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forward and inverse radiometric models for translucent materials

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BxDiff JRP 18SIB03

EMPIR EURAMET

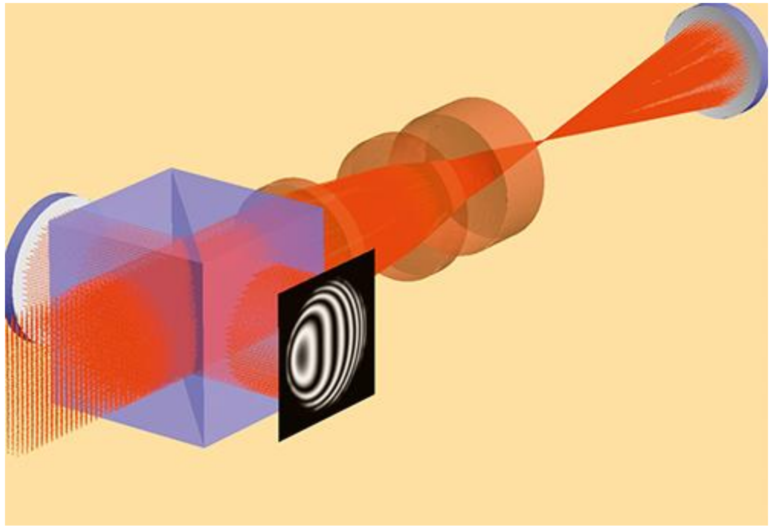
The EMPIR initiative is co-funded by the European Union's Horizon 2020 research and innovation programme and the EMPIR Participating States

forward problem

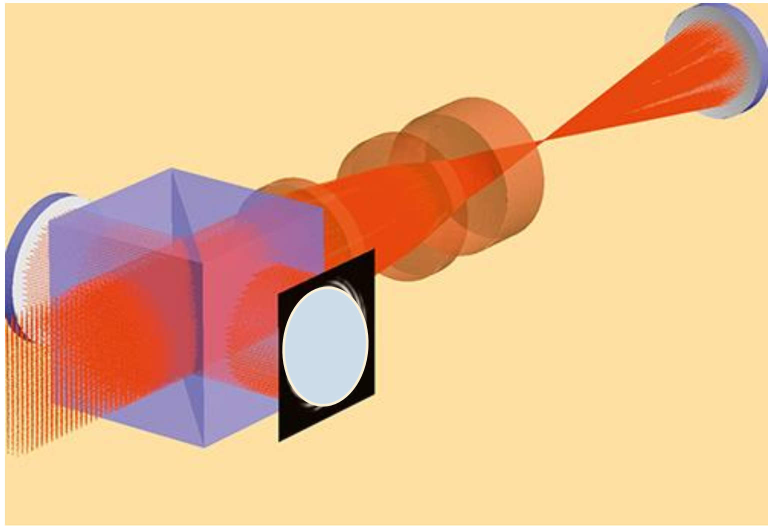
using radiometric models to simulate translucent materials

what are radiometric models?

model radiant energy propagation through a system/material without explicitly including phase/coherence

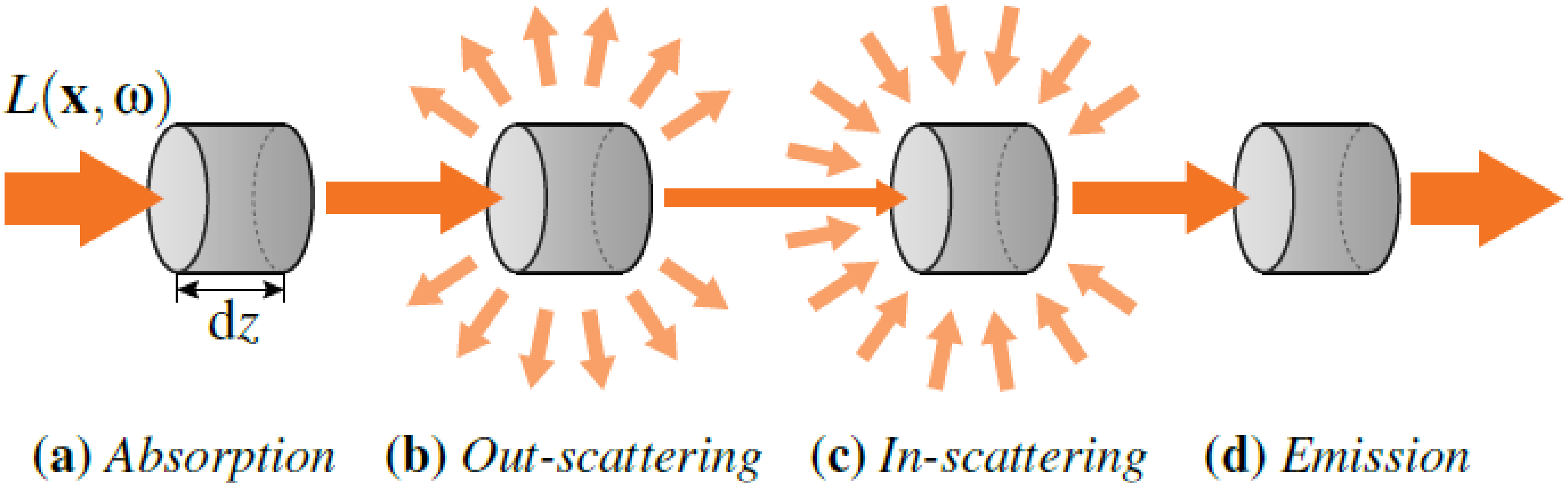


includes coherence/phase



ignores coherence/phase

radiometric models are based on the radiative transfer equation (RTE)



$$(\vec{\omega}\cdot\nabla)L(\boldsymbol{x},\vec{\omega}) = -\mu_a(\boldsymbol{x})L(\boldsymbol{x},\vec{\omega}) - \mu_s(\boldsymbol{x})L(\boldsymbol{x},\vec{\omega}) + \mu_s(\boldsymbol{x})\int_{4\pi} p(\boldsymbol{x},\vec{\omega}',\vec{\omega})L(\boldsymbol{x},\vec{\omega}') + l_e(\boldsymbol{x},\vec{\omega})$$

the RTE depends on the scattering and absorption coefficients …

heterogeneous, anisotropic material		homogeneous, isotropic material
$\mu_a(\boldsymbol{x}, \vec{\omega}, \lambda)$	$\rightarrow$	$\mu_a(\lambda)$
$\mu_s(\boldsymbol{x}, \vec{\omega}, \lambda)$	$\rightarrow$	$\mu_s(\lambda)$

