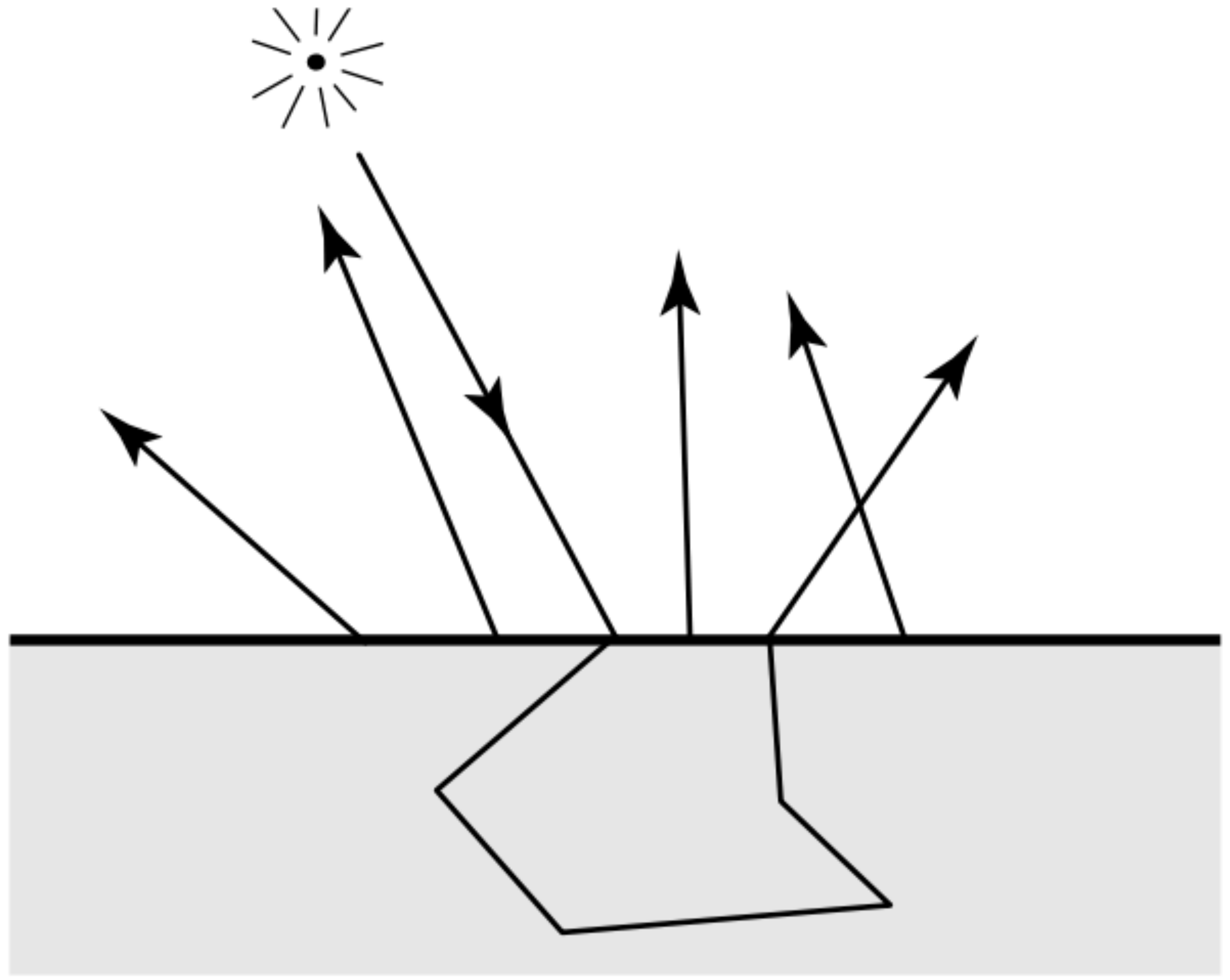
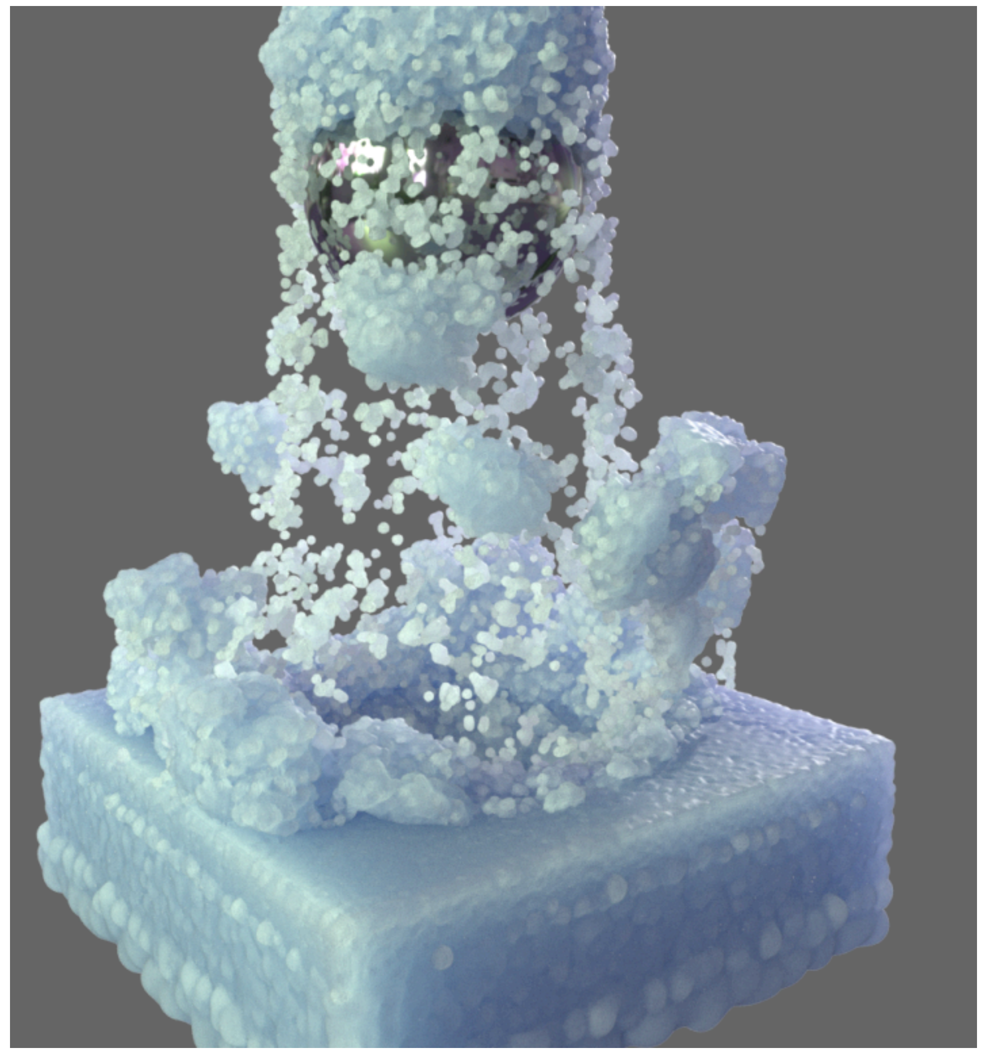
Diffusion approximation

UCSD CSE 272
Advanced Image Synthesis

Tzu-Mao Li

Today: multiple-scattering approximation





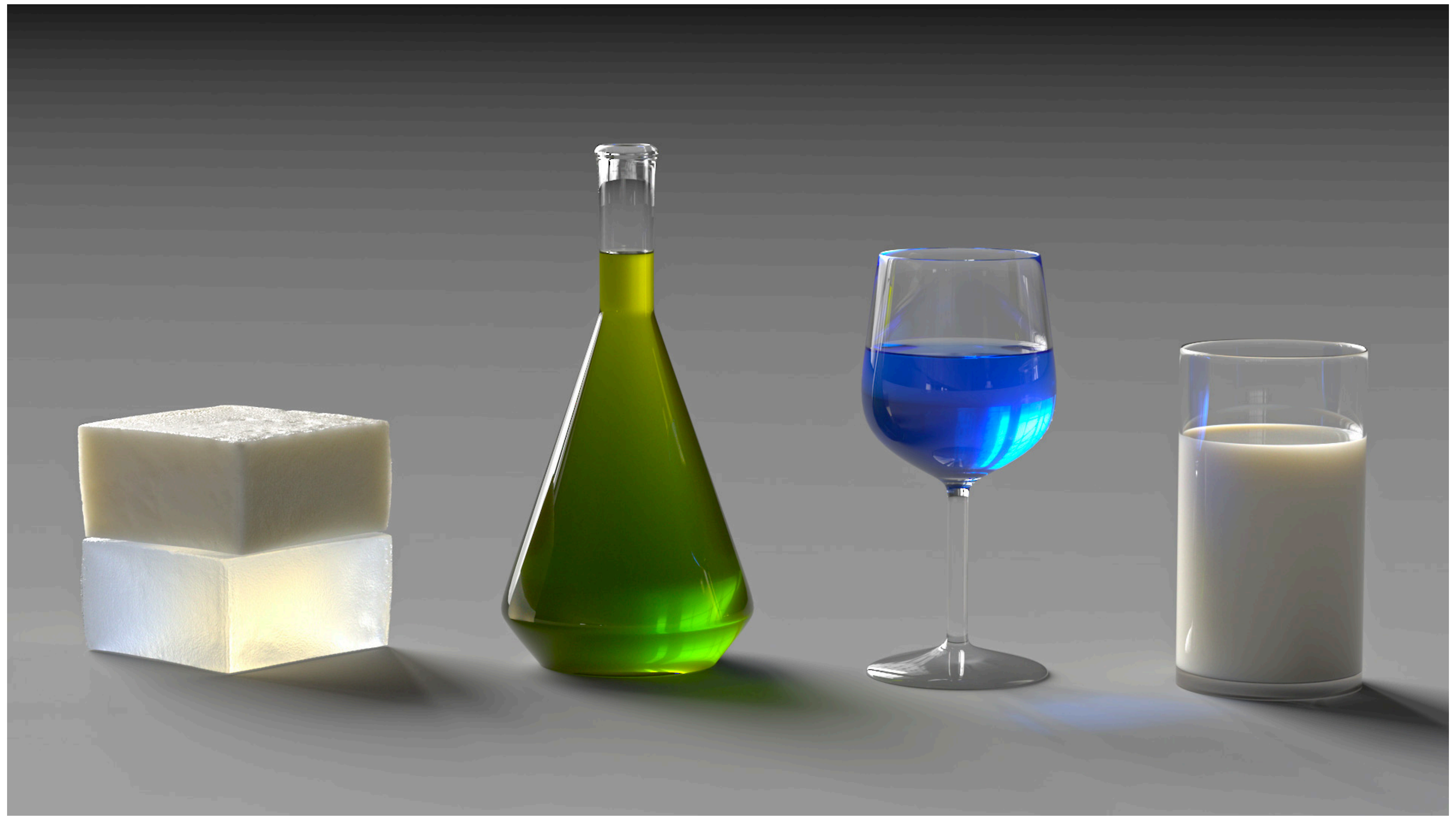
https://blog.selfshadow.com/publications/s2015-shading-course/burley/s2015_pbs_disney_bsdf_notes.pdf

