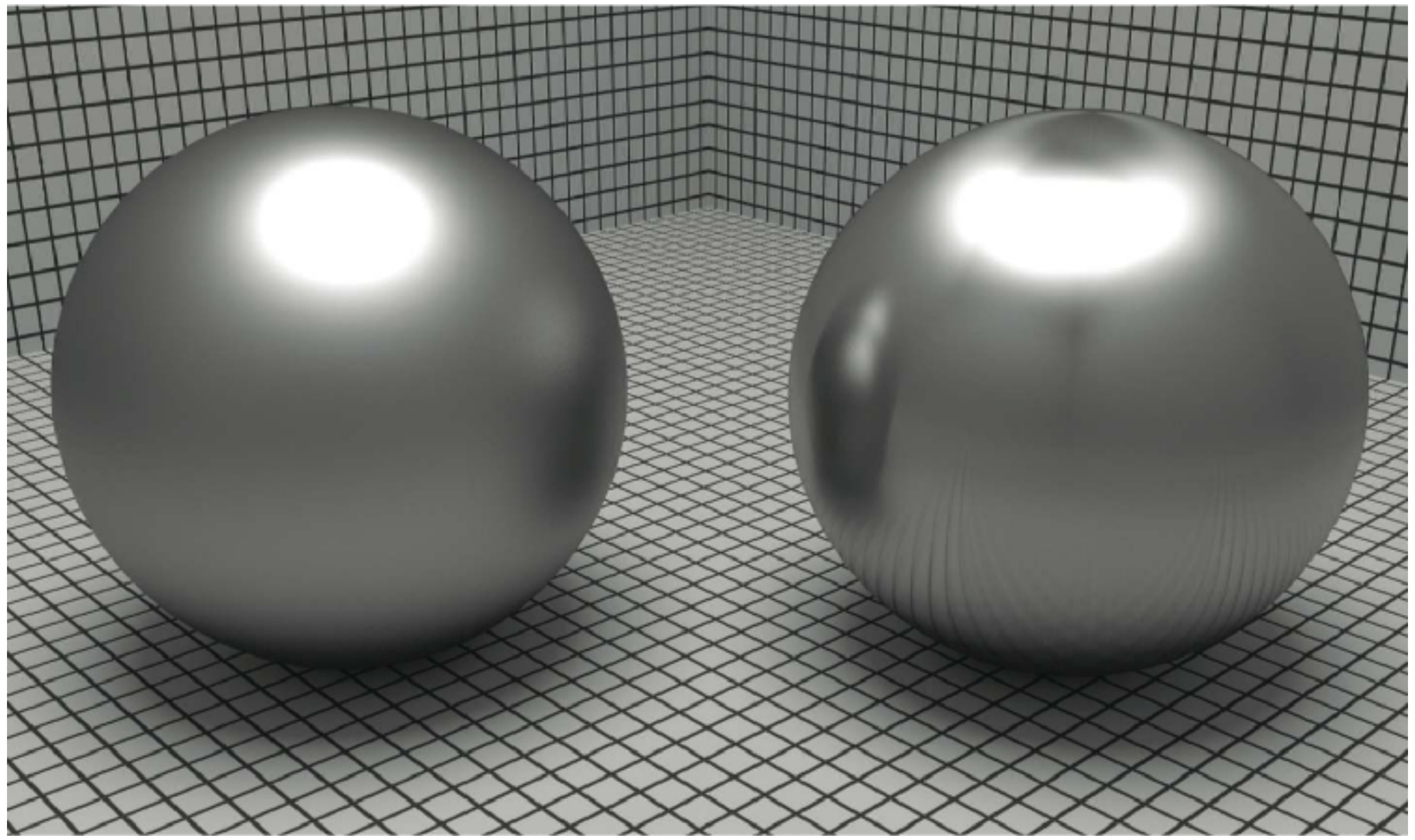

Walter et al. 2007

Quick survey of more