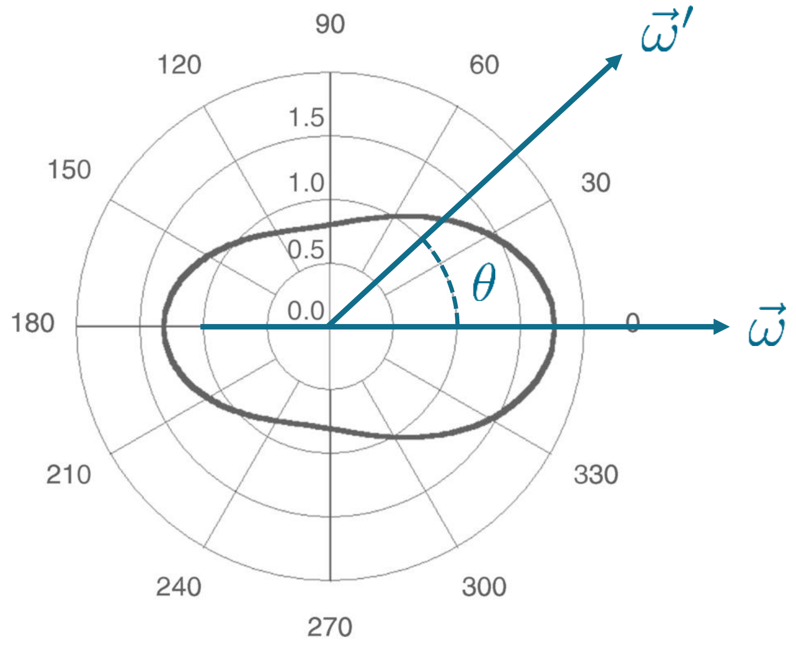
absorption/scattering coefficient: probability of absorption/scattering per unit distance

… and on the phase function

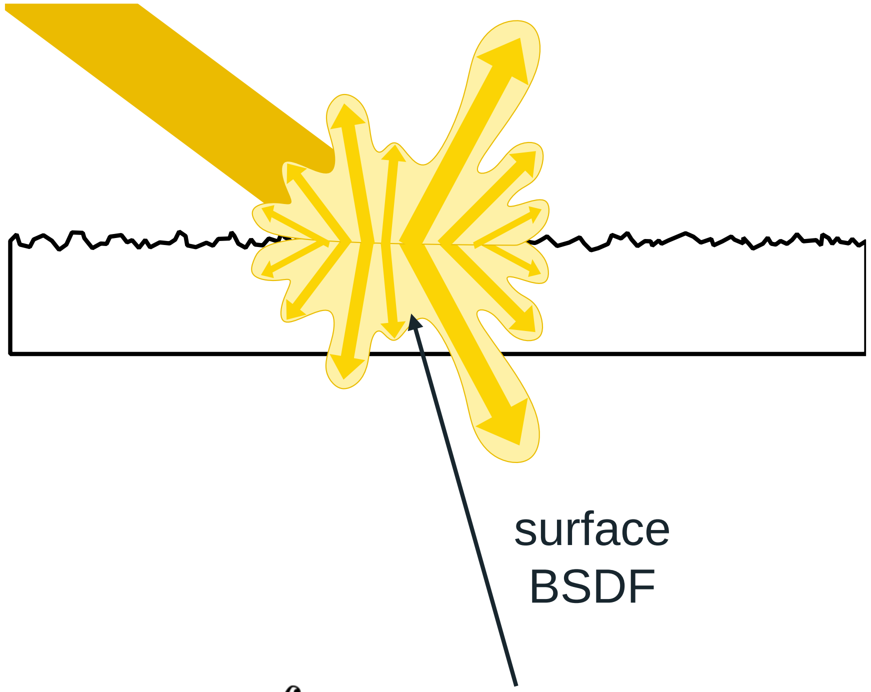
$$p(\boldsymbol{x}, \vec{\omega}, \vec{\omega}', \lambda) \qquad \rightarrow \qquad p(\theta, \lambda)$$

phase function:

angular probability distribution of the scattered light



surface scattering is a boundary condition to the RTE



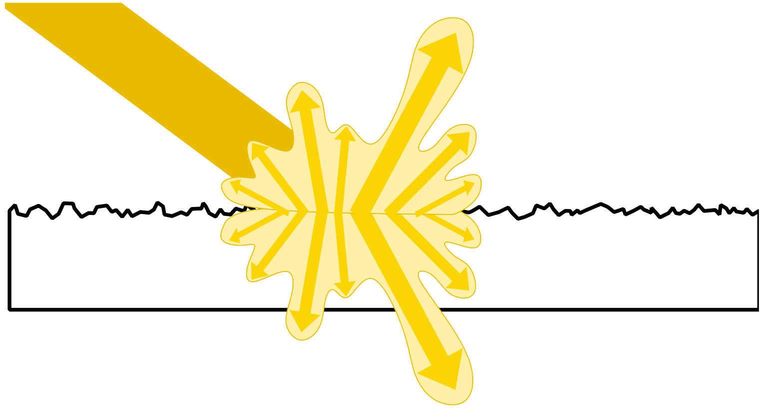
$$L_{out}(\boldsymbol{x}, \vec{\omega}') = \int_{4\pi} f_s(\boldsymbol{x}, \vec{\omega}, \vec{\omega}') L_i(\boldsymbol{x}, \vec{\omega}) |\cos\theta| \, d\omega$$

