02 Shading and Frames

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Light reflection physics

Radiometry redux

Power

Intensity power per unit solid angle

Irradiance power per unit area

Radiance power per unit (solid angle × area)

Sources of light

Point sources

- intensity
- can be directionally varying—spotlights

Area sources

- radiance
- can be spatially varying

Directional sources

- irradiance (normal irradiance)

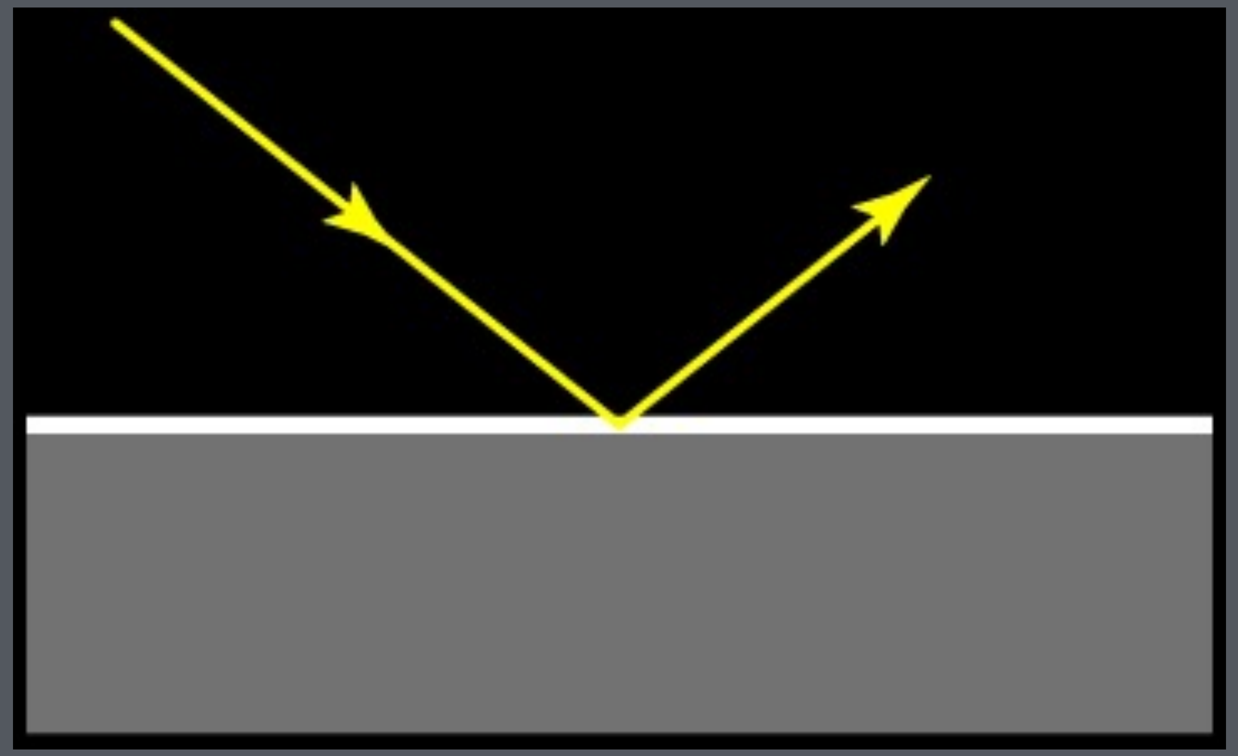
Environment lighting

- radiance (usually spatially varying)
- sun-sky models

Simple kinds of scattering

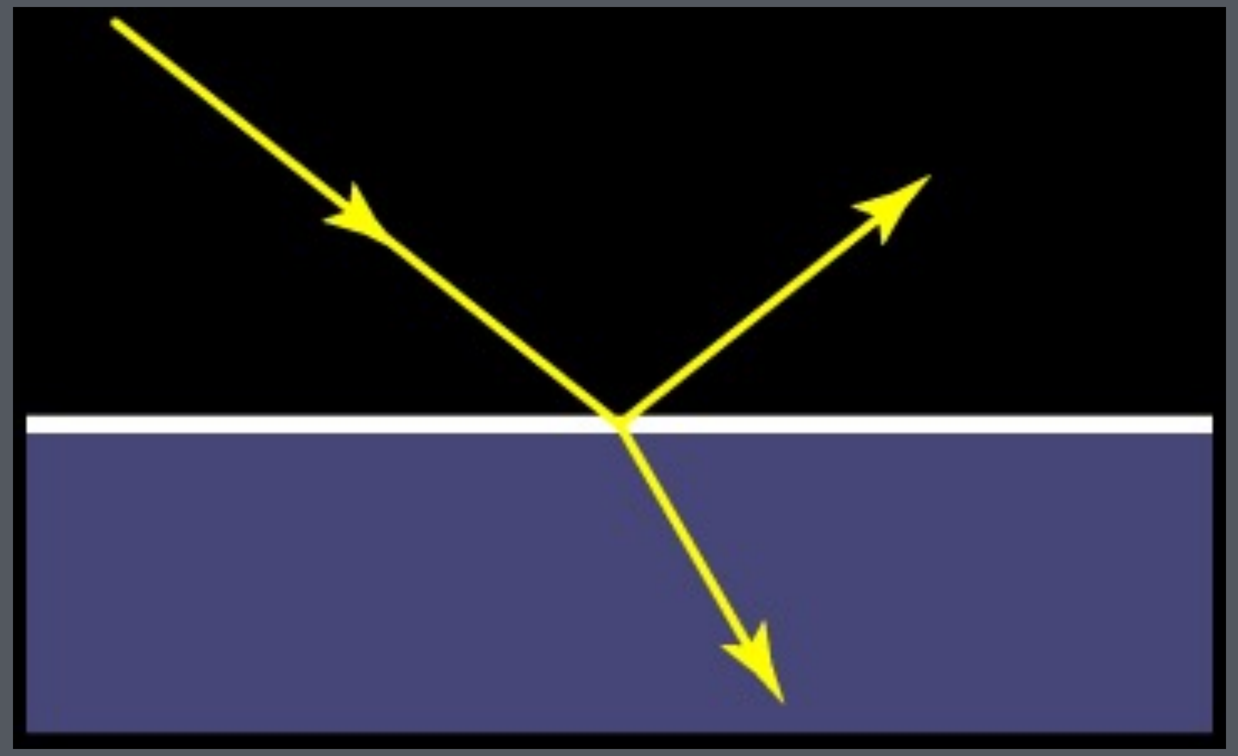
Ideal specular reflection

- incoming ray reflected to a single direction
- mirror-like behavior
- arises at smooth surfaces



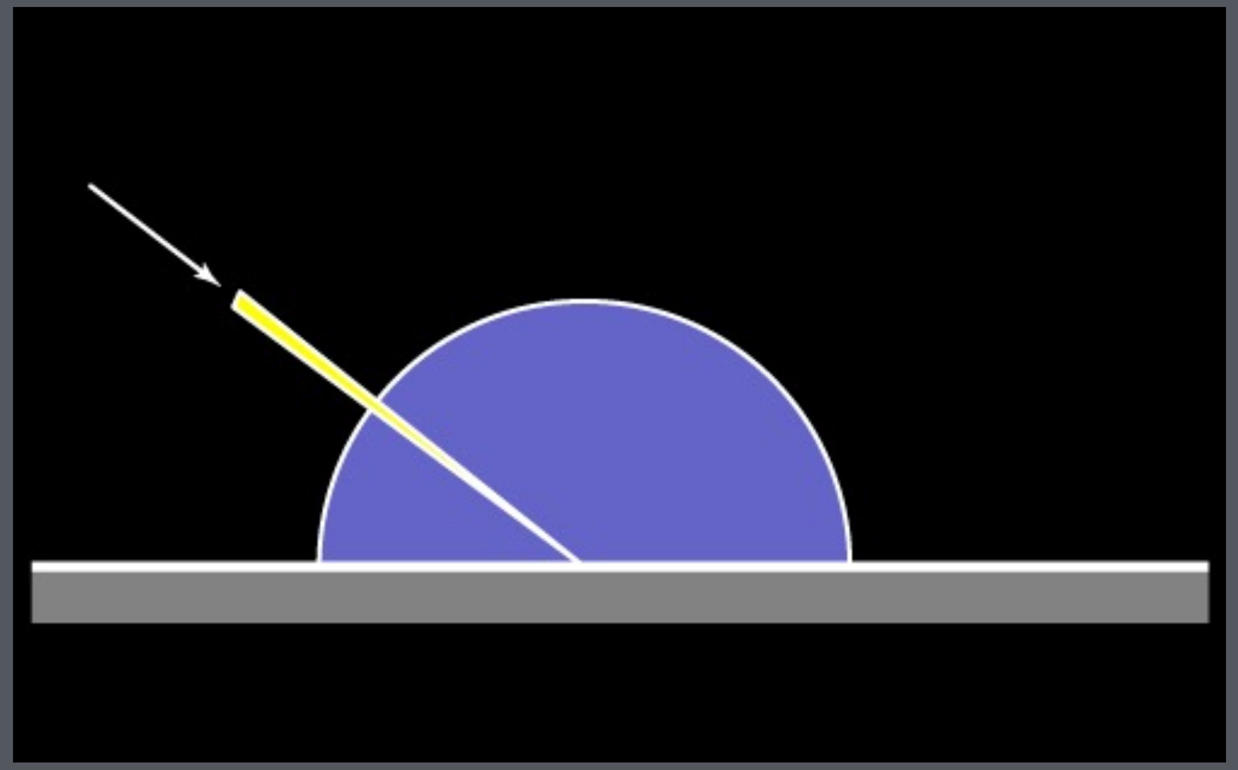
Ideal specular transmission

- incoming ray refracted to a single direction
- glass-like behavior
- arises at smooth dielectric (nonmetal) surfaces