complicated materials

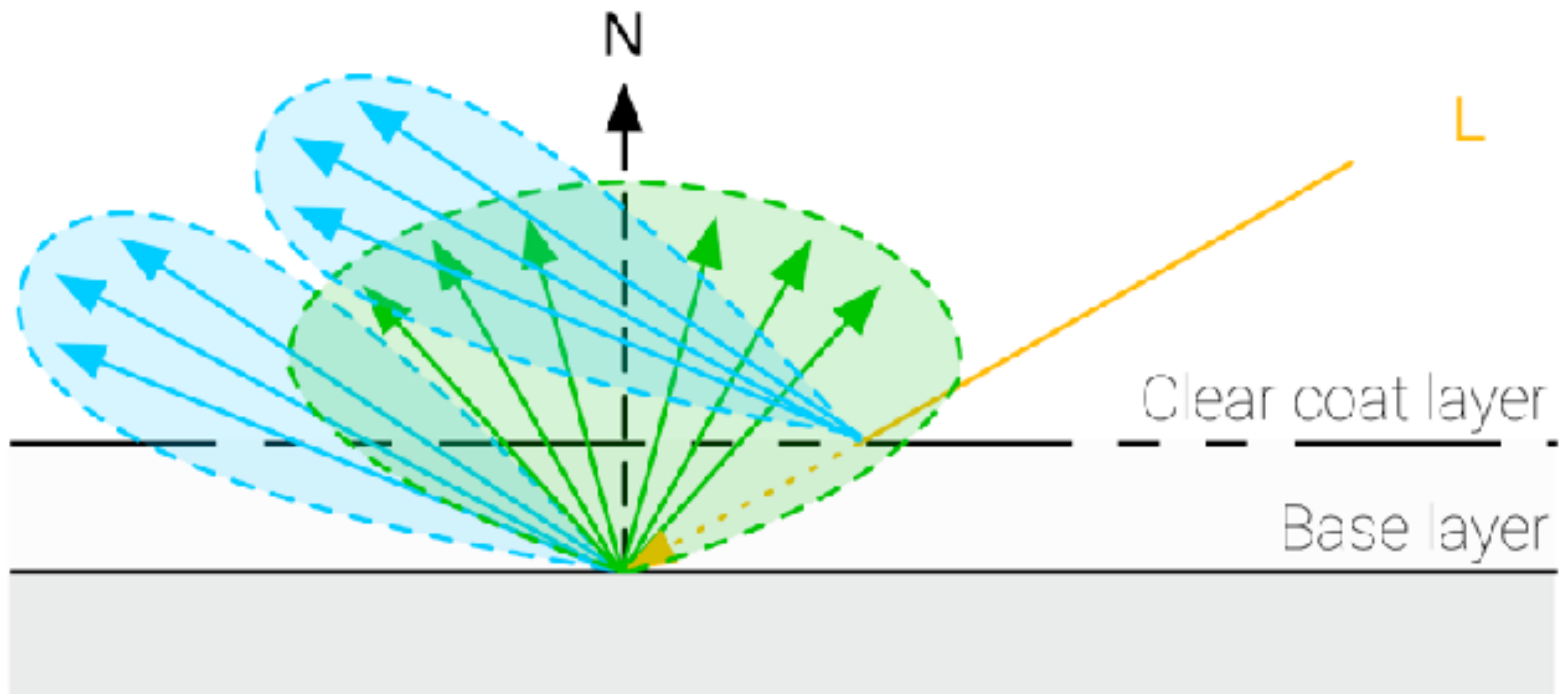
Anisotropic roughness