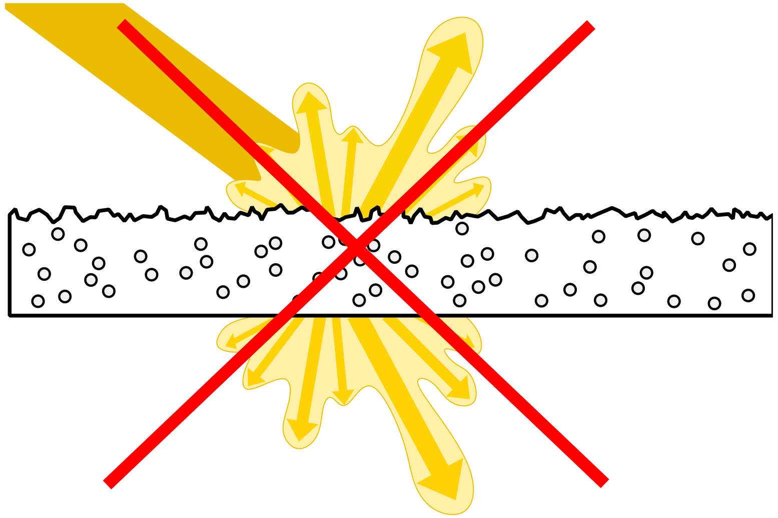
the surface BSDF does not describe bulk scattering

surface BSDF:

proportionality factor of scattered radiance to the incident irradiance

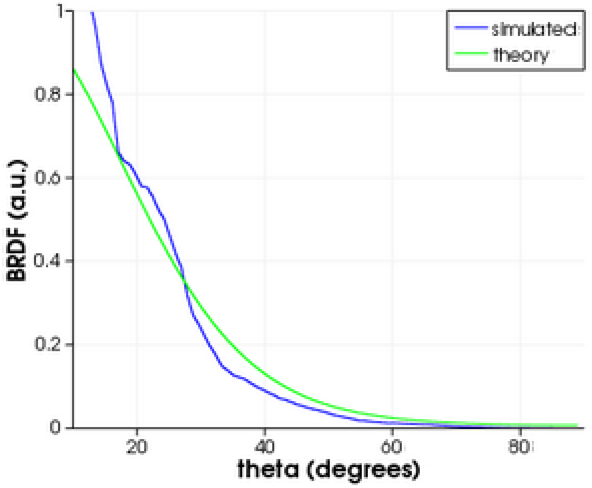
$$f_s(\boldsymbol{x}, \vec{\omega}, \vec{\omega}') = \frac{L_{out}(\boldsymbol{x}, \vec{\omega}')}{E_{in}(\boldsymbol{x}, \vec{\omega})}$$



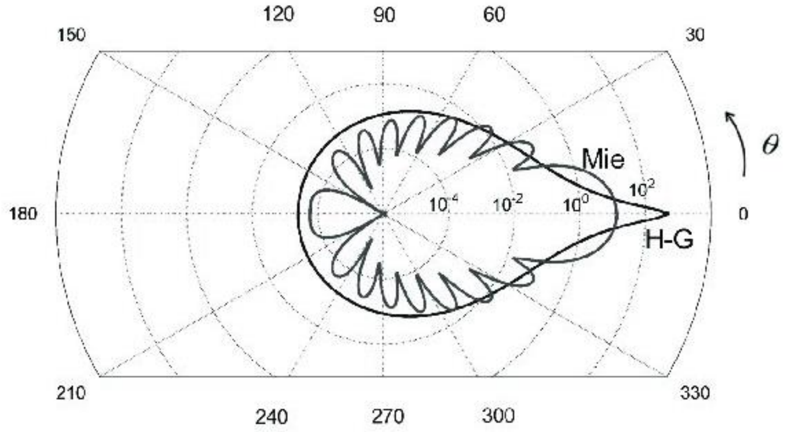


certain phase effects are included in radiometric models

surface BSDF models wave scattering



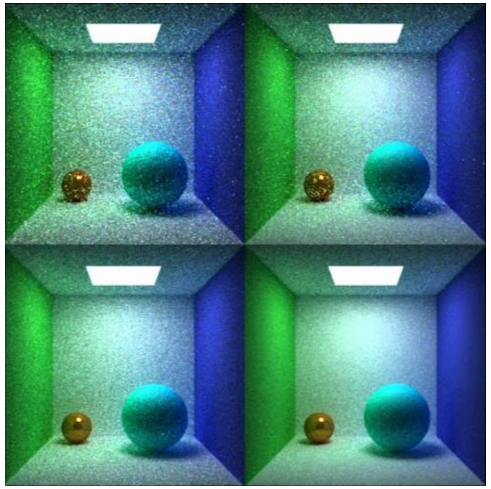
wave effects are included in the phase function



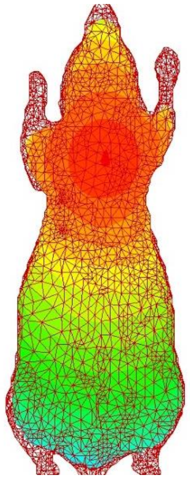
Lumerical Inc.: Bidirectional scattering distribution function