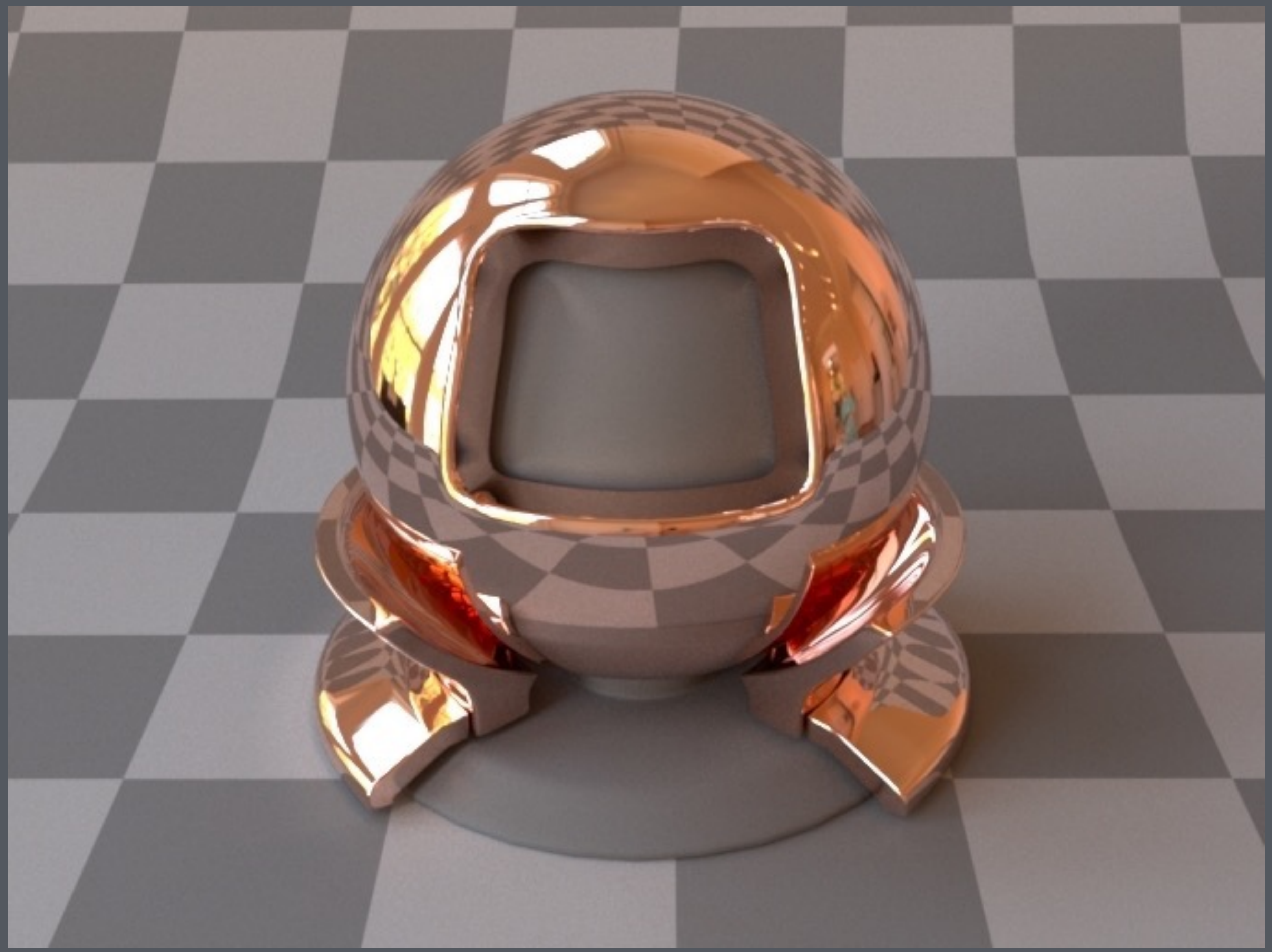


Ideal diffuse reflection or transmission

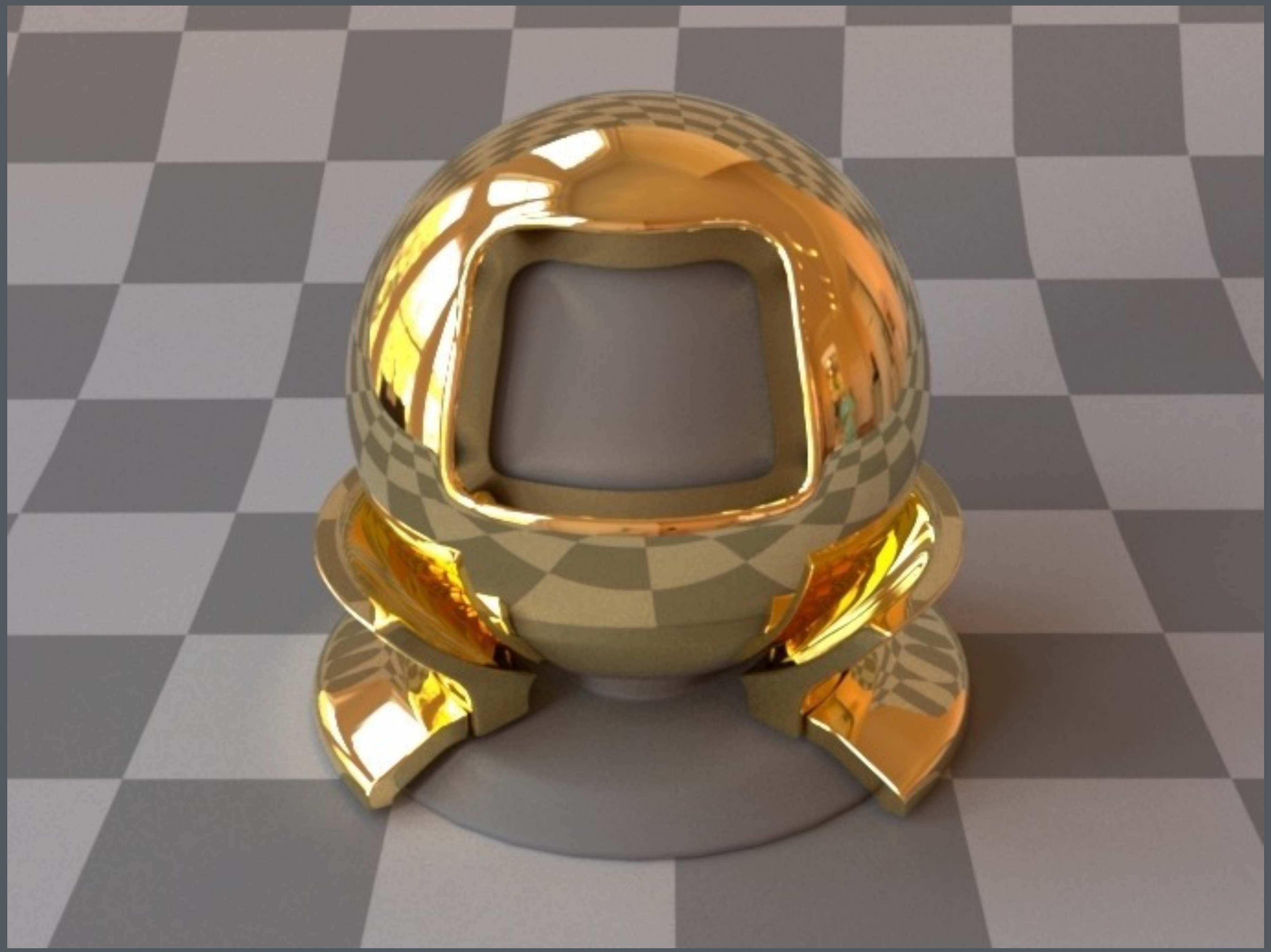
- outgoing radiance independent of direction
- arises from subsurface multiple scattering



Ideal specular reflection from metals



Cu



Au

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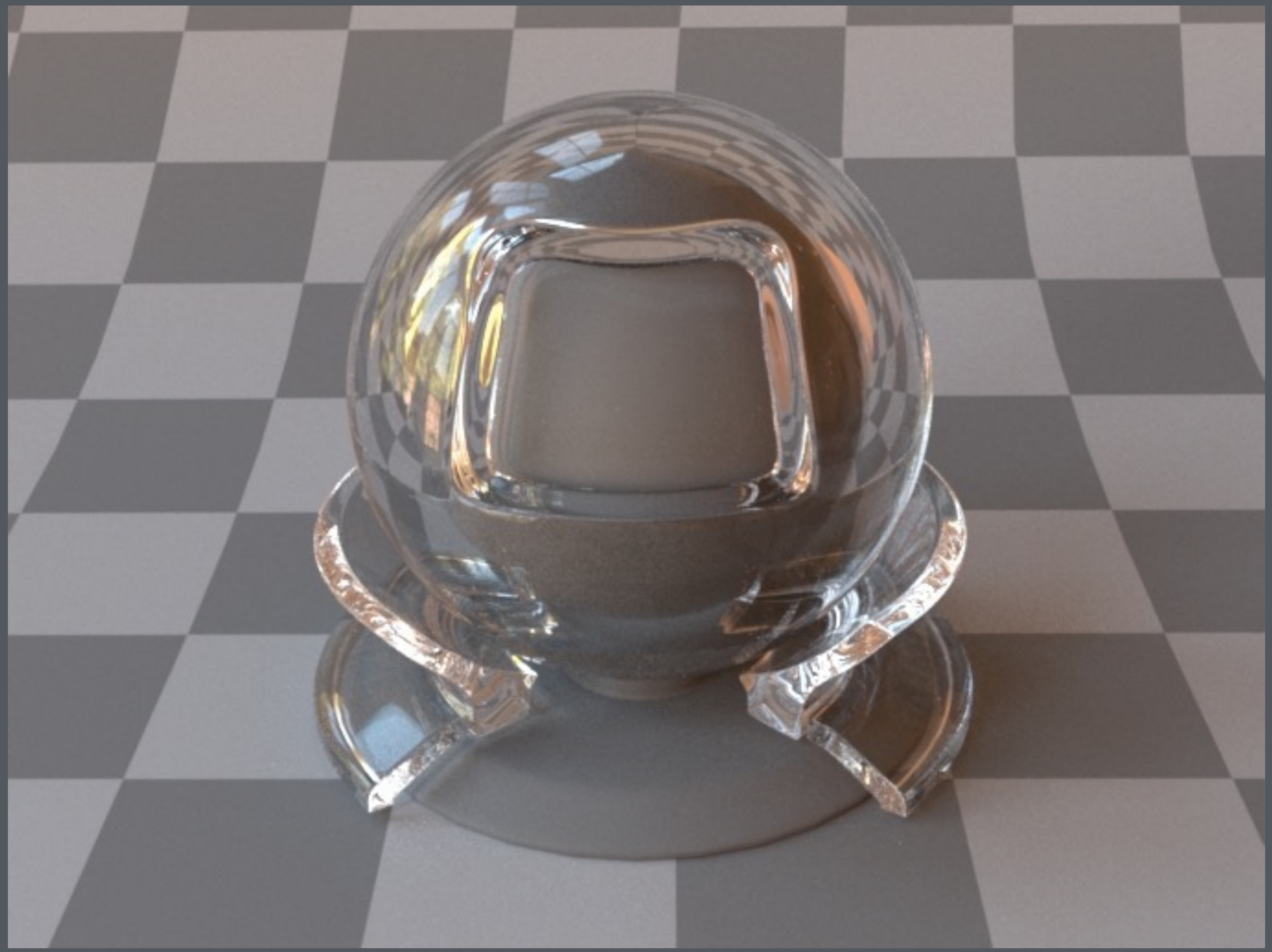
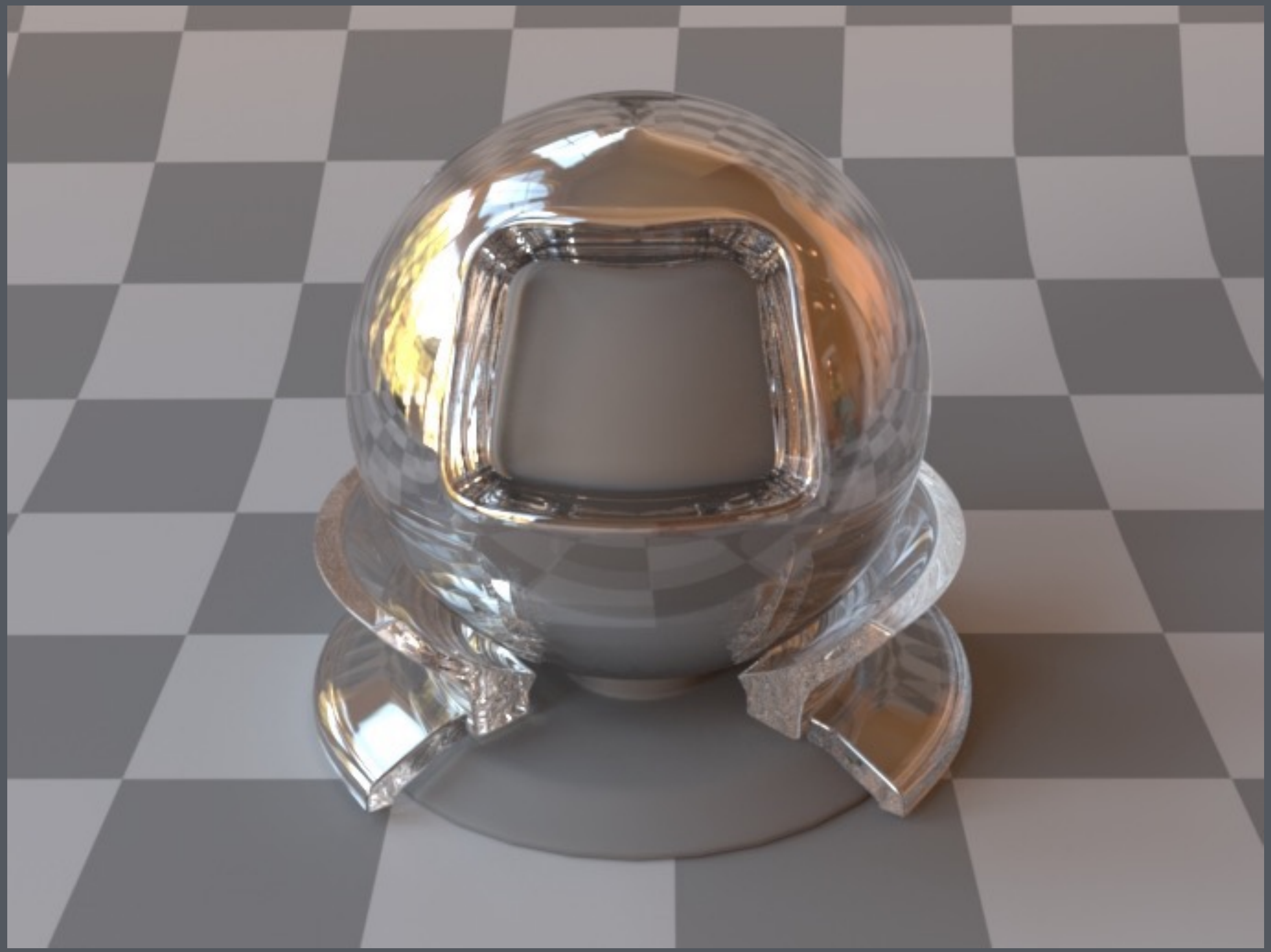
Ideal reflection and transmission from smooth dielectrics