http://graphics.ucsd.edu/~henrik/papers/bssrdf/

https://naml.us/paper/deon2011_subsurface.pdf

Challenge: multiple-scattering in dense media requires many bounces

these images usually require hundreds of bounces

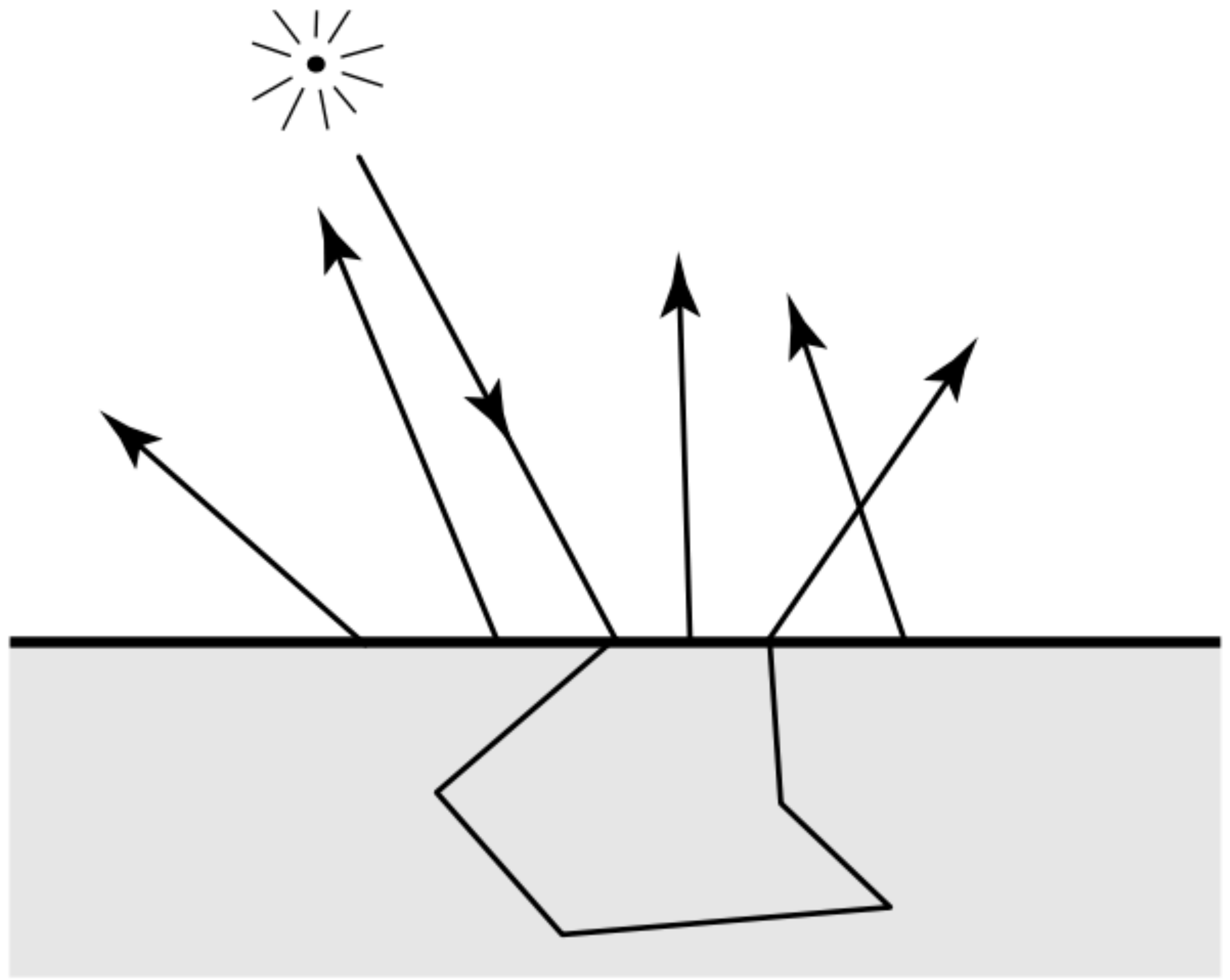


https://rgl.epfl.ch/publications/Jakob2010Radiative

https://cs.dartmouth.edu/~wjarosz/publications/bitterli18framework.html

https://www.cs.cornell.edu/projects/translucency/#acquisition-sa13

Trick: aggregate multiple scattering events using a "BSSRDF"



Bidirectional Subsurface Scattering
Reflectance Distribution Function

$$f(\omega, \omega')$$ BRDF / BSDF

$$f(p, \omega, p', \omega')$$ BSSRDF

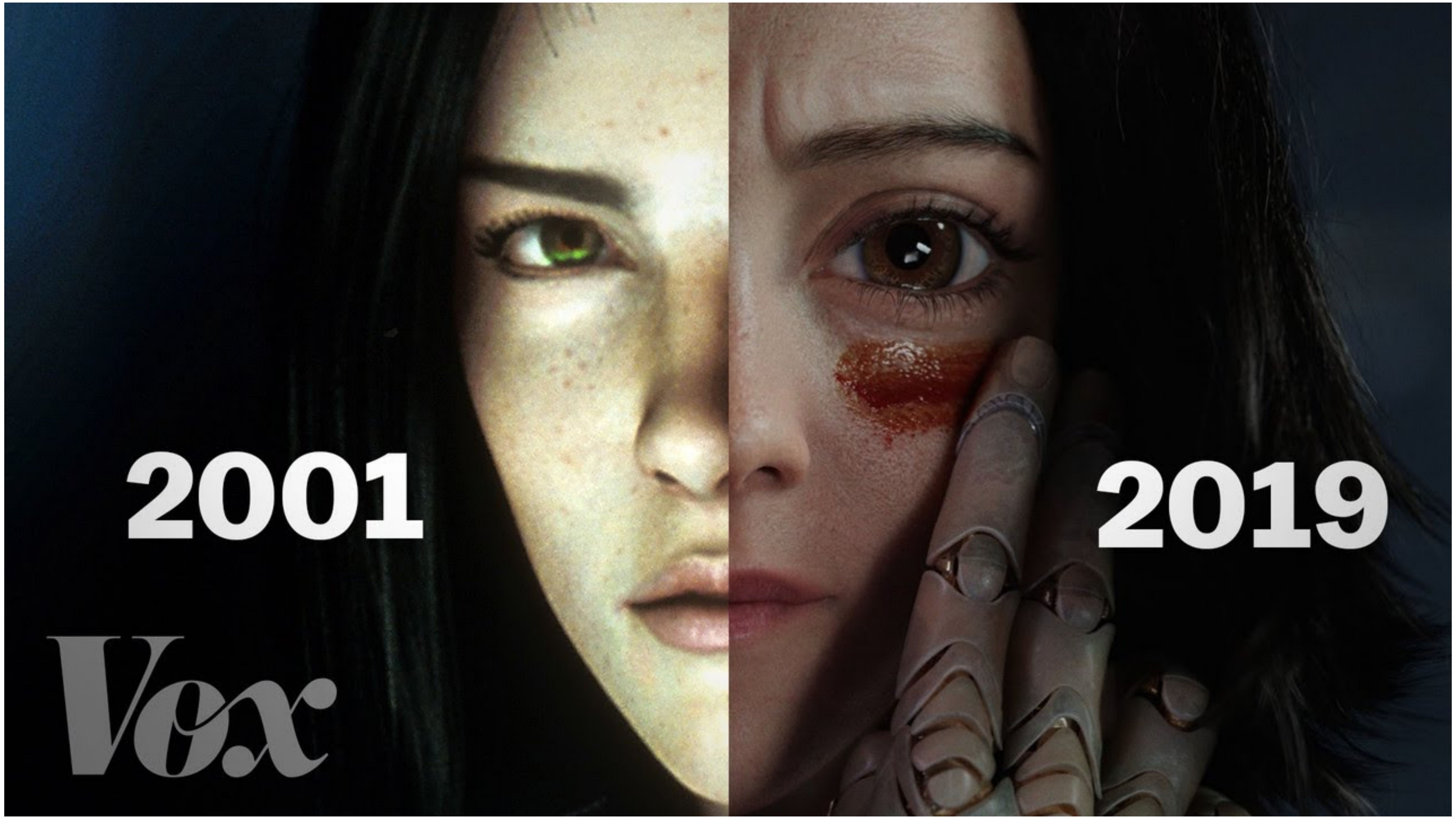
BRDF vs BSSRDF

BRDF

BSSRDF

http://graphics.ucsd.edu/~henrik/papers/bssrdf/bssrdf.pdf

Cool Vox video!