there are multiple methods available to solve the RTE

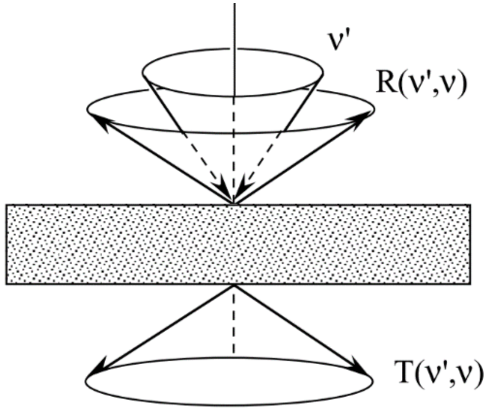
Monte Carlo ray tracing



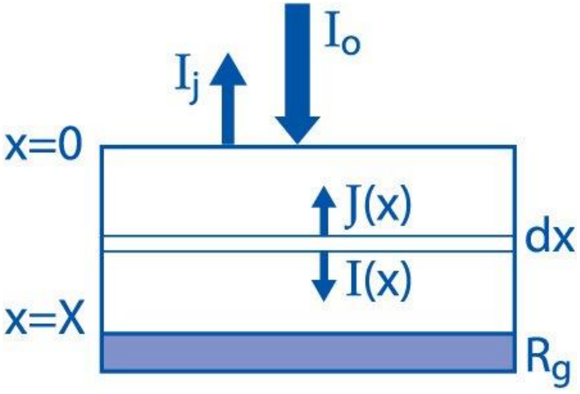
finite element methods



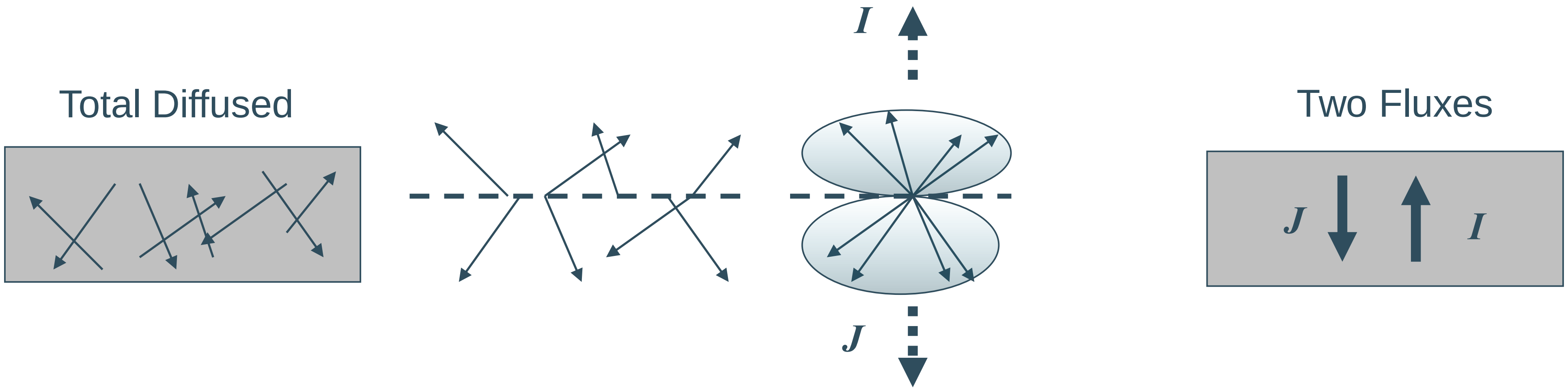
adding-doubling method



Kubelka-Munk model



Kubelka-Munk model is applicable to many sample types

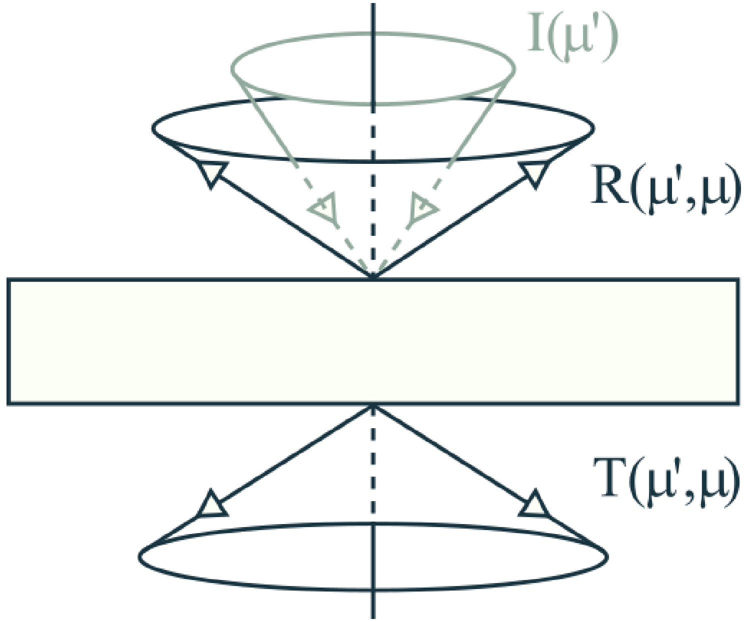


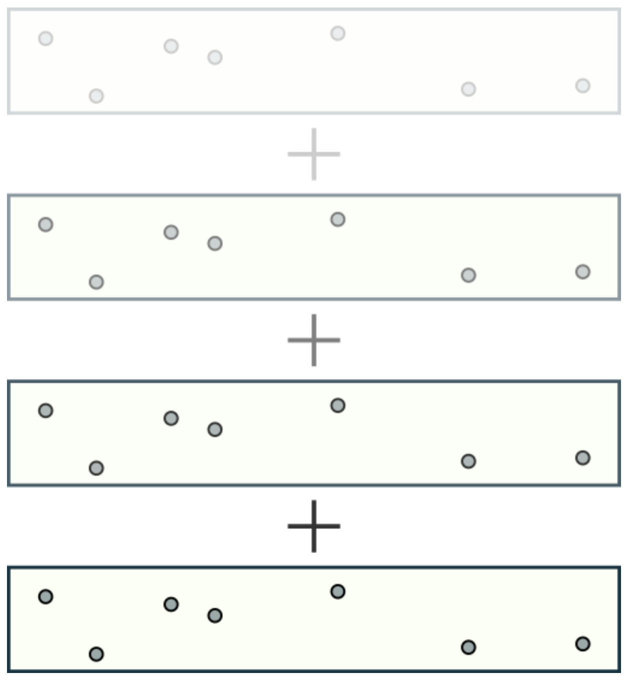
diffusely illuminated thick scattering samples