Water (ior = 1.33)



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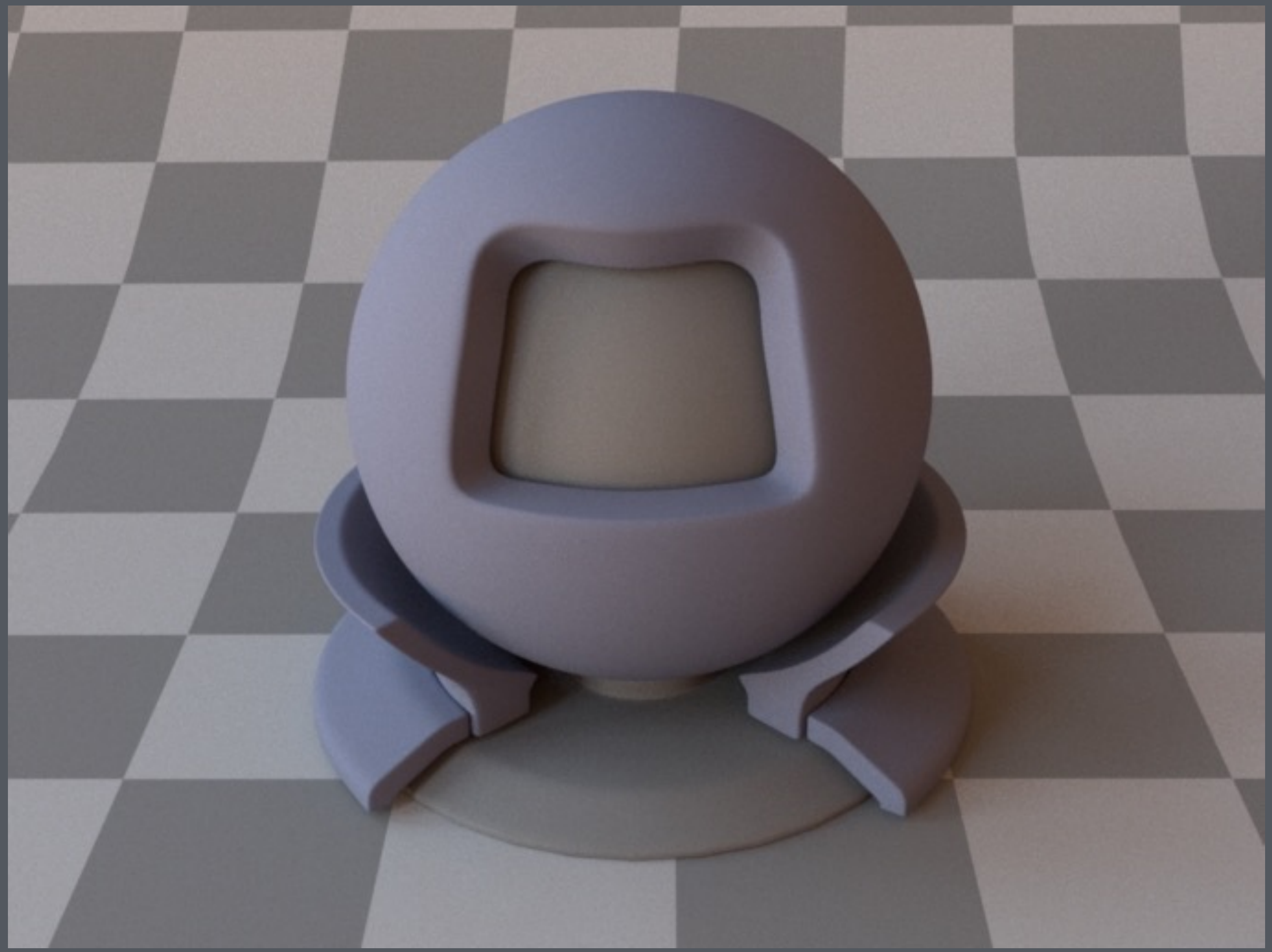
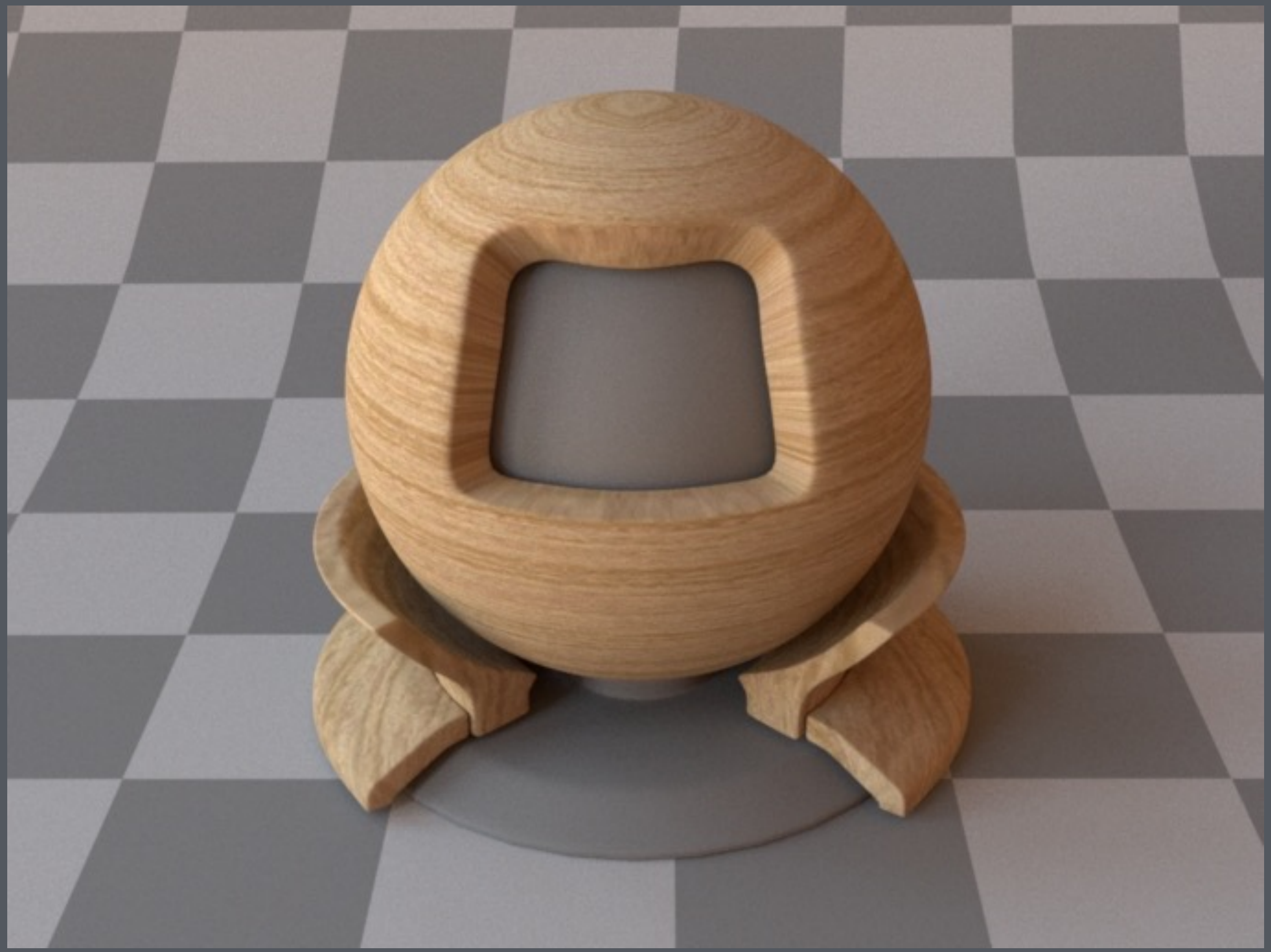
Diamond (ior = 2.4)