https://www.youtube.com/watch?v=NvFoKkWyZ5Y

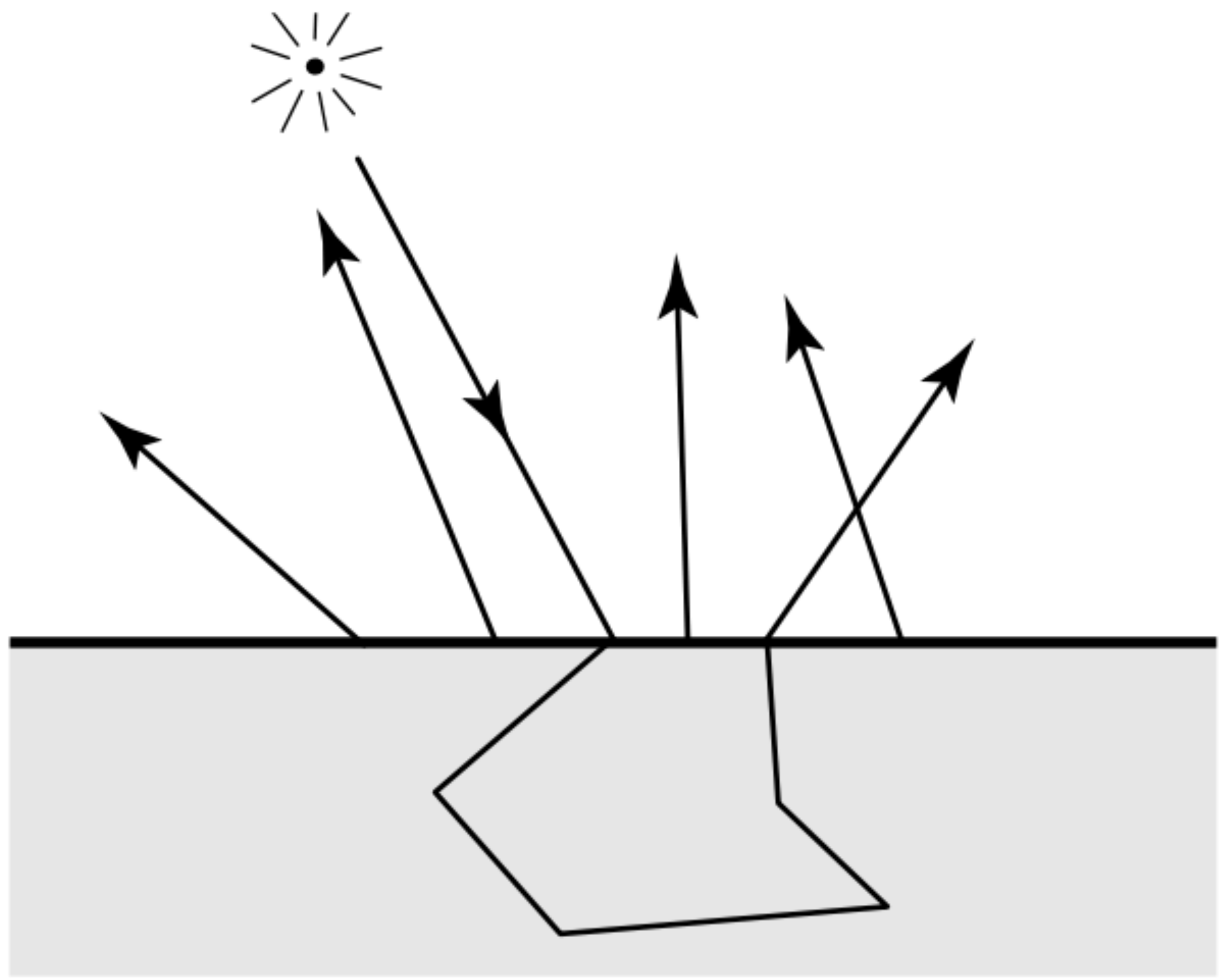
Goal: deriving BSSRDF from radiative transfer equation

$$\frac{\mathrm{d}}{\mathrm{d}t}L(\mathbf{p}(t),\omega) = -\sigma_t L(\mathbf{p}(t),\omega) + L_e(\mathbf{p}(t),\omega) + \sigma_s \int_{S^2} \rho(\omega,\omega')L(\mathbf{p}(t),\omega')\mathrm{d}\omega'$$

$$\Big\downarrow$$

$$f(p,\omega,p',\omega')$$

Simple BSSRDFs



$$f(p, \omega, p', \omega') = \big(1 - F(\omega)\big)\, R\left(\;\| p - p' \|\;\right) \big(1 - F(\omega')\big)$$

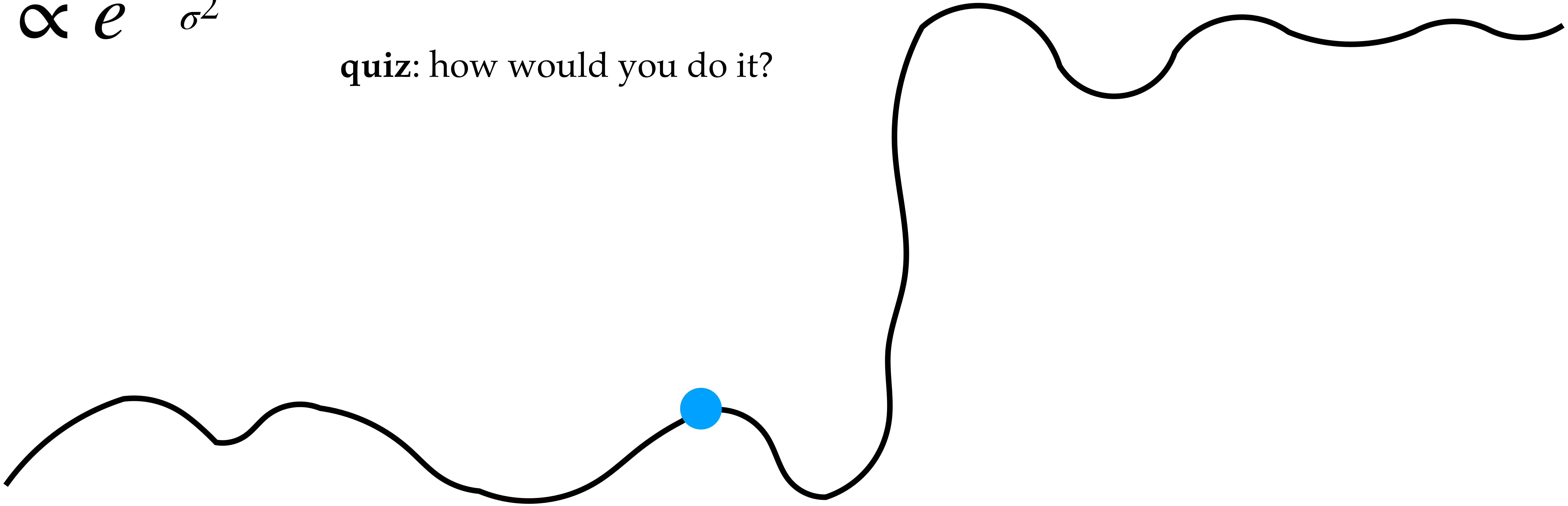
$$R(r) \propto e^{-\frac{r^2}{\sigma^2}}$$

R: "diffuse reflectance profile"

Sampling BSSRDFs

$$R(r) \propto e^{-\frac{r^2}{\sigma^2}}$$

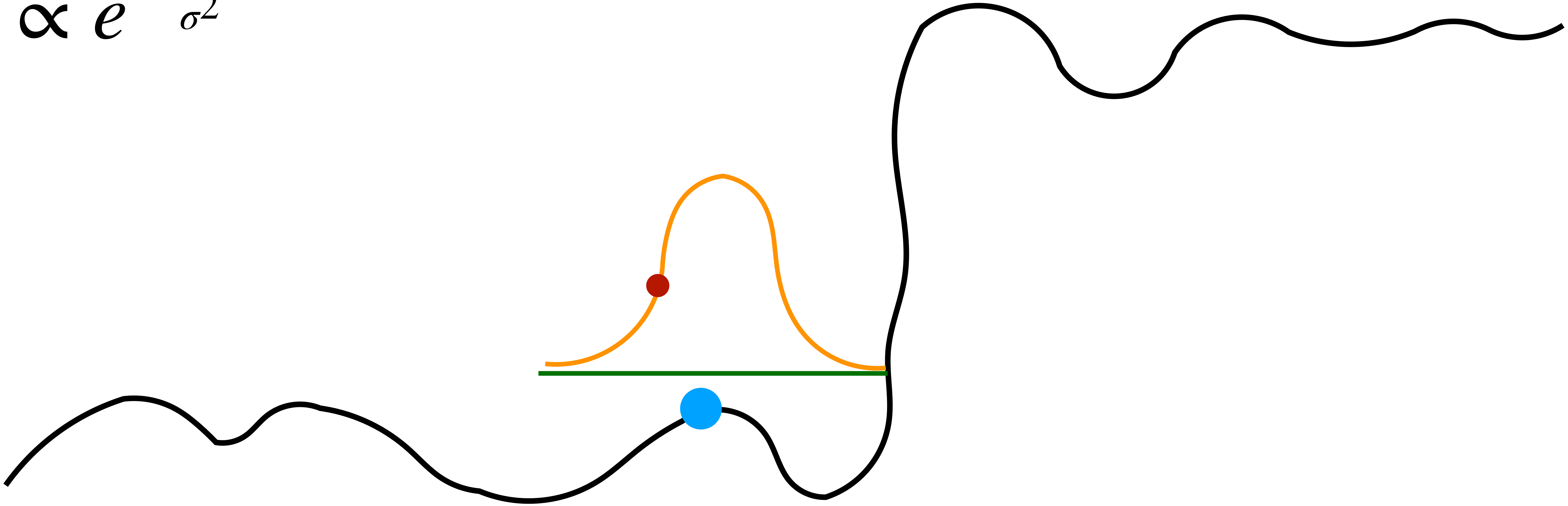
quiz: how would you do it?