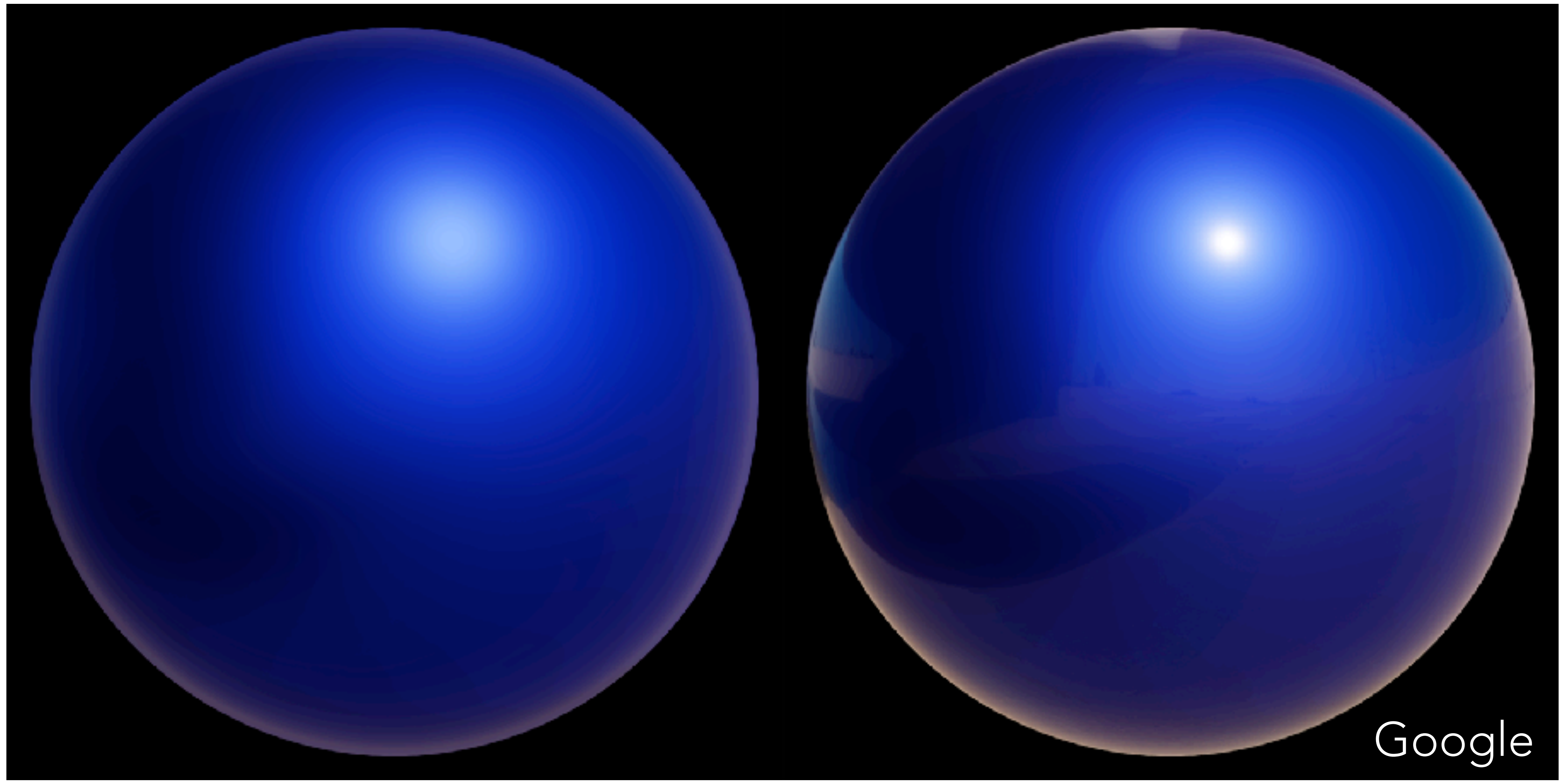
NDF is anisotropic due to oriented microstructure