Two diffuse surfaces





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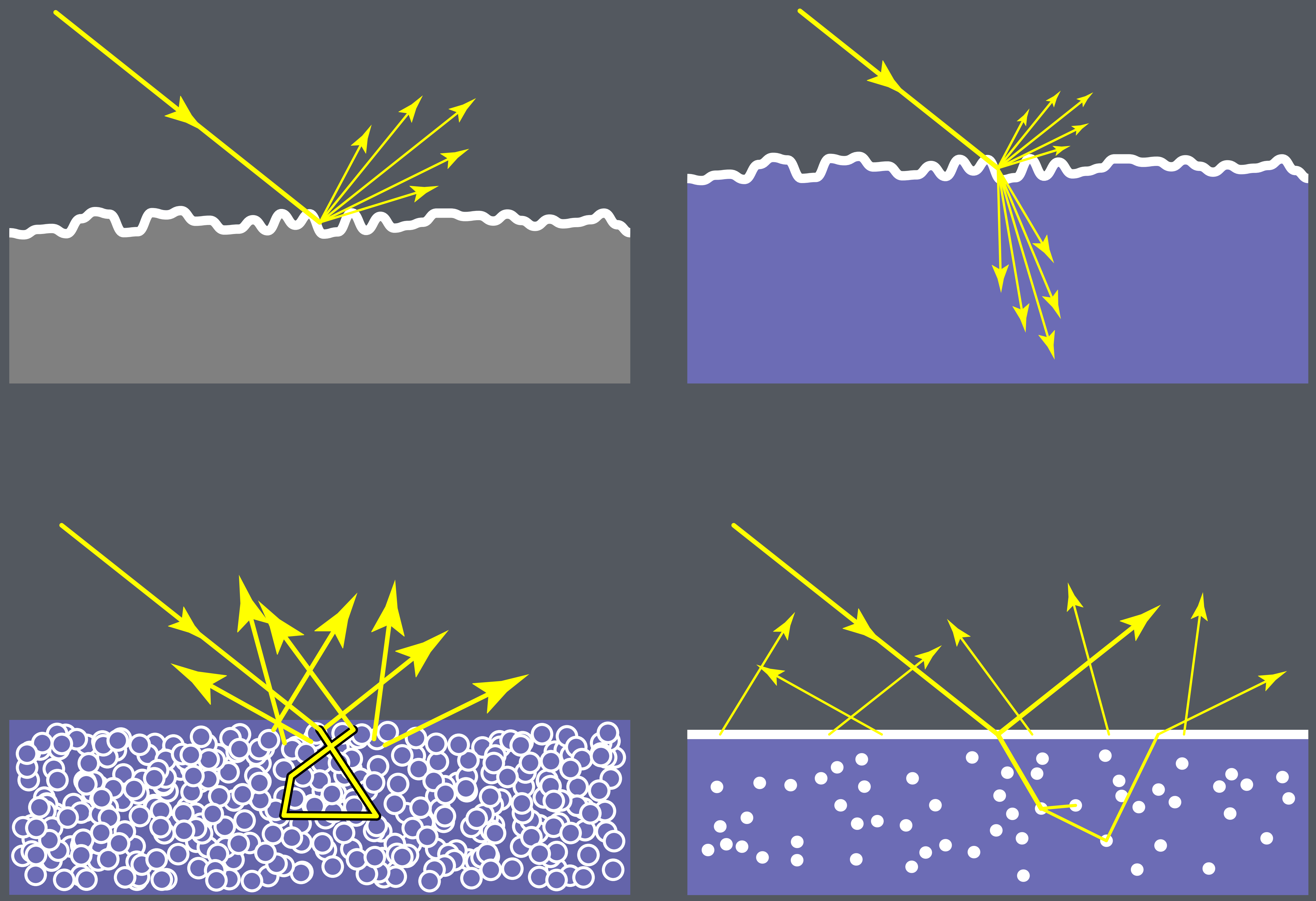
More complex scattering

Rough interfaces

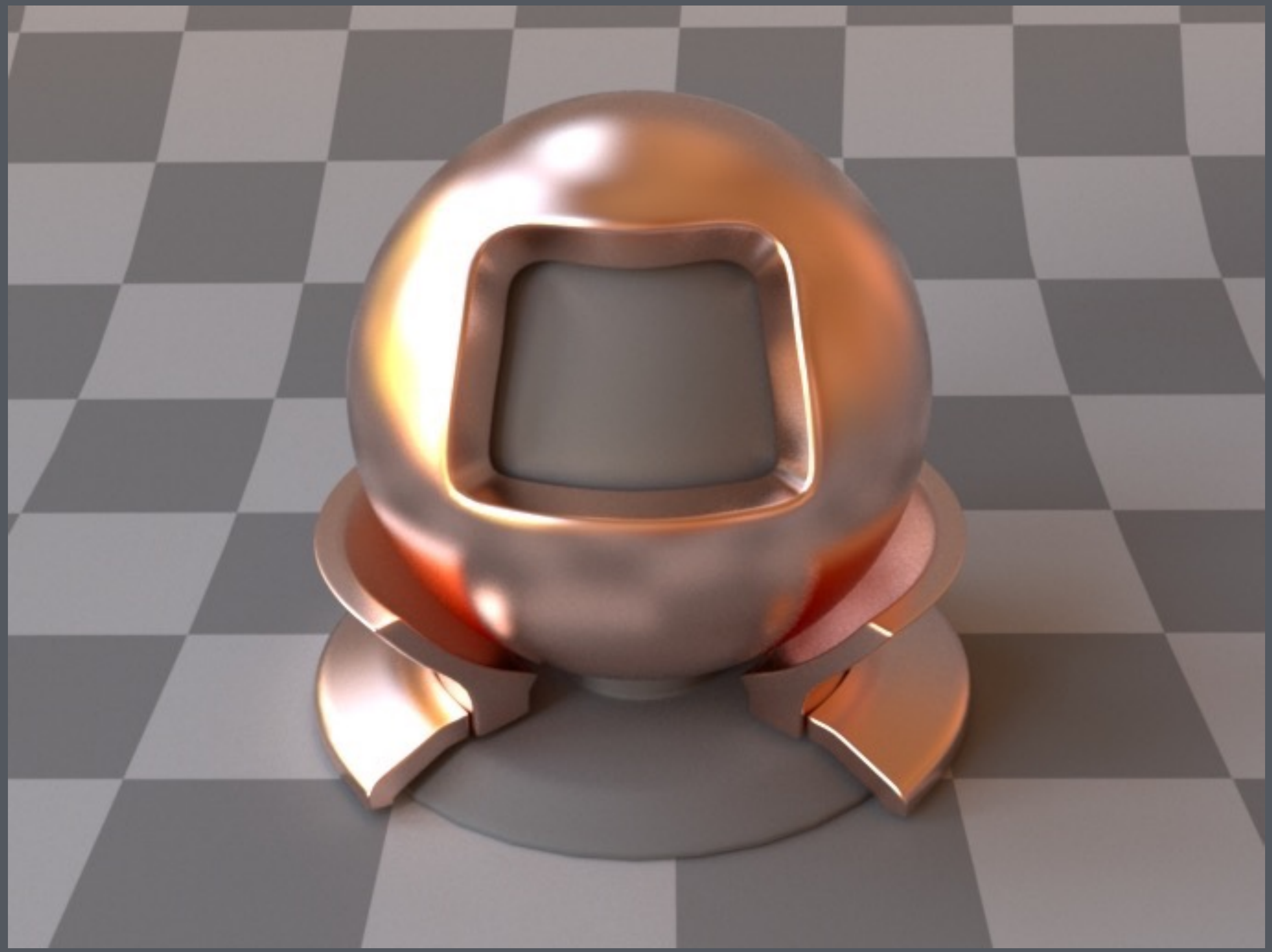
- metal interfaces: blurred reflection
- dielectric interfaces: blurred transmission

Subsurface scattering

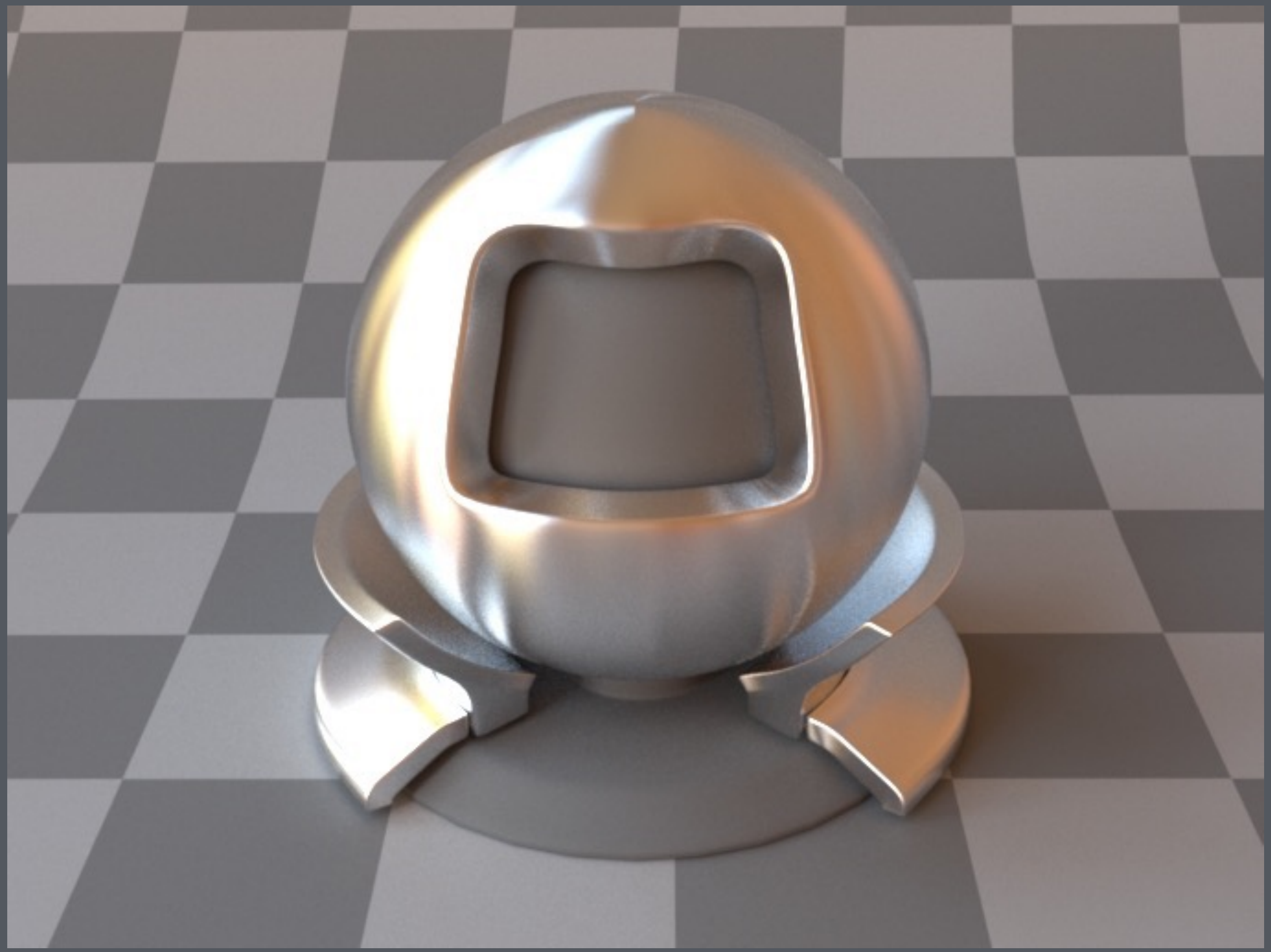
- liquids—milk, juice, beer, …
- coatings—paint, glaze, varnish, …
- natural materials—wood, marble, …
- biological materials—skin, plants, …
- low optical density leads to *translucency*