thin scattering samples in which light distribution is partially diffused

absorbing media in which light distribution varies with degree of absorption

adding-doubling can simulate radiant intensity distributions





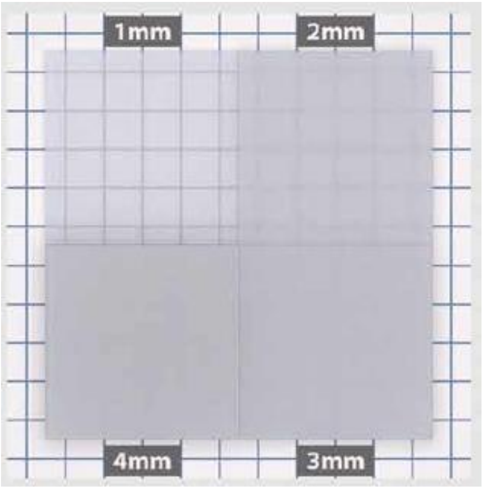
inverse problem

estimating the scattering parameters of translucent materials

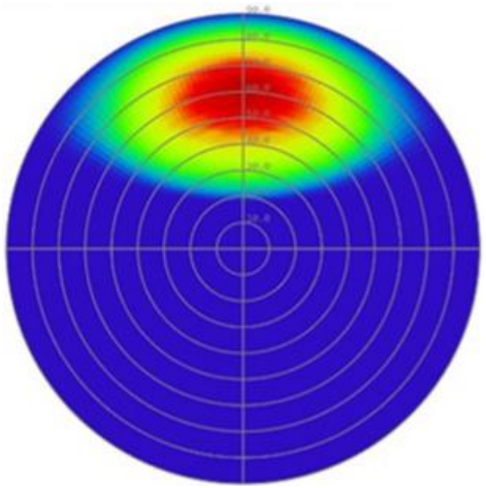
what scattering properties do we need to estimate?

$$\mu_a(\lambda) \quad \mu_s(\lambda) \quad p(\theta, \lambda) \quad f_s(\vec{\omega}, \vec{\omega}')$$

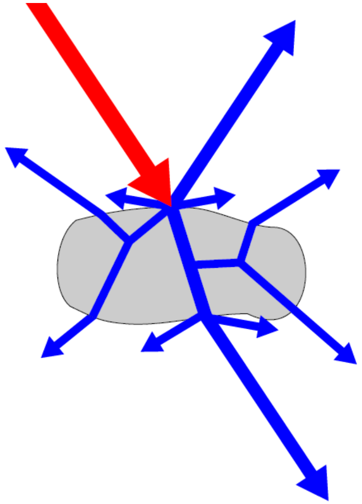
appearance



optical performance



BSSRDF



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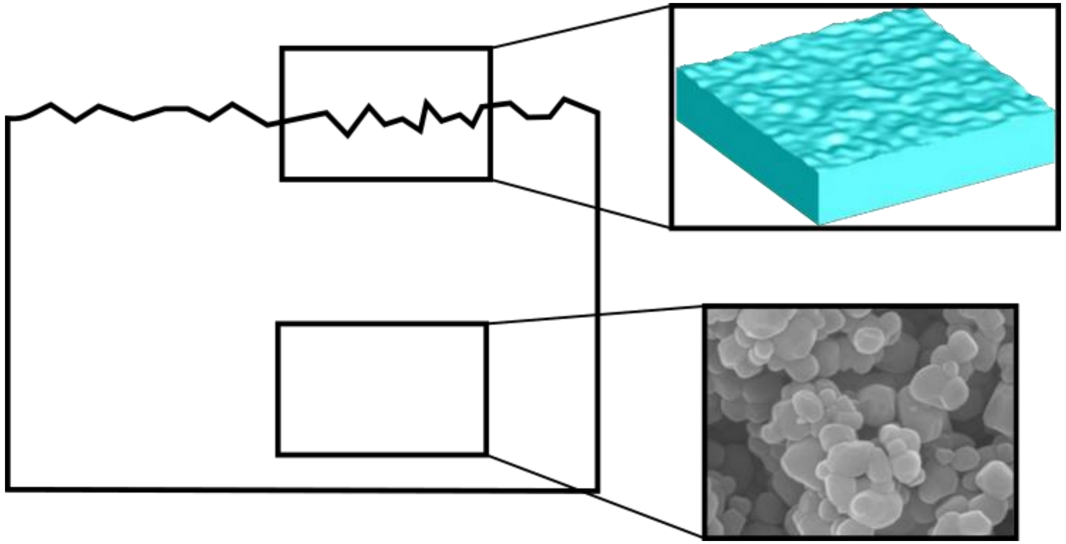
how do we estimate the surface and bulk properties?

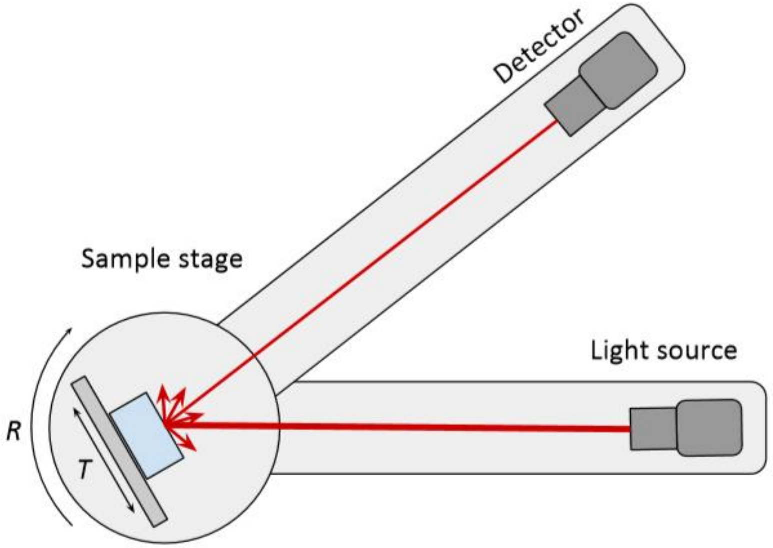
model

(geometry & material properties)



measure

(fit to simulations)