Sampling BSSRDFs

1. sample on a disk using $R(r)$

$$R(r) \propto e^{-\frac{r^2}{\sigma^2}}$$



BSSRDF Importance Sampling

Alan King
Solid Angle

Christopher Kulla
Sony Pictures Imageworks

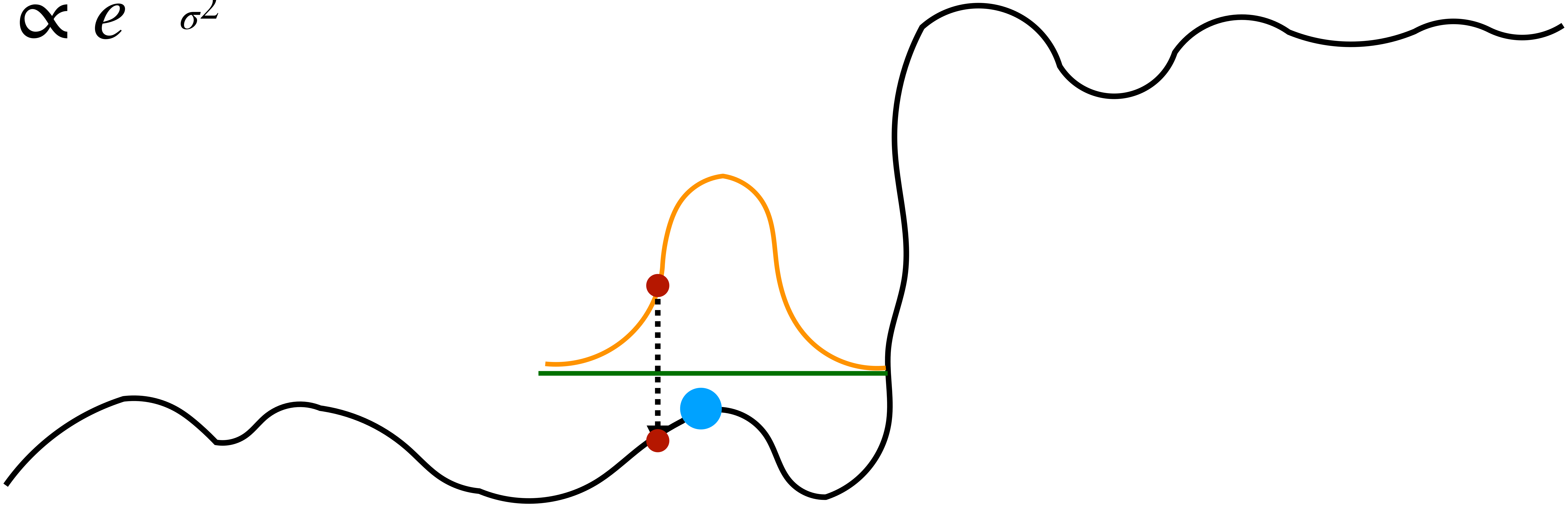
Alejandro Conty
Sony Pictures Imageworks

Marcos Fajardo
Solid Angle

Sampling BSSRDFs

1. sample on a disk using $R(r)$
2. project onto the surface

$$R(r) \propto e^{-\frac{r^2}{\sigma^2}}$$



BSSRDF Importance Sampling

Alan King
Solid Angle

Christopher Kulla
Sony Pictures Imageworks

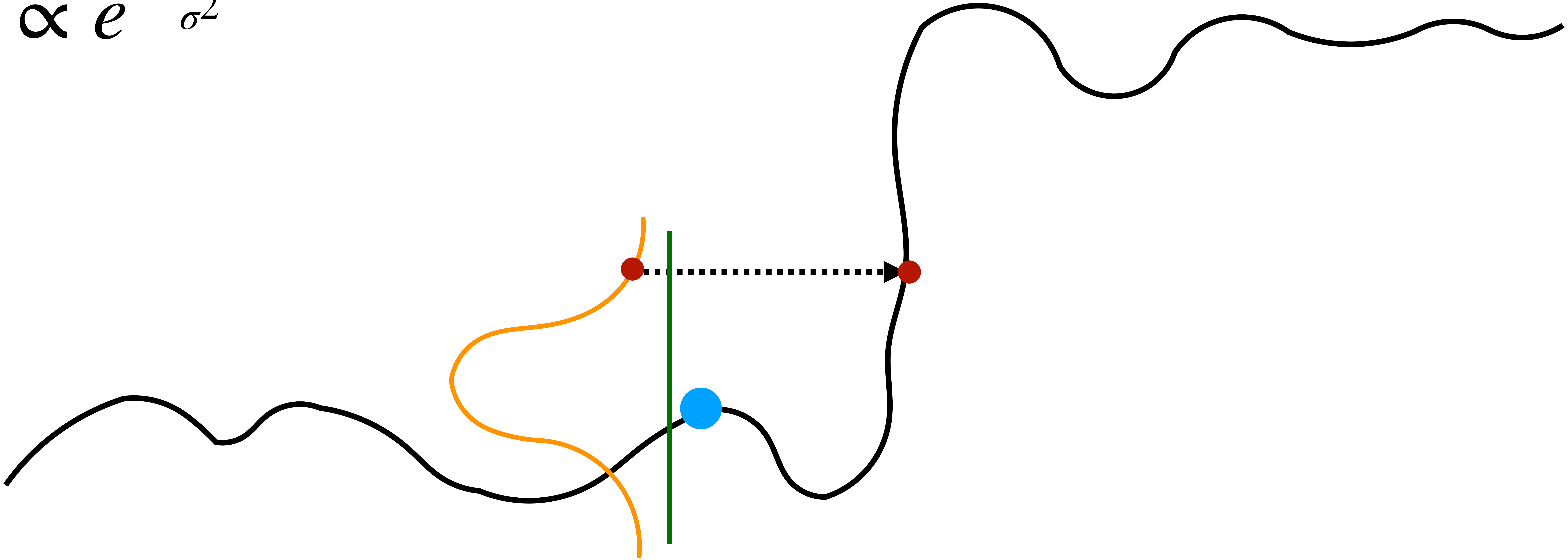
Alejandro Conty
Sony Pictures Imageworks