Reflection from rough metal interfaces



Cu ($\alpha = 0.1$)



Al (anisotropic)

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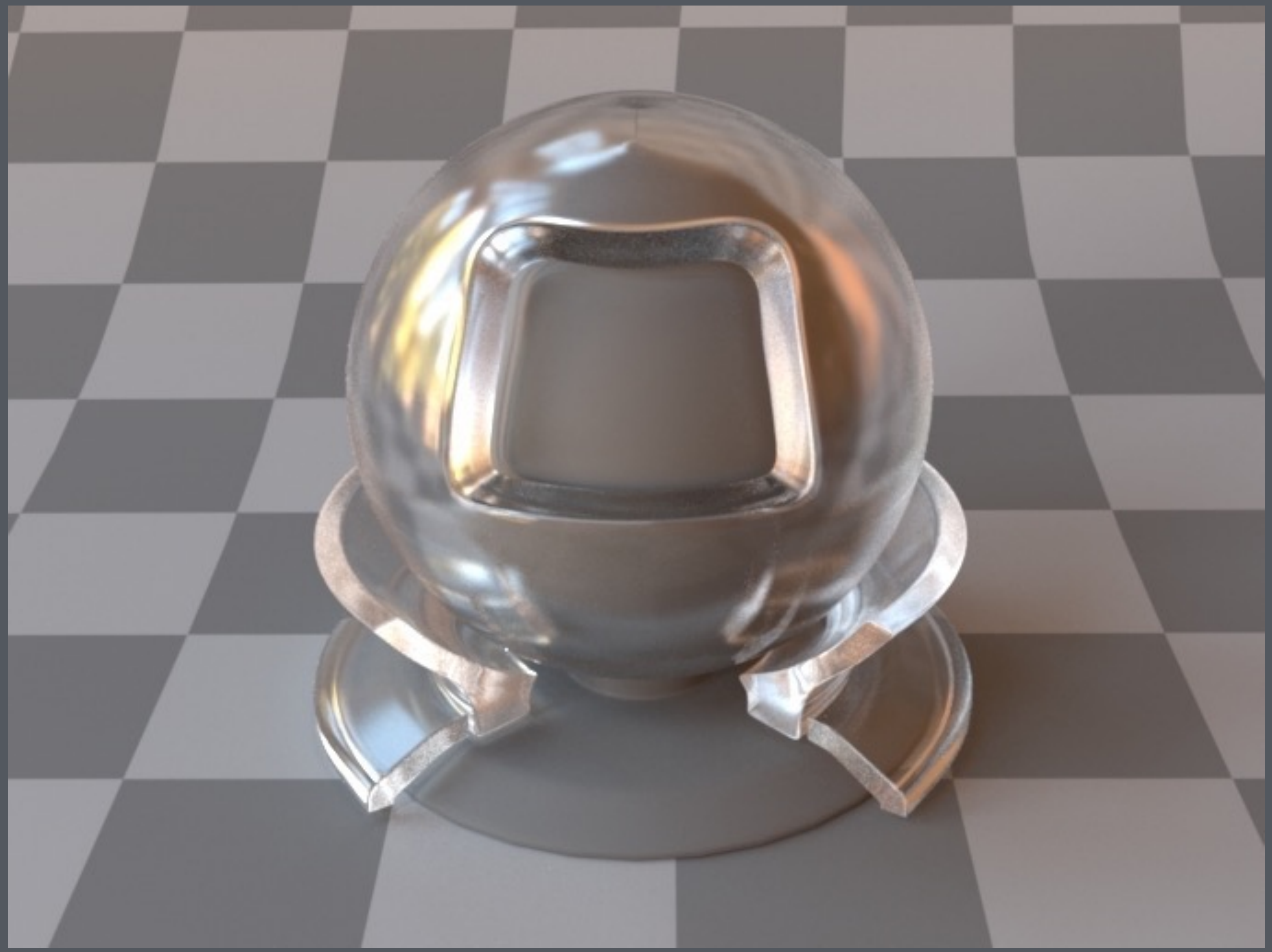
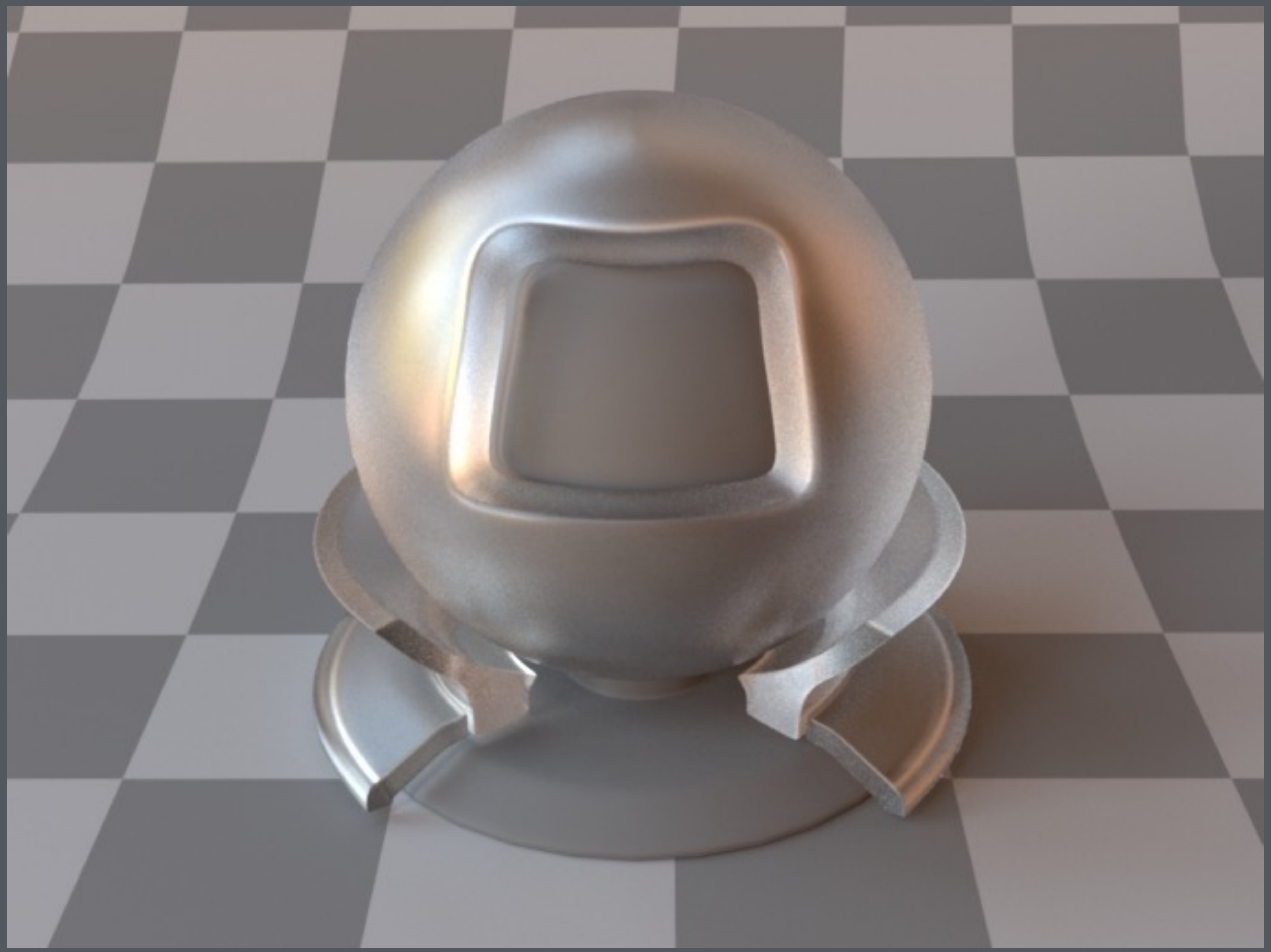
Ling-qi Yan & Milos Hasan | work in progress

Reflection and refraction at rough dielectric interfaces



Anti-glare glass (α = 0.02)



Etched glass (α = 0.1)