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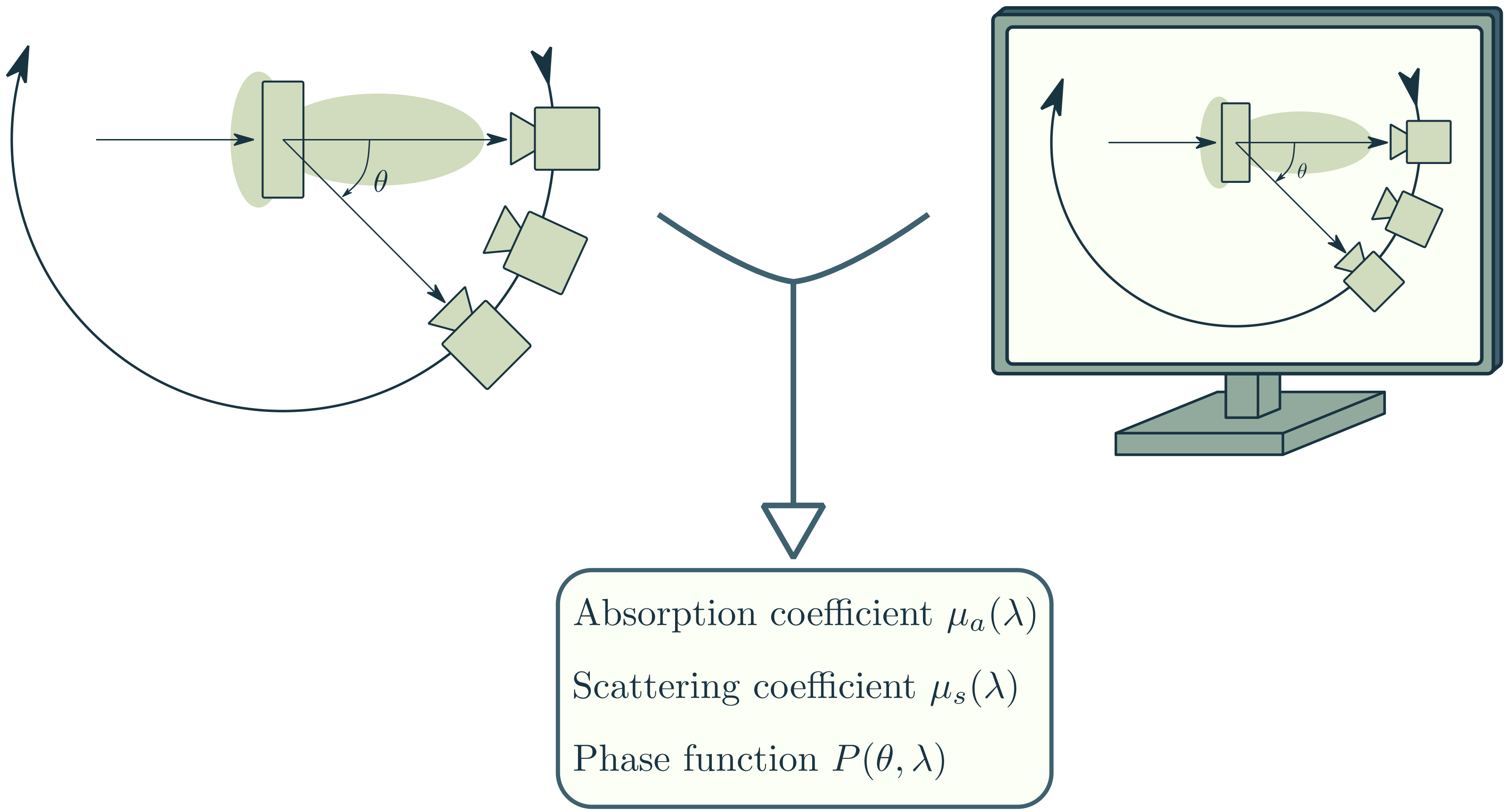
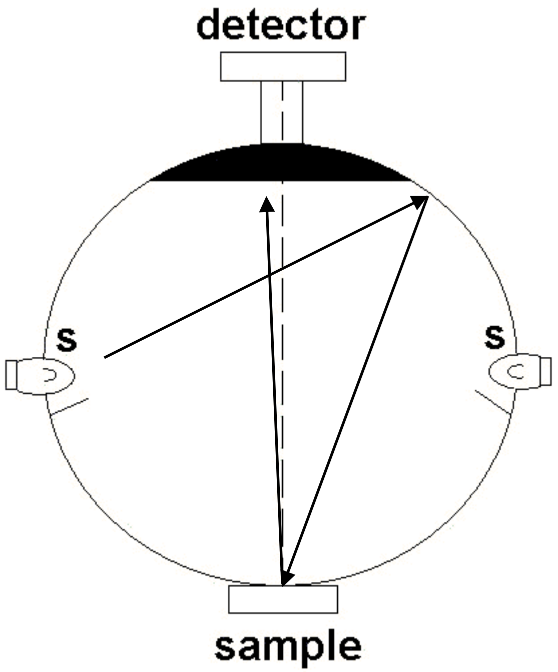
fitting simulations to measurements