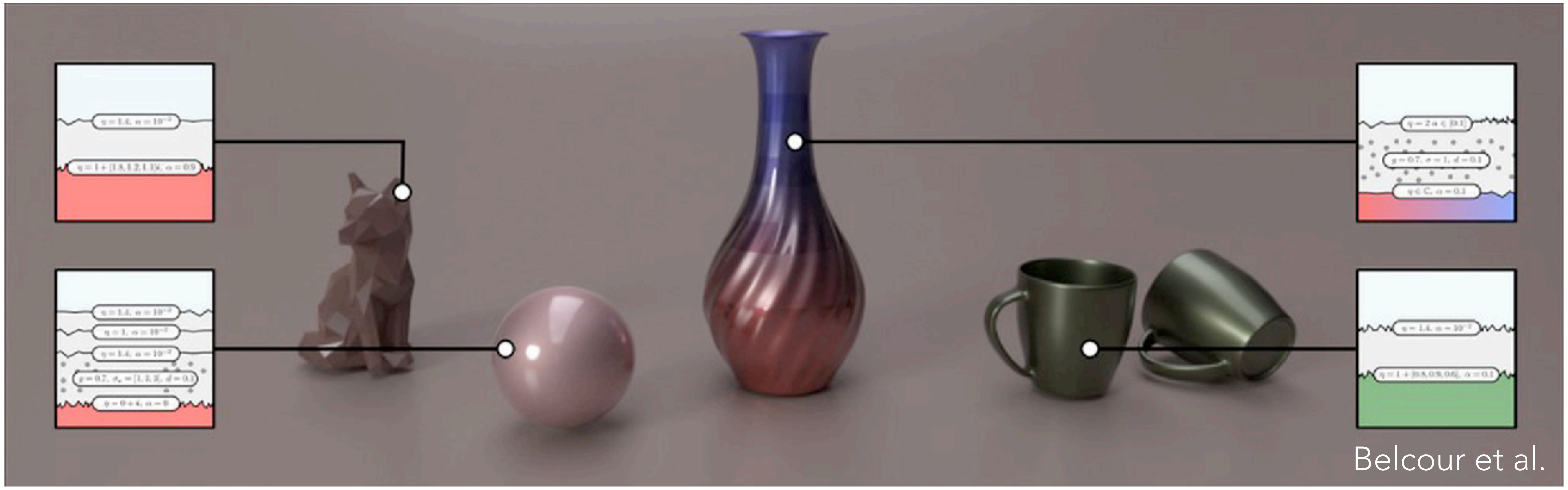




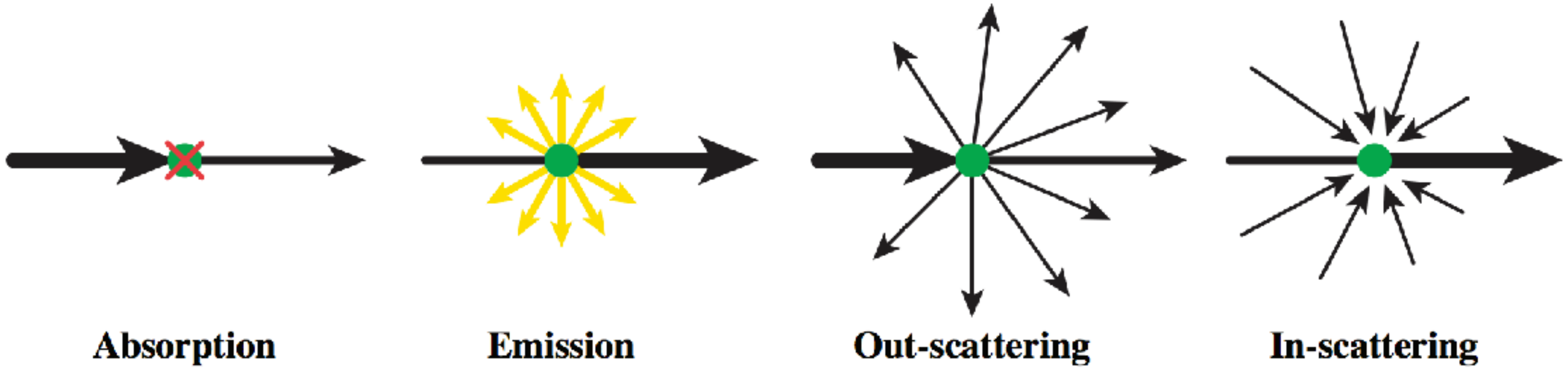
Layered materials







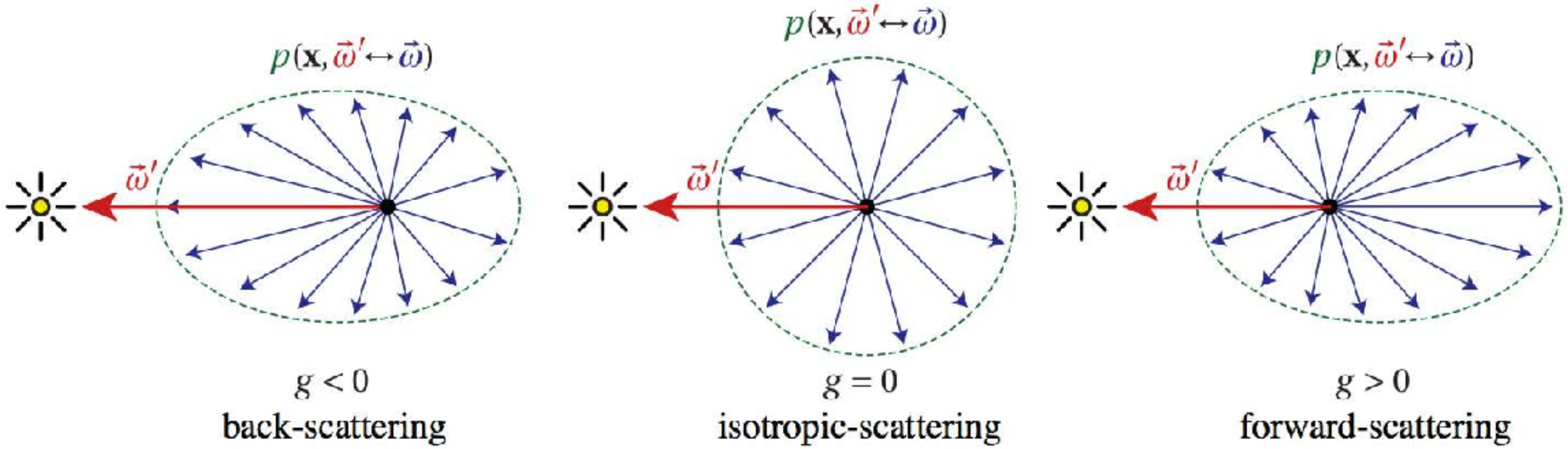
Participating media



Wojciech Jarosz