Marcos Fajardo
Solid Angle

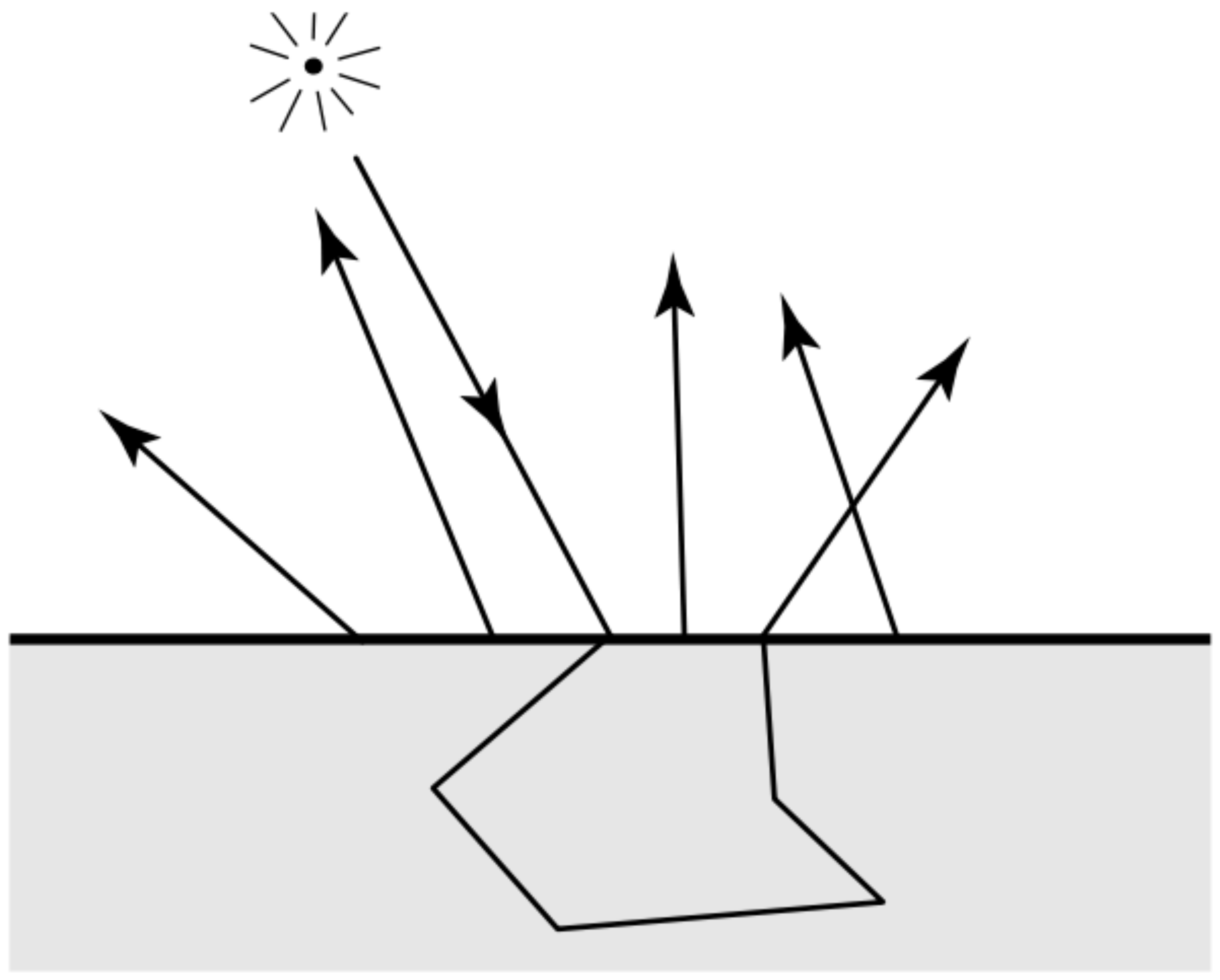
Sampling BSSRDFs

1. sample on a disk using $R(r)$
2. project onto the surface
3. repeat this for different axes, combine with MIS

$$R(r) \propto e^{-\frac{r^2}{\sigma^2}}$$



How do we know if simple BSSRDFs are sufficient?



$$f(p,\omega,p',\omega') = \left(1 - F(\omega)\right) R\left(\| p - p' \| \right) \left(1 - F(\omega')\right)$$

$$R(r) \propto e^{-\frac{r^2}{\sigma^2}}$$

R: “diffuse reflectance profile”

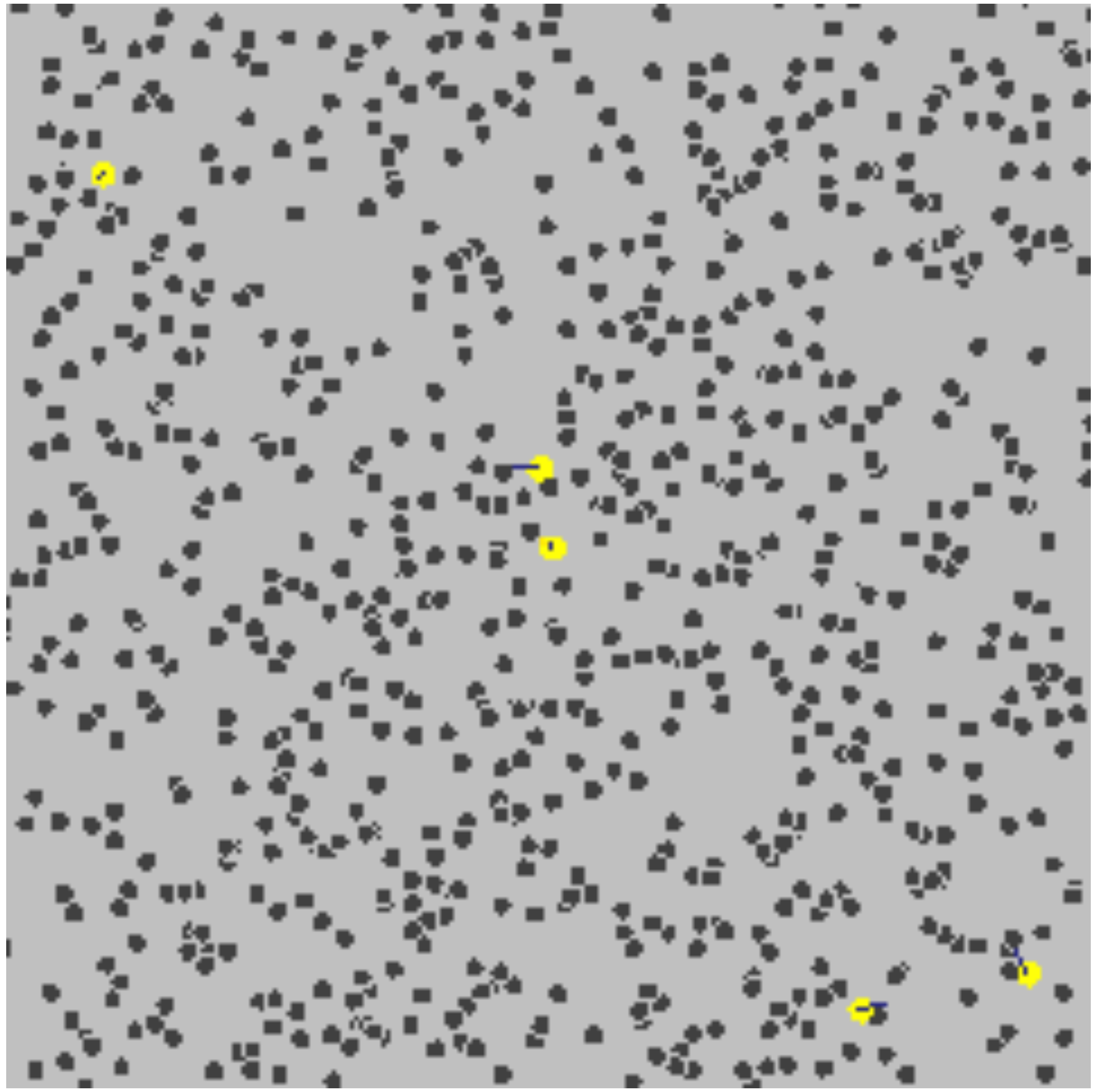
Goal: deriving BSSRDF from radiative transfer equation

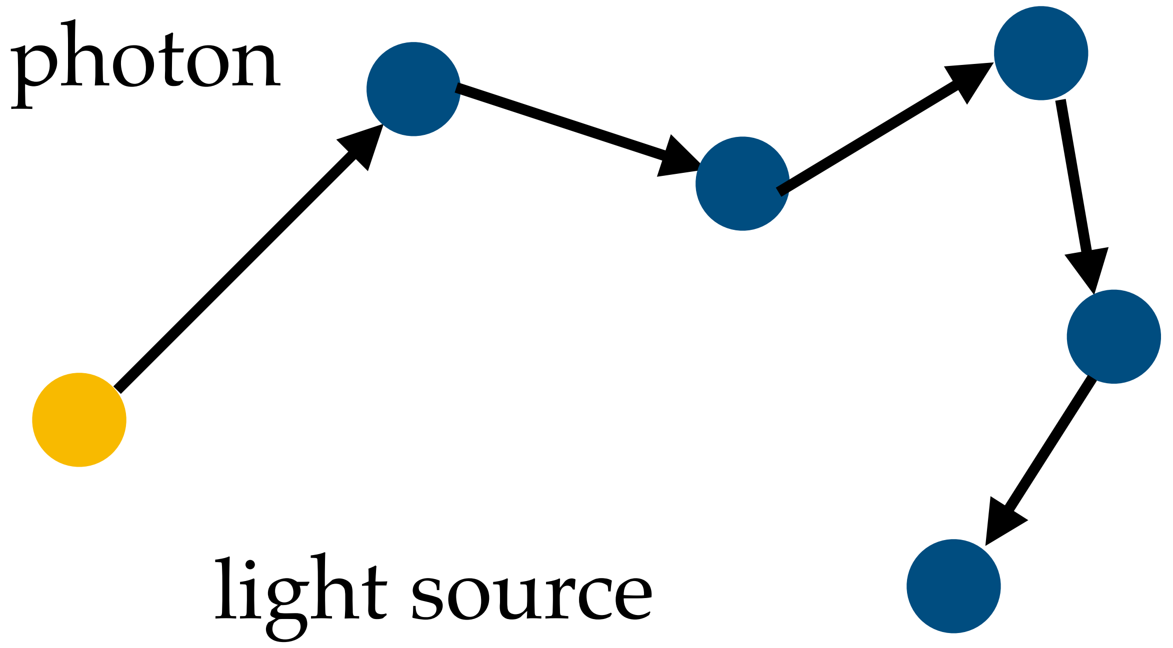
$$\frac{\mathrm{d}}{\mathrm{d}t}L(\mathbf{p}(t),\omega) = -\sigma_t L(\mathbf{p}(t),\omega) + L_e(\mathbf{p}(t),\omega) + \sigma_s \int_{S^2} \rho(\omega,\omega')L(\mathbf{p}(t),\omega')\mathrm{d}\omega'$$