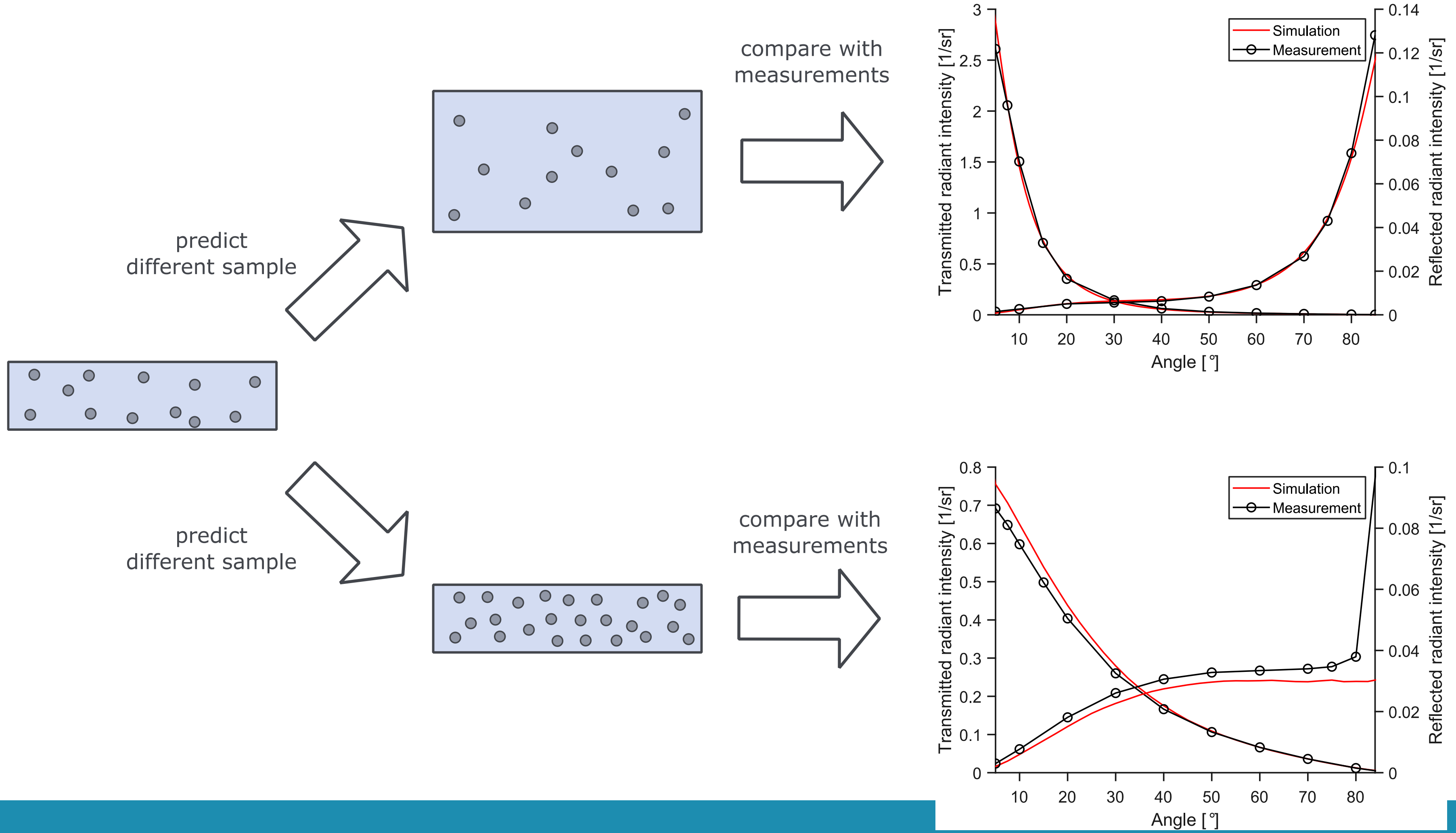


spectral reflection and the Kubelka-Munk method



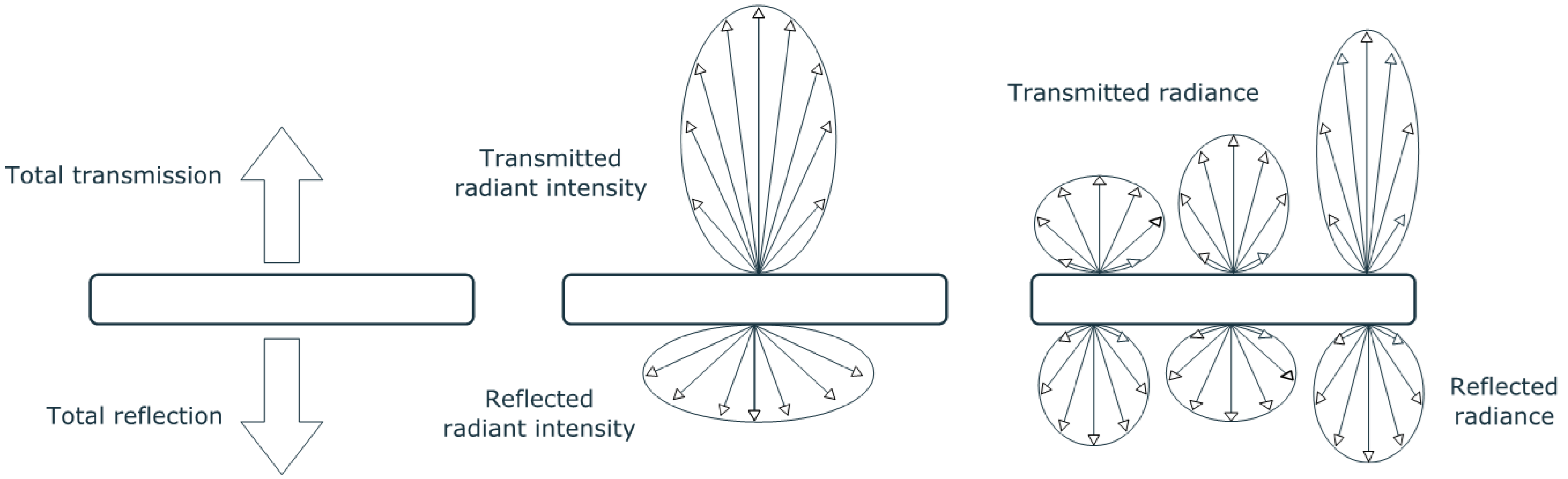
$\rightarrow$ $R(\lambda)$ $\rightleftarrows$ (K,S) $\rightleftarrows$ (μ_s, μ_a)