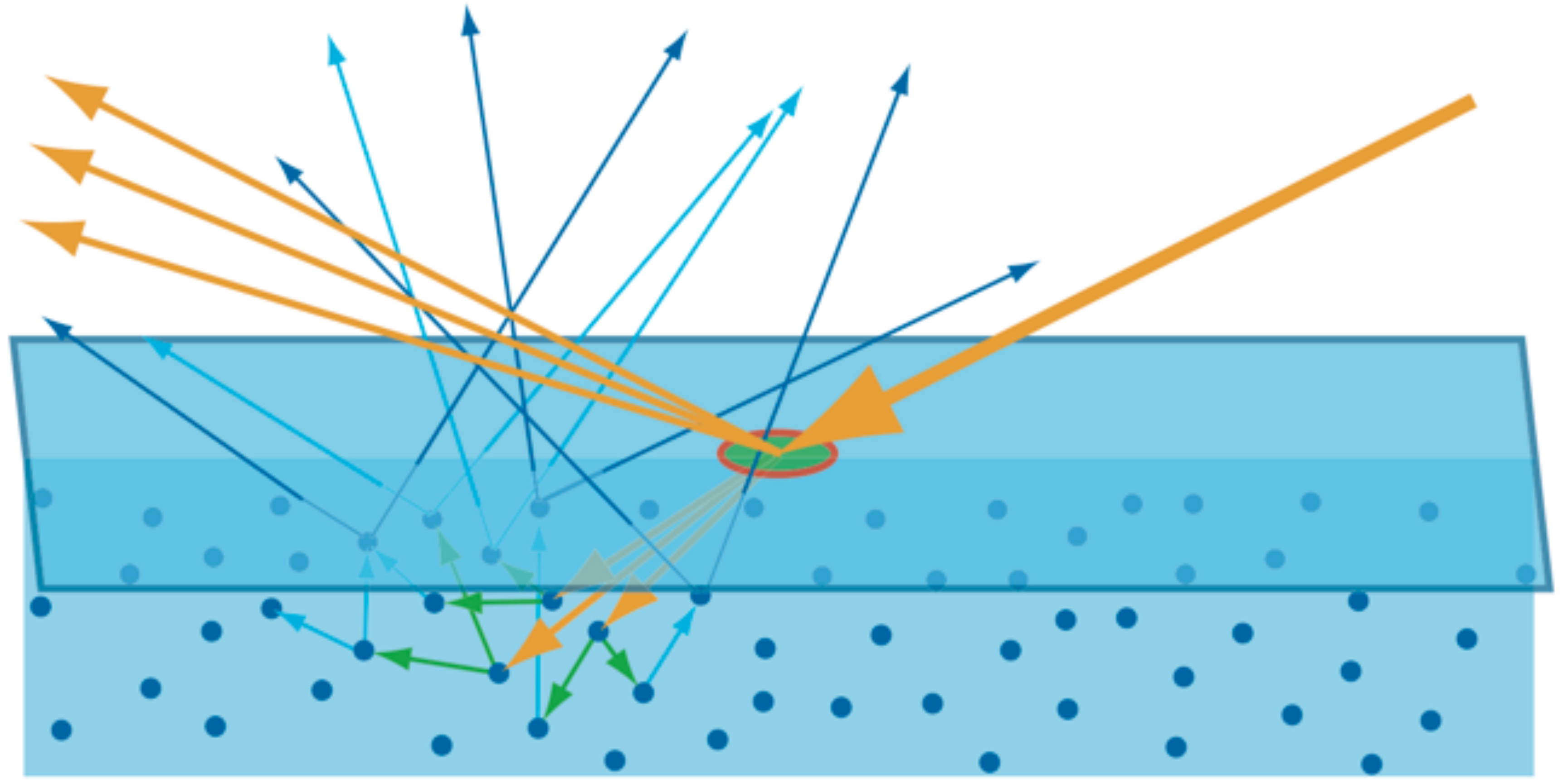
Bitterli et al. 2018

Phase function describes distribution of scattered ray directions



Wojciech Jarosz

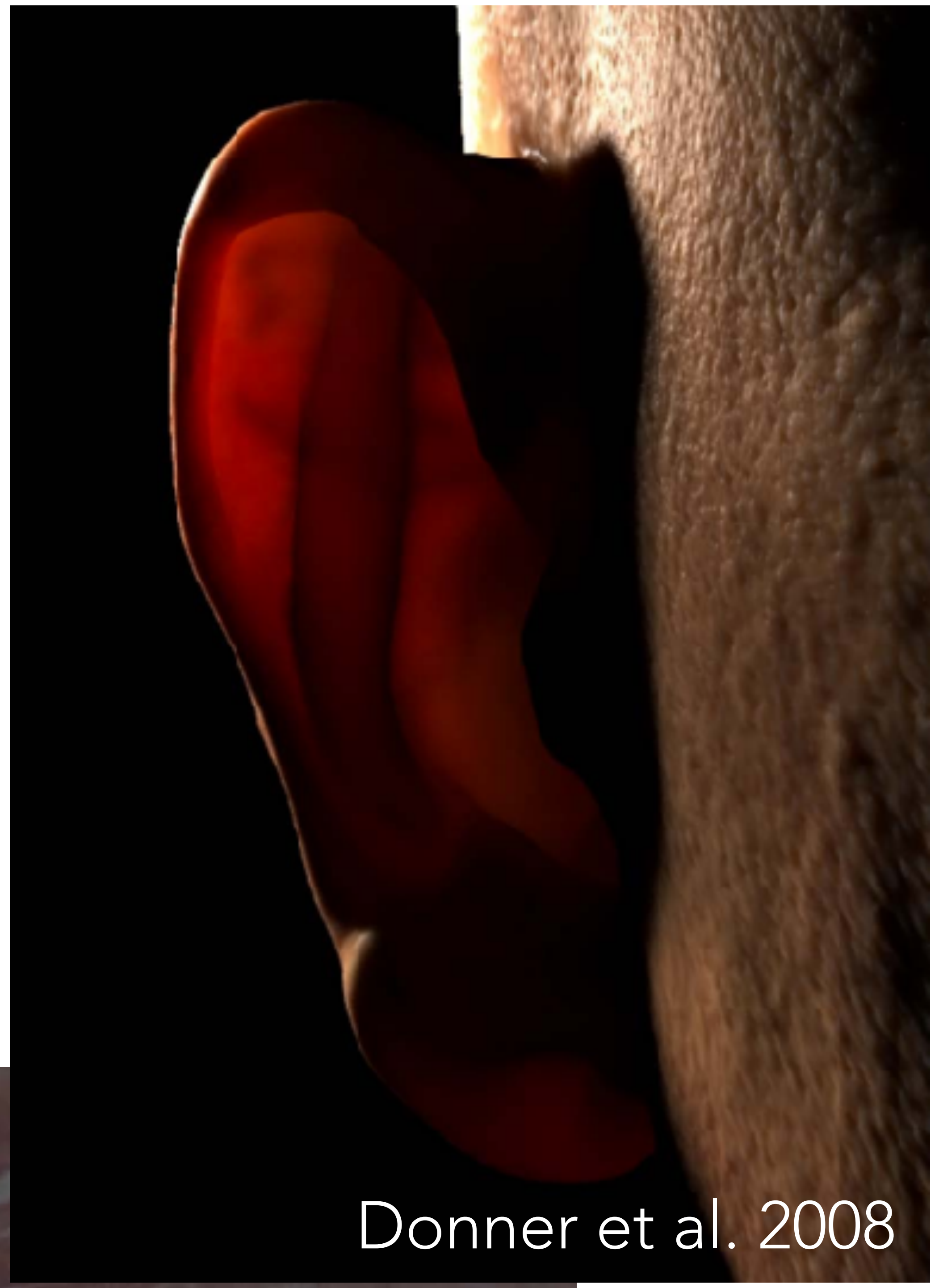
Translucent materials



Real-Time Rendering

Subsurface scattering:
Light bounces around for a non-negligible distance in the material before emerging

Cannot be described by BRDF!