$$\Big\downarrow$$

$$f(p,\omega,p',\omega')$$

Intuition: volumetric path tracing looks like Brownian motion

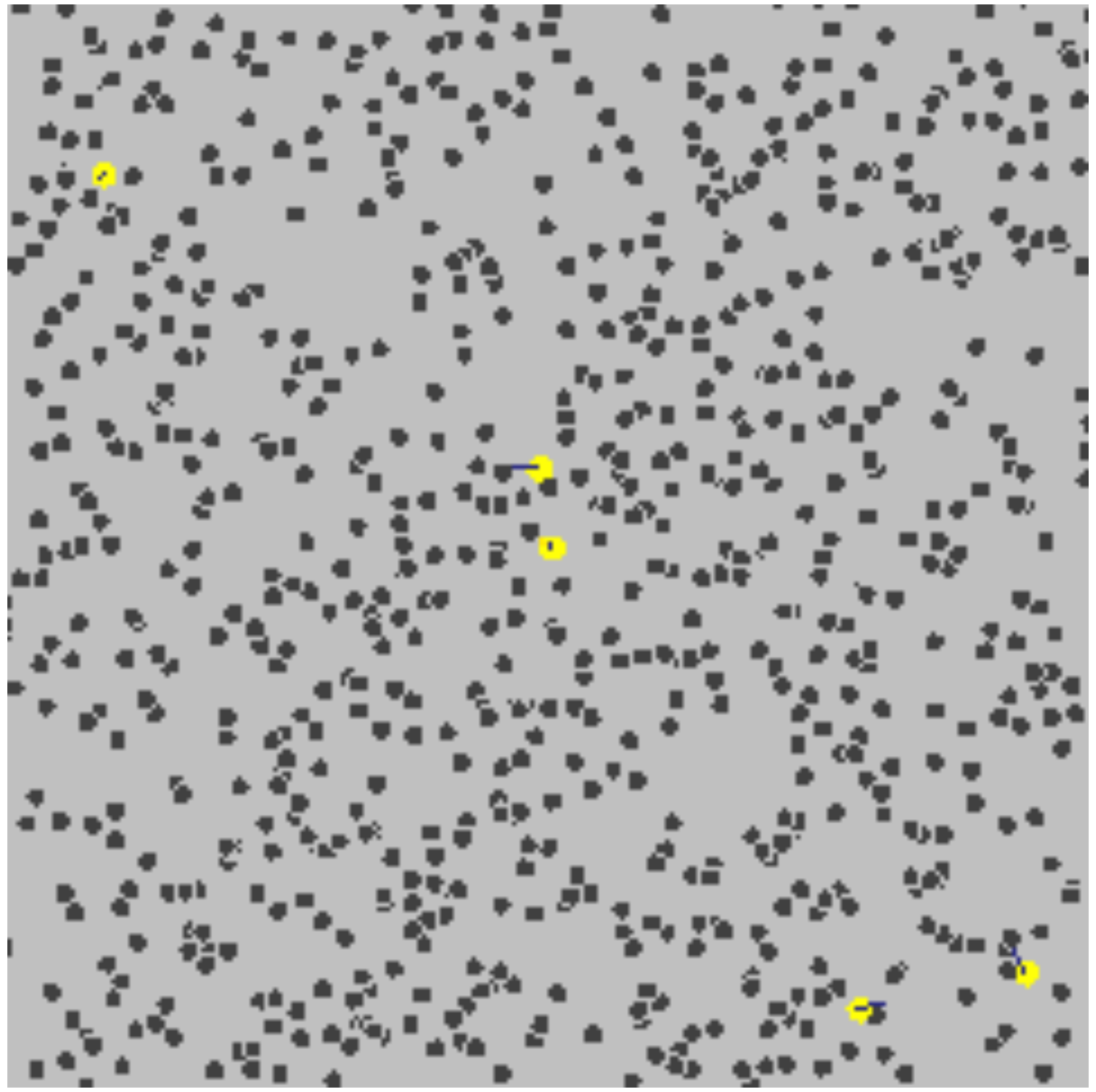


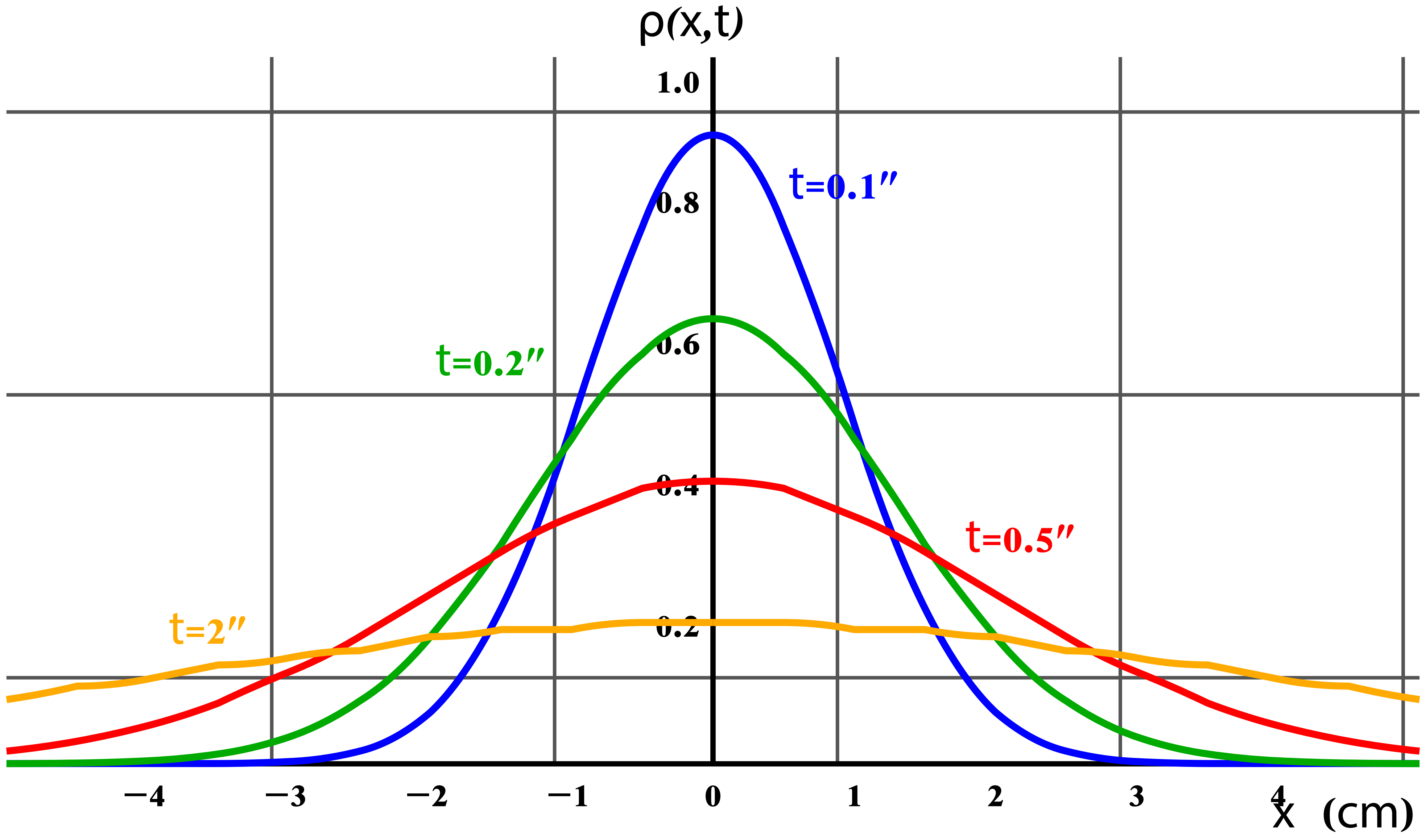


https://en.wikipedia.org/wiki/Brownian_motion

Physics: expectation of Brownian motions is a solution to a PDE

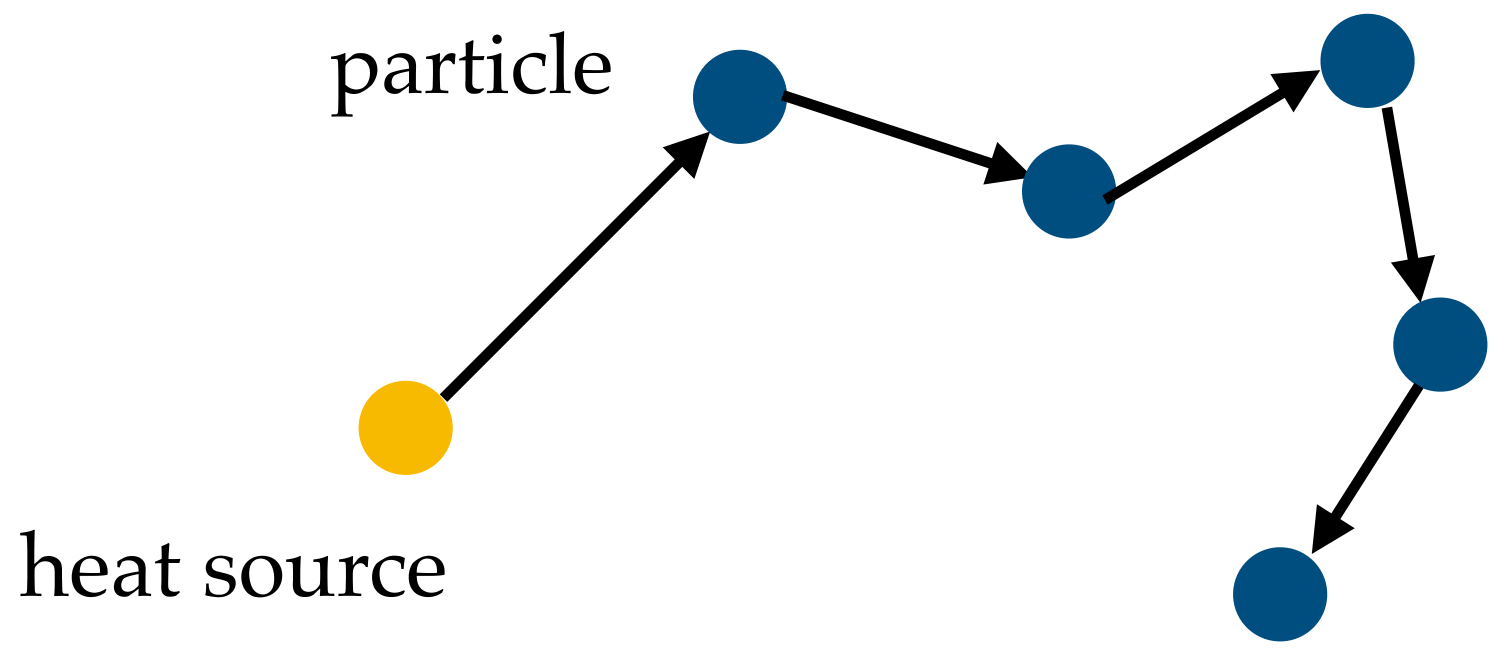
- c.f. Fick, Einstein, Feynman-Kac formula