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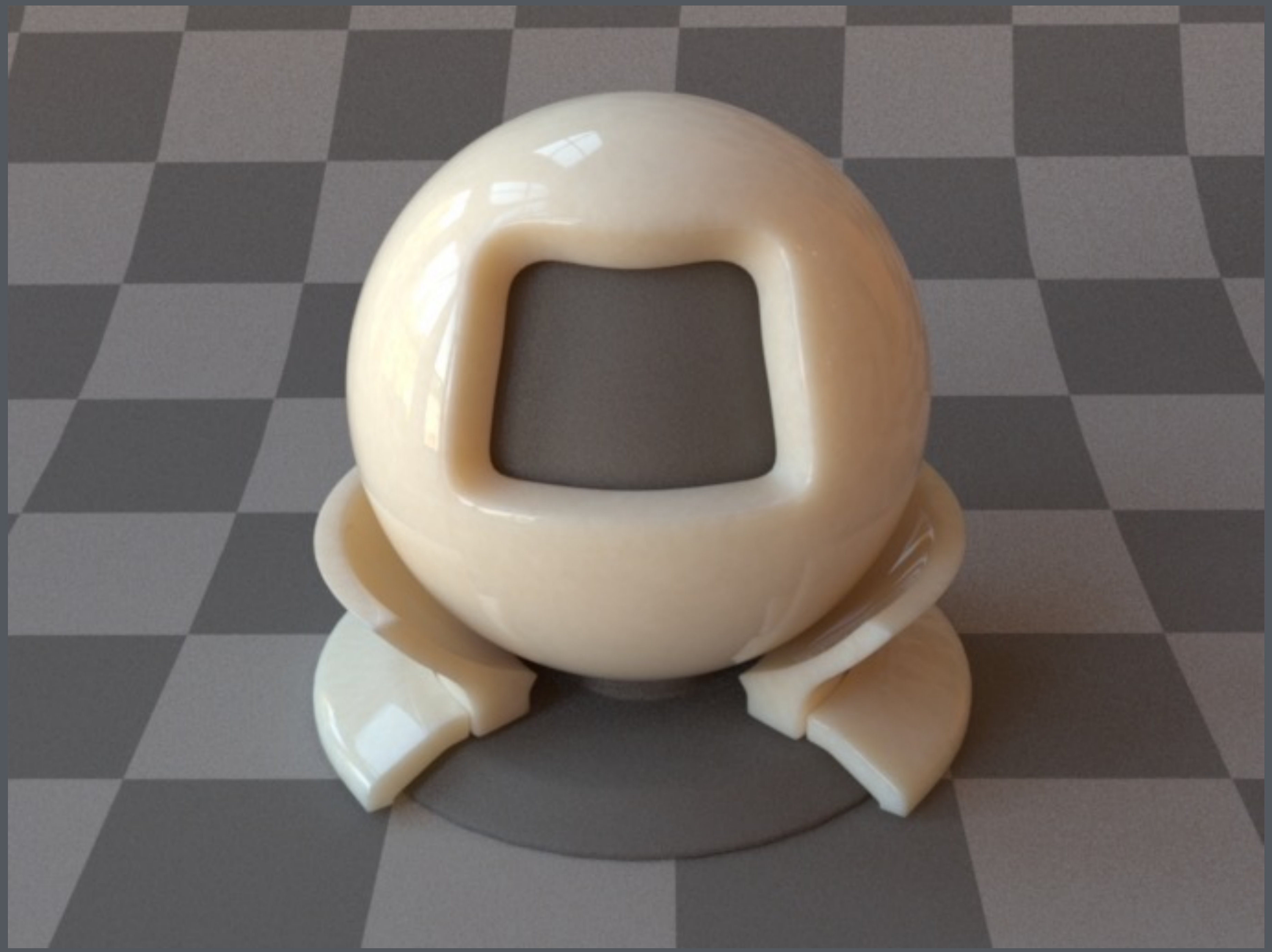
Translucent materials



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“skim milk”

low optical density

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high optical density

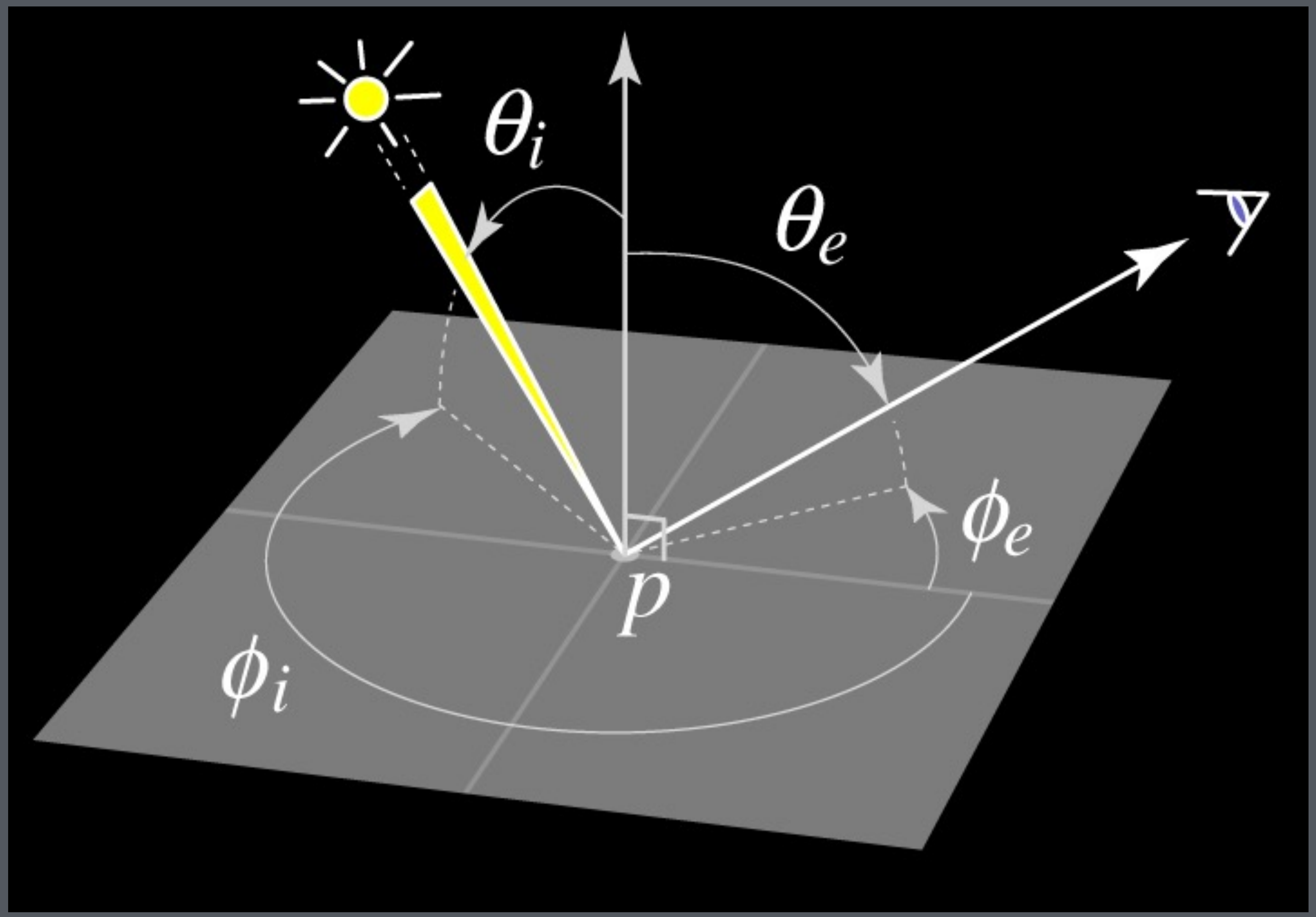
Modeling complex scattering

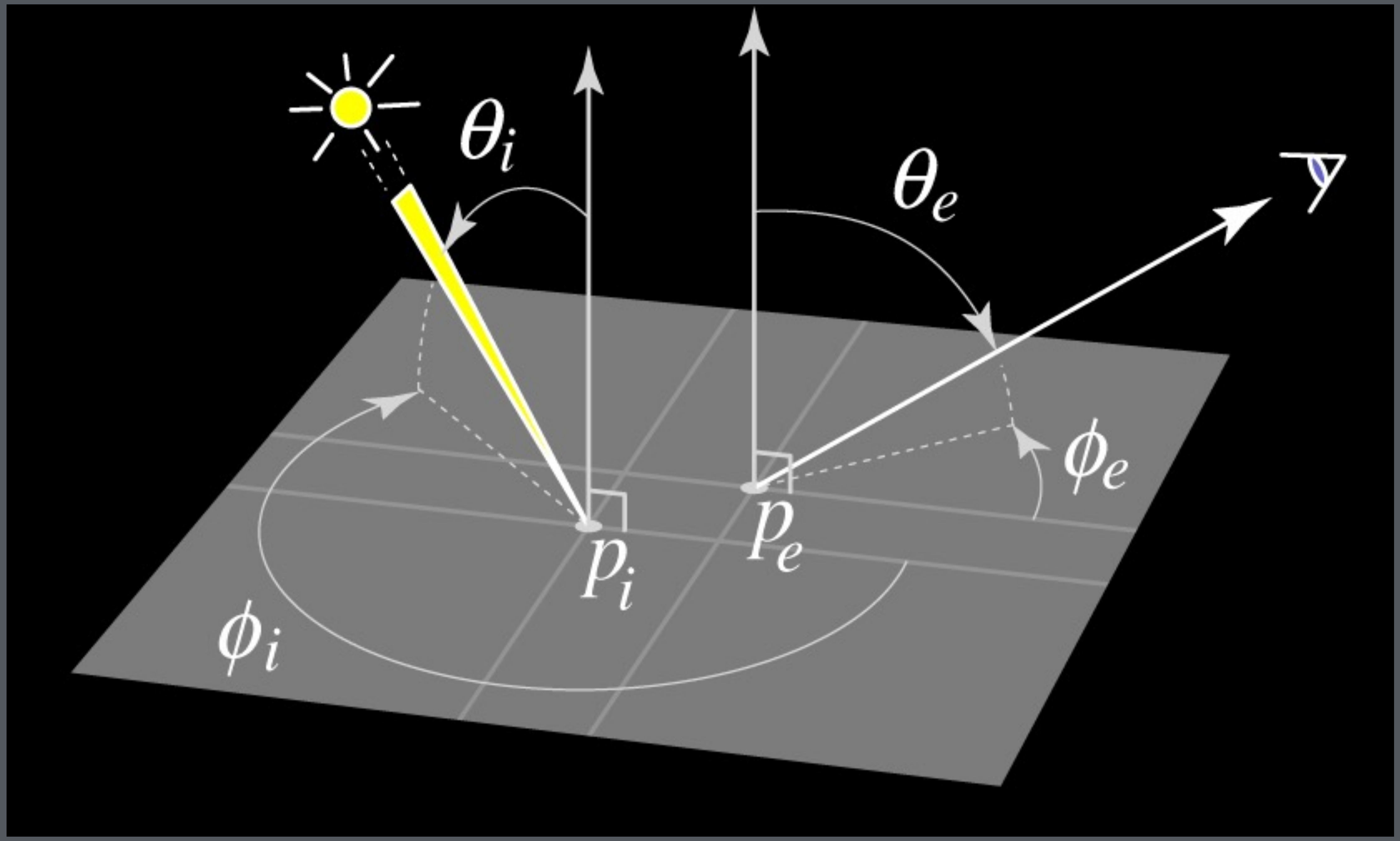
Opaque materials

- reflection: bidirectional reflectance distribution function (BRDF)
- transmission: bidirectional transmittance distribution function (BTDF)
- both: bidirectional scattering distribution function (BSDF)