using radiant intensity with IAD improves generalization



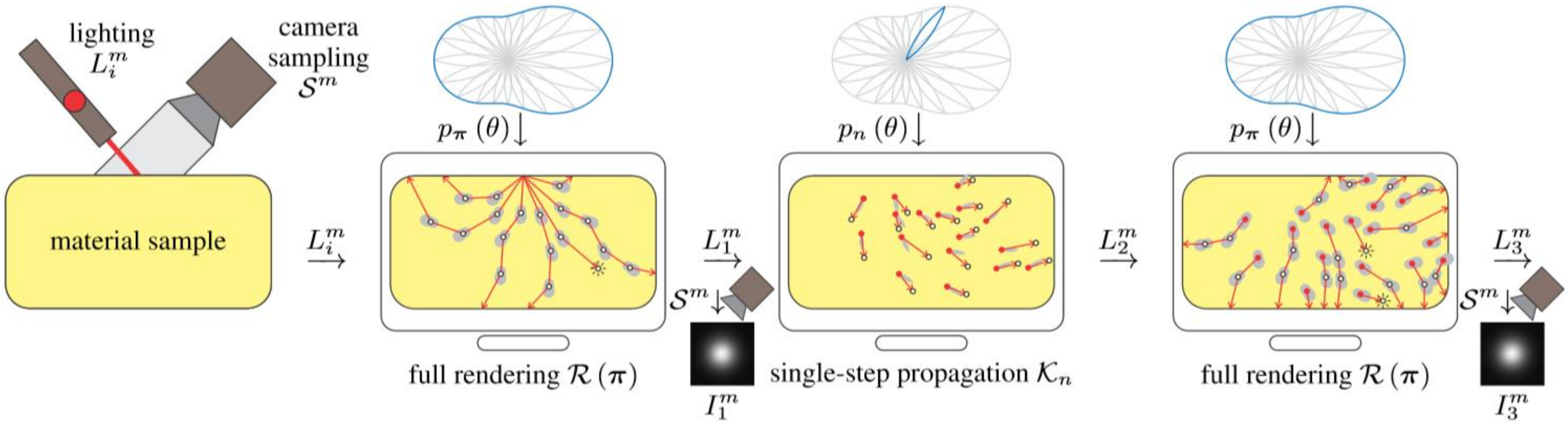
Accurate and robust characterization of volume scattering materials using the intensity-based inverse adding-doubling method, Correia et al (2019)

more complex measurements can further improve accuracy



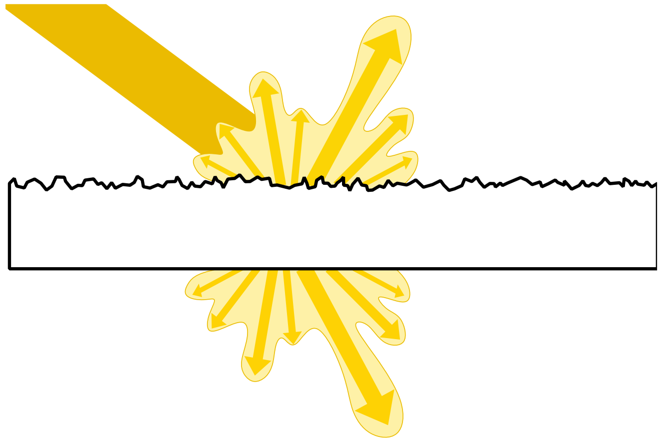
similarity theory: for very opaque samples, different sets of parameter produce indistinguishable images or optical performance

using radiance measurements is one such example



Inverse volume rendering with material dictionaries, Gkioulekas et al. (2013)

obtaining scattering properties for combined scattering samples is not trivial but BSSRDF may help

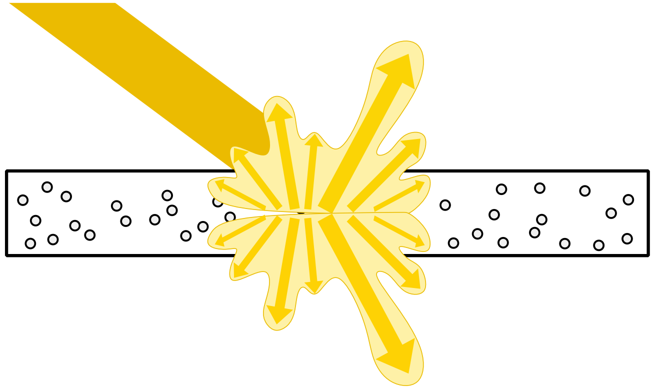


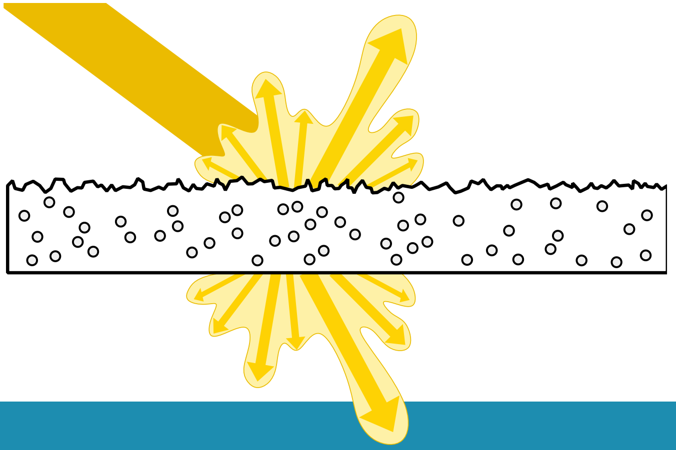
$$f_s(\vec{\omega}, \vec{\omega}')$$

$$p(\theta, \lambda)$$

$$\mu_a(\lambda)$$

$$\mu_s(\lambda)$$





unknown

$$\mu_a(\lambda) \quad p(\theta, \lambda)$$

$$\mu_s(\lambda) \quad f_s(\vec{\omega}, \vec{\omega}')$$