https://en.wikipedia.org/wiki/Brownian_motion

Heat equation

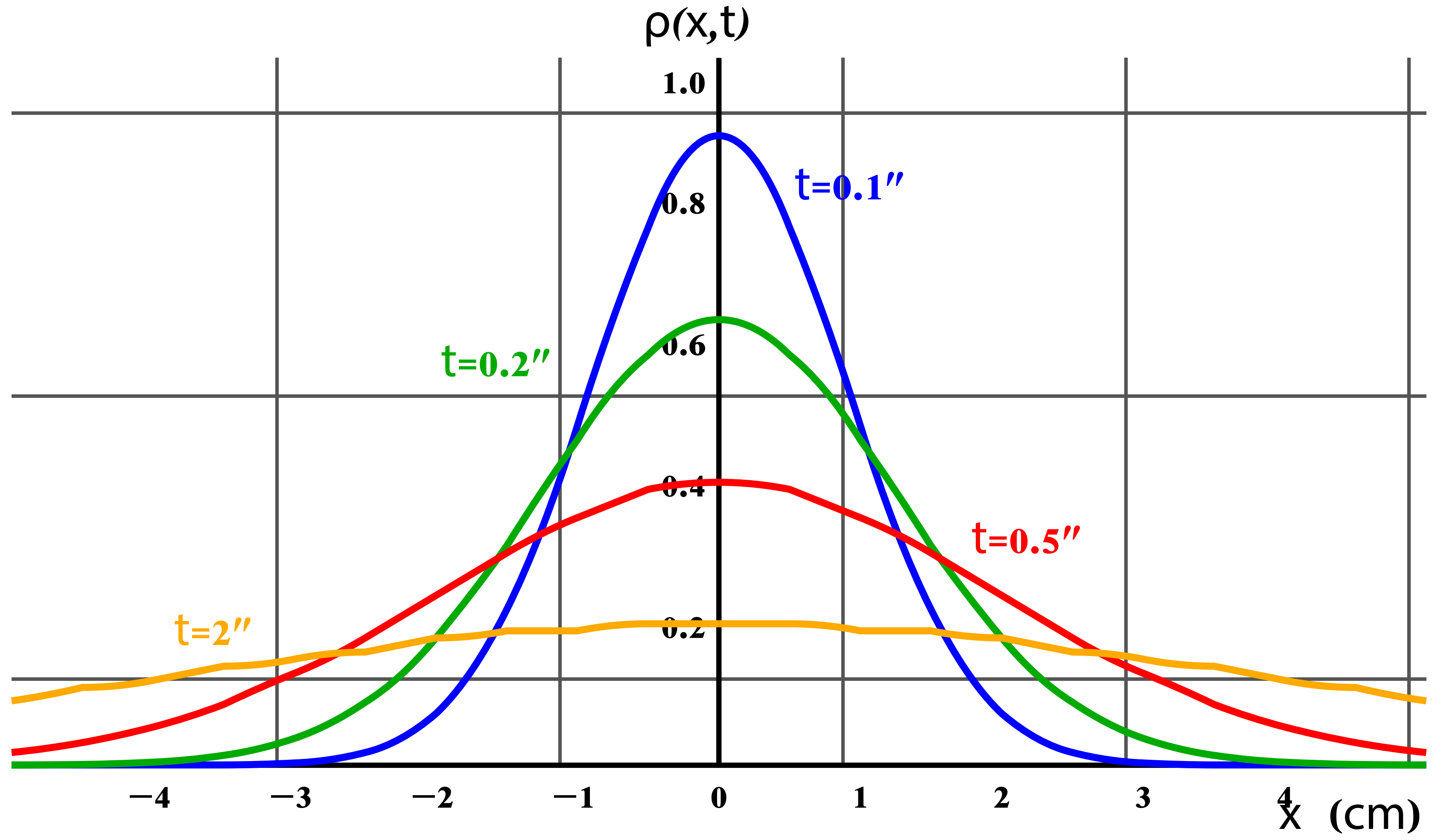


$$\frac{\partial u}{\partial \tau} = \left(\frac{\partial^2 u}{\partial x^2} + \frac{\partial^2 u}{\partial y^2} + \frac{\partial^2 u}{\partial z^2}\right) + Q(x, y, z)$$

time derivative

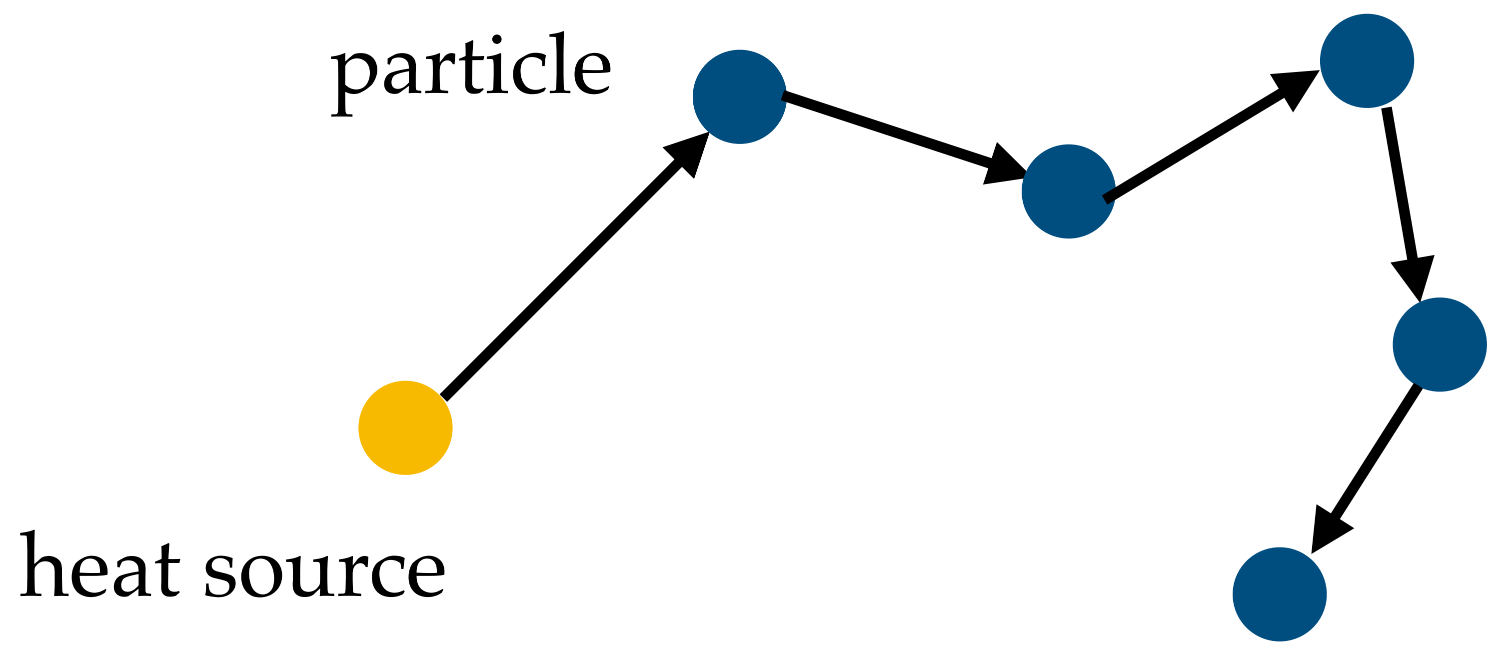
spatial diffusion

heat source



Equilibrium of heat equation: Poisson equation

Poisson equation is also the equilibrium of a electric field assuming no magnetic field



$$\frac{\partial u}{\partial \tau} = \left(\frac{\partial^2 u}{\partial x^2} + \frac{\partial^2 u}{\partial y^2} + \frac{\partial^2 u}{\partial z^2}\right) + Q(x, y, z)$$