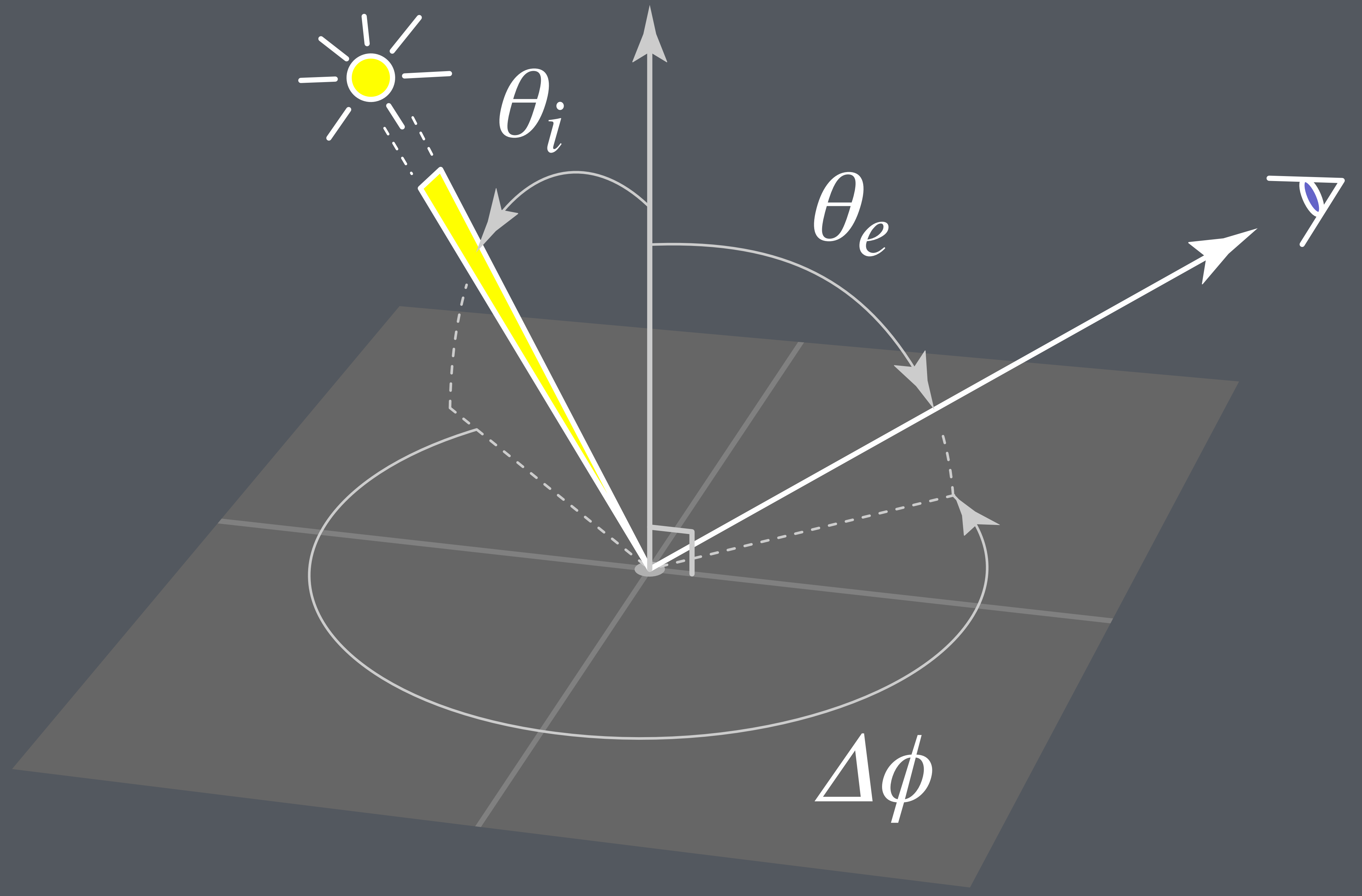
Translucent materials

- bidirectional subsurface scattering reflectance distribution function (BSSRDF)
- more on this later, maybe