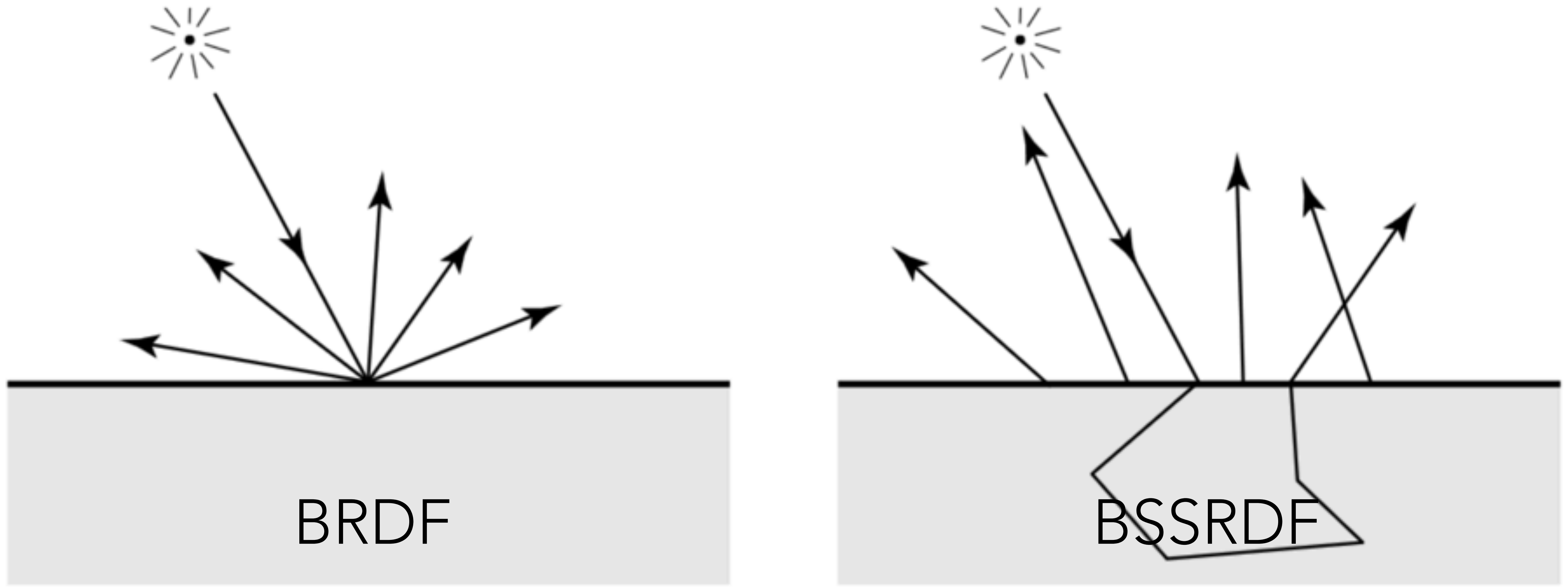


Donner et al. 2008

Jensen et al. 2001

BRDF: R($\boldsymbol{\omega}_i$, $\boldsymbol{\omega}_o$)

BSSRDF (bidirectional surface scattering RDF): $S(\mathbf{x}_i, \boldsymbol{\omega}_i, \mathbf{x}_o, \boldsymbol{\omega}_o)$



Now exitant radiance is

$$L_o(\mathbf{x}_o, \boldsymbol{\omega}_o) = \int_A \int_{H^2} S(\mathbf{x}_i, \boldsymbol{\omega}_i, \mathbf{x}_o, \boldsymbol{\omega}_o)\, L_i\,(\mathbf{x}_i, \boldsymbol{\omega}_i) \cos(\theta_i)\, \mathrm{d}\boldsymbol{\omega}_i\, \mathrm{d}A$$

Jensen et al. 2001