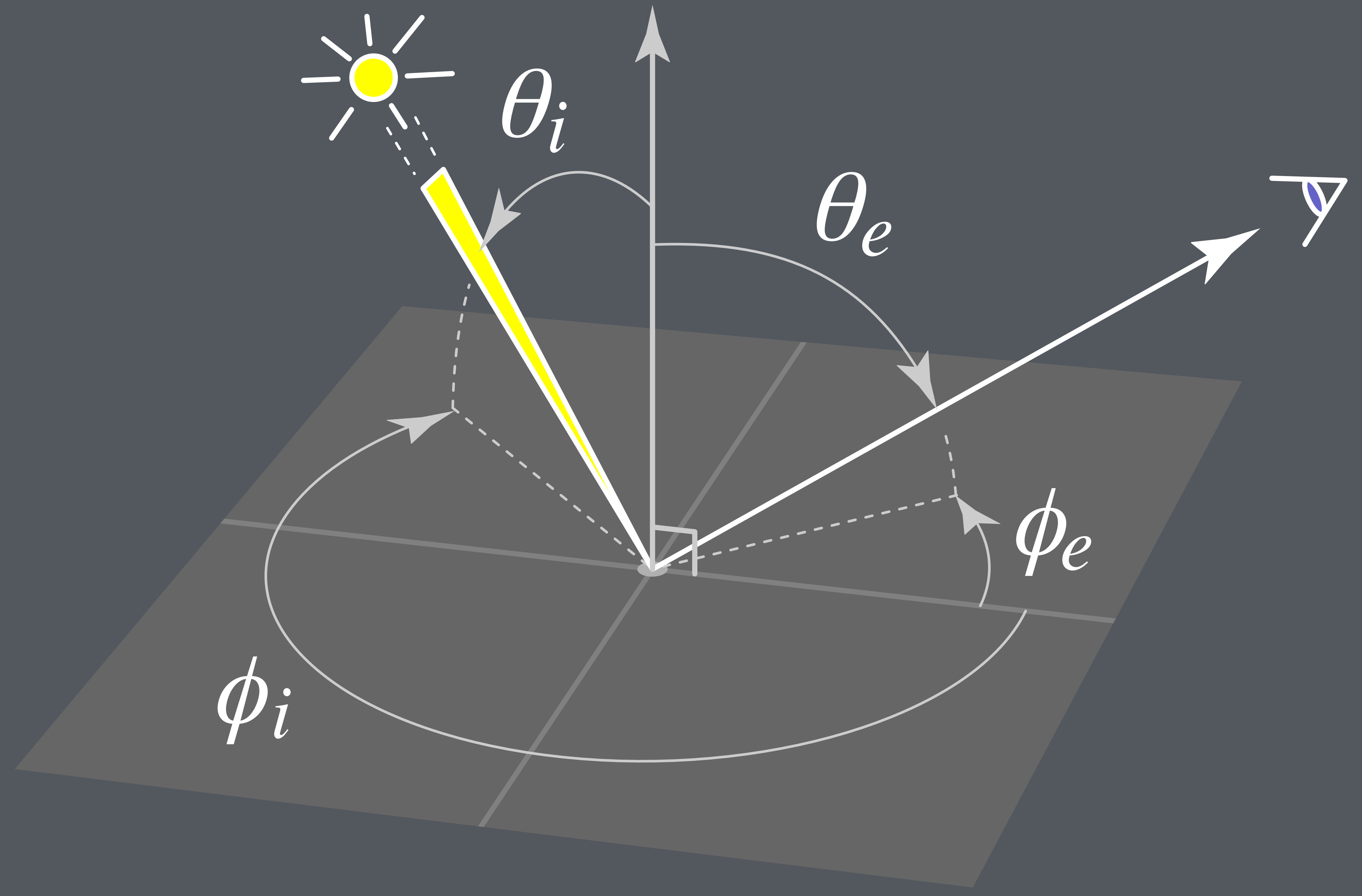




Isotropy vs. anisotropy

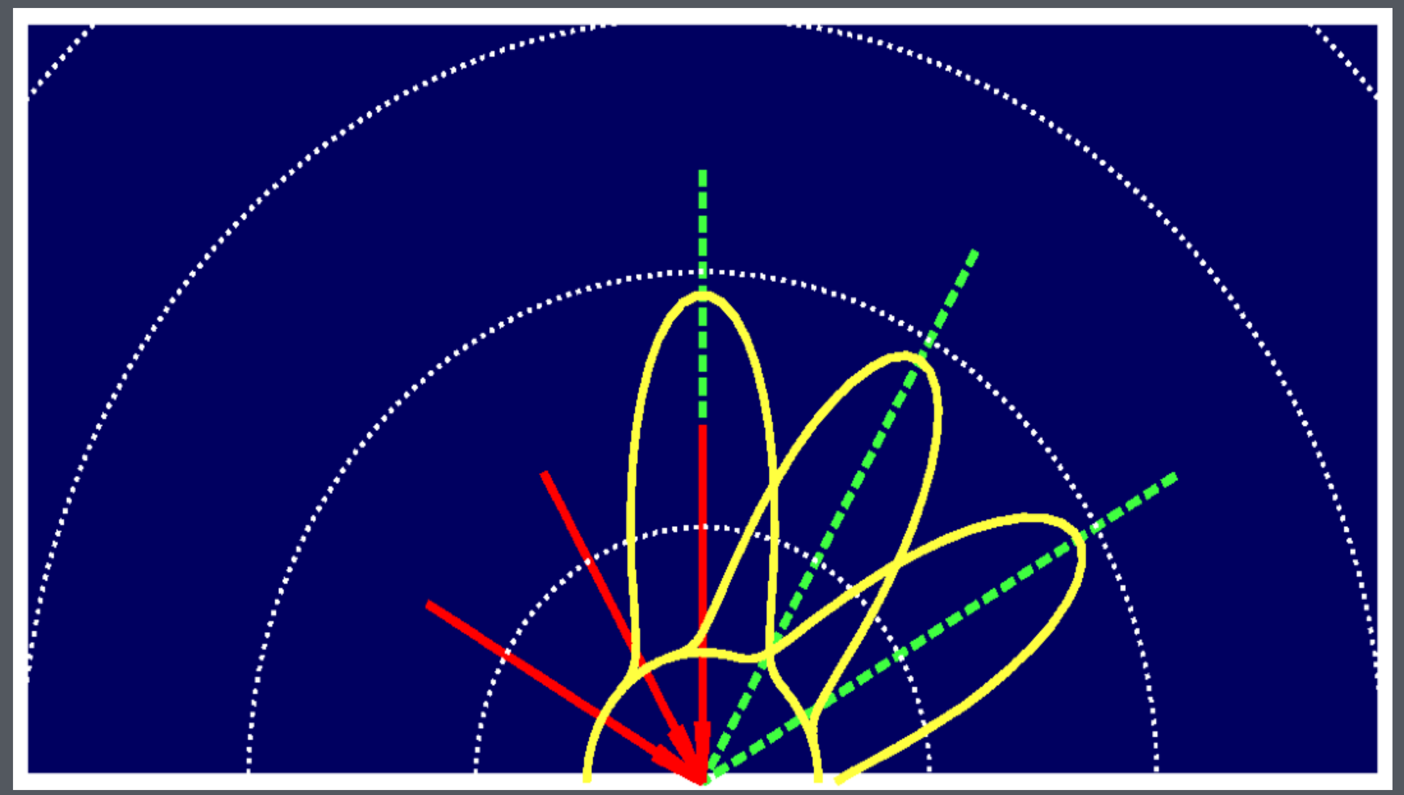


isotropic



anisotropic

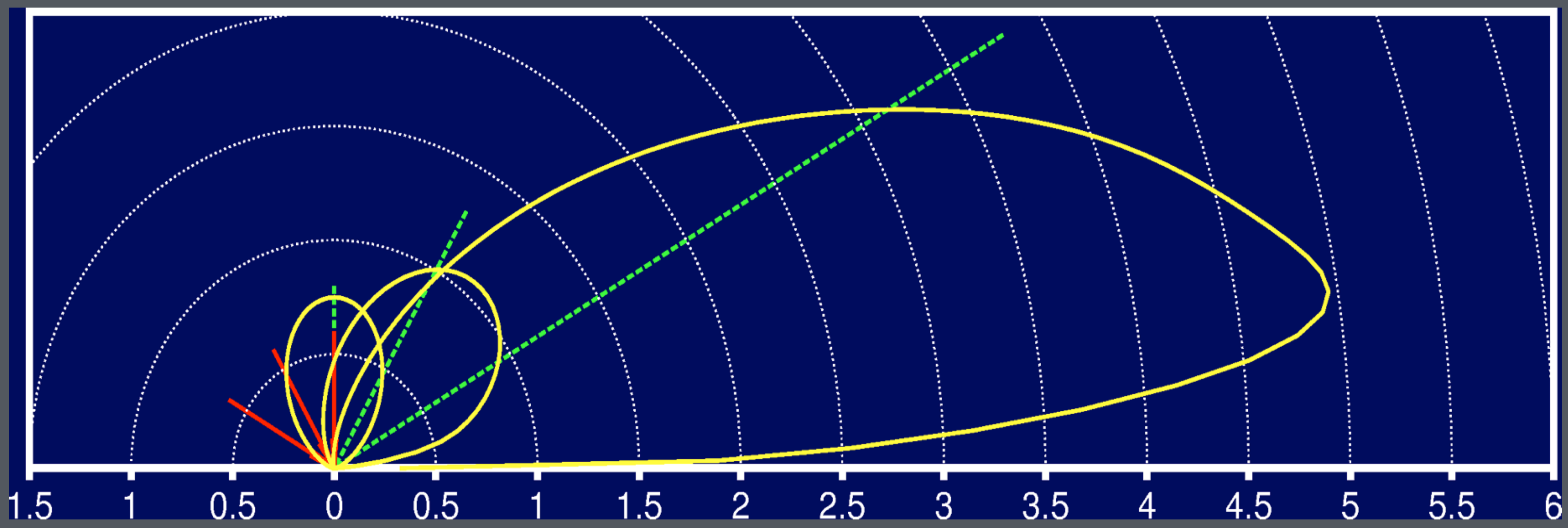
Types of BRDF/BSDF models



Ad hoc formulas

- e.g. Blinn-Phong

Physics-based analytical models



- Lambertian
- Microfacet-based models
- Kirchhoff-based models

Measured data

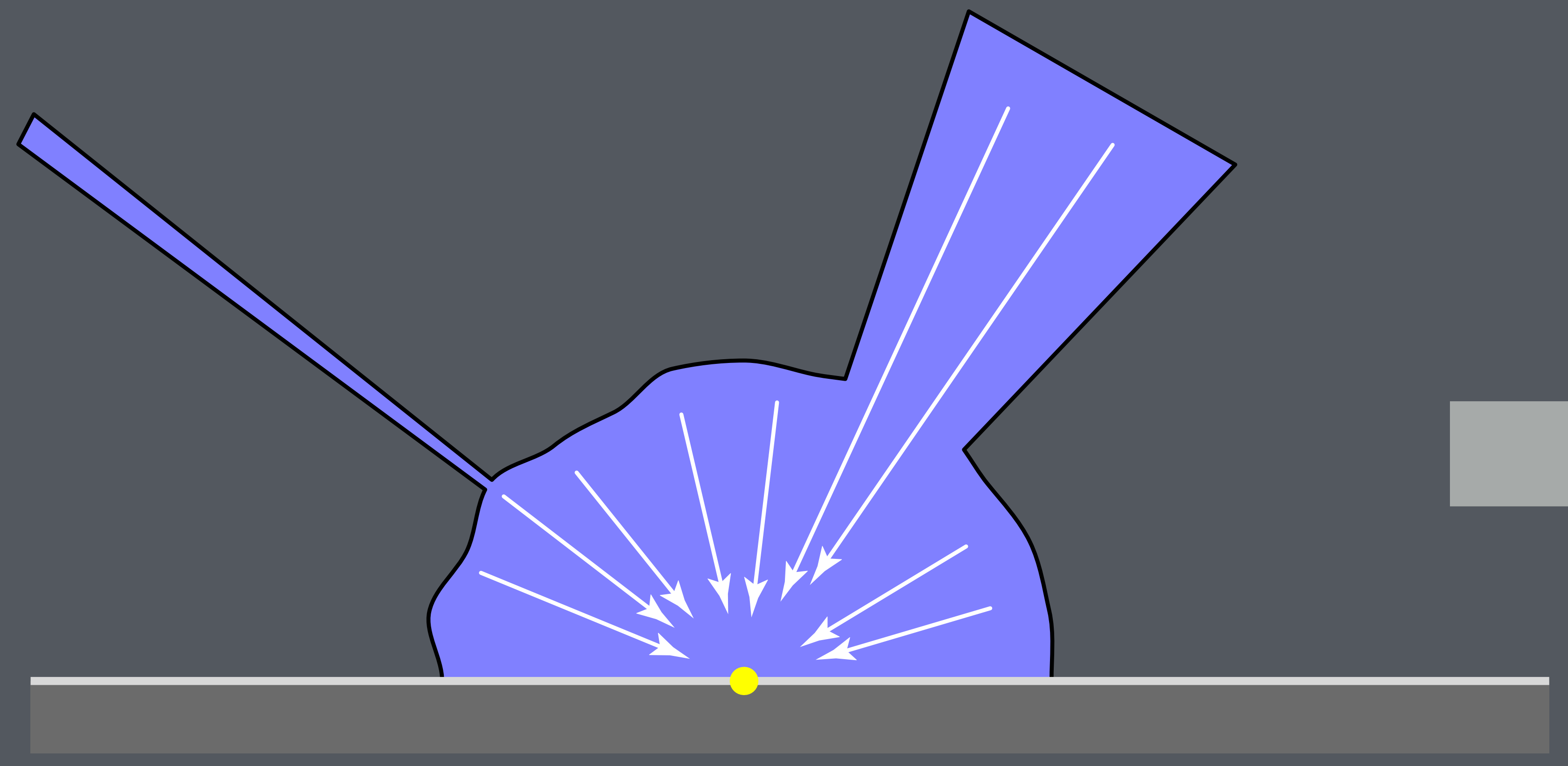
- tables of data from pointwise BRDF measurements
- image-based BRDF measurements

Light reflection in shaders

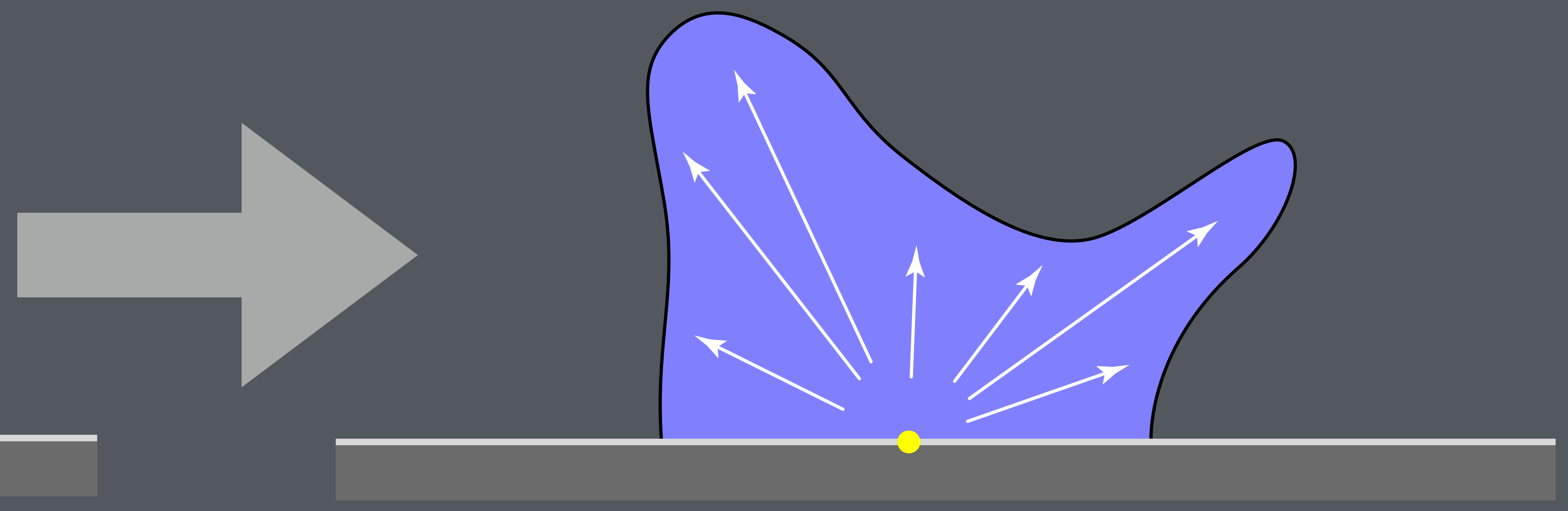
Light reflection: full picture

all types of reflection reflect all types of illumination

- diffuse, glossy, mirror reflection
- environment, area, point illumination



incident distribution
(function of direction)



reflected distribution
(function of direction)

Categories of illumination

	diffuse	glossy	mirror
indirect	soft indirect illumination	blurry reflections of other objects	reflected images of other objects
environment	soft shadows	blurry reflection of environment	reflected image of environment
area	soft shadows	shaped specular highlight	reflected image of source
point/directional	hard shadows	simple specular highlight	point reflections

■ = easy to compute using standard shaders

How to compute shading

Basic case: point or directional lights; diffuse or glossy BRDF

Type in BRDF model, plug in illumination and view direction

- can write down model in world space, use world-space vectors
- can write down model in surface frame, transform vectors
- really not different

Subtleties are all about what frame to use for shading

Interpolated shading

Coarse triangle meshes are fast

Discontinuities are bad

Therefore: interpolate geometric quantities across triangles

- goal: shading is smooth across edges

What do we interpolate?

- what do we need to compute shading?

Shading frames

When we carry around a normal, we are defining a tangent plane

- interpolated normal defines an approximate, smoothly varying tangent plane

For some purposes, the tangent plane is enough

- e.g. computing shading for isotropic BRDFs
- any coordinate system conforming to the normal is equally good

In other cases, need a complete frame

- whenever directions within the plane are inequivalent
- e.g. anisotropic BRDFs
- e.g. tangent-frame normal maps

How to compute these from normals and texture coordinates? (blackboard)

What to interpolate

Need plane: can just interpolate a normal

Need frame: interpolate enough data to define a tangent frame

One and a half vectors rounds up to two

- normal and one tangent vector
- two tangent vectors

Rebuilding a frame from the vectors

- worry about handedness matching texture coordinates (or not)
- orthonormality gets broken by interpolation (when does that matter?)

What you need for shading

When/why you need full frames

- when you care (or not) what the orientation is
- when you care (or not) about orthonormality

What to interpolate

- underlying math question: representation of frames
- representations that behave well under interpolation

How to author orientation

- with maps
- by following a parameterization

How to deal with corner cases