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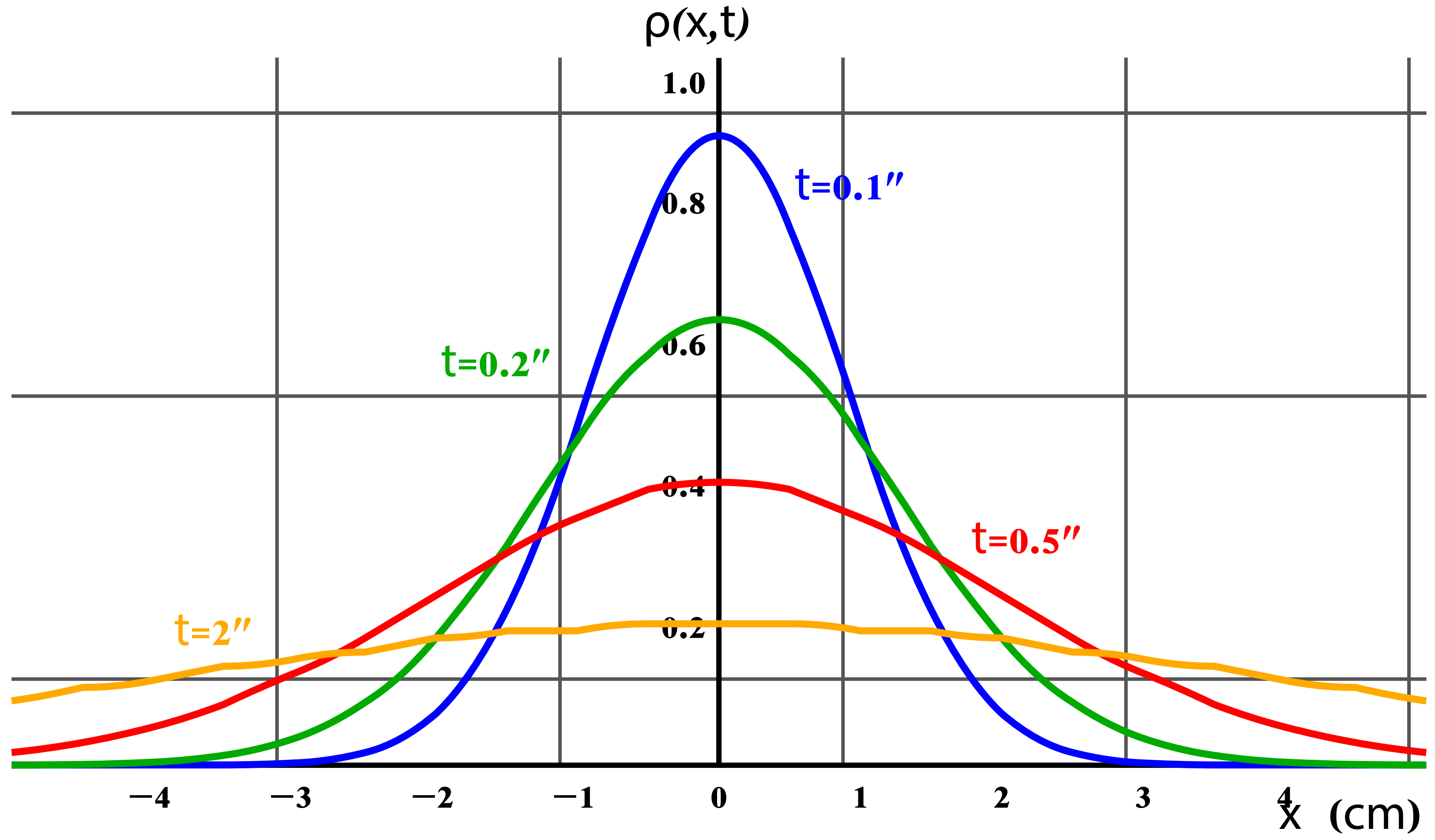

$$0 = \left(\frac{\partial^2 u}{\partial x^2} + \frac{\partial^2 u}{\partial y^2} + \frac{\partial^2 u}{\partial z^2}\right) + Q(x, y, z)$$

$$= \Delta u + Q$$

Poisson equation

What is the connection between radiative transfer equation & Poisson equation?

$$\frac{\mathrm{d}}{\mathrm{d}t}L(\mathbf{p}(t),\omega) = -\sigma_t L(\mathbf{p}(t),\omega) + L_e(\mathbf{p}(t),\omega) + \sigma_s \int_{S^2} \rho(\omega,\omega')L(\mathbf{p}(t),\omega')\mathrm{d}\omega'$$

v.s.

$$\Delta u + Q = 0$$

Assumption 1: isotropic phase function

$$\frac{\mathrm{d}}{\mathrm{d}t}L(\mathbf{p}(t),\omega) = -\sigma_t L(\mathbf{p}(t),\omega) + L_e(\mathbf{p}(t),\omega) + \sigma_s \int_{S^2} \rho(\omega,\omega') L(\mathbf{p}(t),\omega')\mathrm{d}\omega'$$

$$\Big\downarrow$$

$$\frac{\mathrm{d}}{\mathrm{d}t}L(\mathbf{p}(t),\omega) = -\sigma_t L(\mathbf{p}(t),\omega) + L_e(\mathbf{p}(t),\omega) + \frac{\sigma_s}{4\pi} \int_{S^2} L(\mathbf{p}(t),\omega')\mathrm{d}\omega'$$

Assumption 2:
first-order spherical moment expansion on L

$$L(\mathbf{p},\omega) \approx \frac{1}{4\pi}\int_{S^2} L(\mathbf{p},\omega')\mathrm{d}\omega' + \frac{3}{4\pi}\omega \cdot \int_{S^2} \omega' L(\mathbf{p},\omega')\mathrm{d}\omega'$$

zero-th order
moment
(total mass)

first order
moment
(center of mass)

$$= \frac{1}{4\pi}\phi(\mathbf{p}) + \frac{3}{4\pi}\omega \cdot \mathbf{E}(\mathbf{p})$$

$$\frac{\mathrm{d}}{\mathrm{d}t}L(\mathbf{p}(t),\omega) = -\sigma_t L(\mathbf{p}(t),\omega) + L_e(\mathbf{p}(t),\omega) + \frac{\sigma_s}{4\pi}\int_{S^2} L(\mathbf{p}(t),\omega')\mathrm{d}\omega'$$

Assumption 3:
matching spherical moments of RTE

plug in $L(\mathbf{p}, \omega) \approx \frac{1}{4\pi}\phi(\mathbf{p}) + \frac{3}{4\pi}\omega \cdot \mathbf{E}(\mathbf{p})$

take 0-th order moment   take 0-th order moment

$$\boxed{\frac{\mathrm{d}}{\mathrm{d}t}L(\mathbf{p}(t), \omega)} = \boxed{-\sigma_t L(\mathbf{p}(t), \omega) + L_e(\mathbf{p}(t), \omega) + \frac{\sigma_s}{4\pi}\int_{S^2} L(\mathbf{p}(t), \omega')\mathrm{d}\omega'}$$

plug in $L(\mathbf{p}, \omega) \approx \frac{1}{4\pi}\phi(\mathbf{p}) + \frac{3}{4\pi}\omega \cdot \mathbf{E}(\mathbf{p})$

take 1st order moment   take 1st order moment

$$\boxed{\frac{\mathrm{d}}{\mathrm{d}t}L(\mathbf{p}(t), \omega)} = \boxed{-\sigma_t L(\mathbf{p}(t), \omega) + L_e(\mathbf{p}(t), \omega) + \frac{\sigma_s}{4\pi}\int_{S^2} L(\mathbf{p}(t), \omega')\mathrm{d}\omega'}$$

Diffusion approximation through moment matching

plug in $L(\mathbf{p}, \omega) \approx \frac{1}{4\pi}\phi(\mathbf{p}) + \frac{3}{4\pi}\omega \cdot \mathbf{E}(\mathbf{p})$

take 0-th order moment　　　take 0-th order moment

$$\boxed{\frac{\mathrm{d}}{\mathrm{d}t}L(\mathbf{p}(t), \omega)} = \boxed{-\sigma_t L(\mathbf{p}(t), \omega) + L_e(\mathbf{p}(t), \omega) + \frac{\sigma_s}{4\pi}\int_{S^2} L(\mathbf{p}(t), \omega')\mathrm{d}\omega'}$$

$$\downarrow$$

$$\nabla \cdot \mathbf{E}(\mathbf{p}) = -\sigma_a \phi(\mathbf{p}) + Q_0(\mathbf{p})$$

$$Q_0(\mathbf{p}) = \int L_e(\mathbf{p}, \omega')\mathrm{d}\omega'$$

See Sec. 5.1 of the tech report for the full derivation
https://rgl.epfl.ch/publications/Jakob2010Radiative

Diffusion approximation through moment matching

plug in $L(\mathbf{p}, \omega) \approx \frac{1}{4\pi}\phi(\mathbf{p}) + \frac{3}{4\pi}\omega \cdot \mathbf{E}(\mathbf{p})$

take 1st order moment

take 1st order moment

$$\boxed{\frac{\mathrm{d}}{\mathrm{d}t}L(\mathbf{p}(t), \omega)} = \boxed{-\sigma_t L(\mathbf{p}(t), \omega) + L_e(\mathbf{p}(t), \omega) + \frac{\sigma_s}{4\pi}\int_{S^2} L(\mathbf{p}(t), \omega')\mathrm{d}\omega'}$$

$$\downarrow$$

$$\frac{1}{3}\nabla\phi(\mathbf{p}) = -\sigma_t \mathbf{E}(\mathbf{p}) + Q_1(\mathbf{p})$$

$$Q_1(\mathbf{p}) = \int \omega' \cdot L_e(\mathbf{p}, \omega')\mathrm{d}\omega'$$

See Sec. 5.1 of the tech report for the full derivation
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Diffusion approximation through moment matching

$$\nabla \cdot \mathbf{E}(\mathbf{p}) = -\sigma_a \phi(\mathbf{p}) + Q_0(\mathbf{p})$$

$$\frac{1}{3} \nabla \phi(\mathbf{p}) = -\sigma_t \mathbf{E}(\mathbf{p}) + Q_1(\mathbf{p})$$

$$Q_0(\mathbf{p}) = \int L_e(\mathbf{p}, \omega') \mathrm{d}\omega' \qquad Q_1(\mathbf{p}) = \int \omega' \cdot L_e(\mathbf{p}, \omega') \mathrm{d}\omega' \qquad L(\mathbf{p}, \omega) \approx \frac{1}{4\pi} \int_{S^2} L(\mathbf{p}, \omega') \mathrm{d}\omega' + \frac{3}{4\pi} \omega \cdot \int_{S^2} \omega' L(\mathbf{p}, \omega') \mathrm{d}\omega' = \frac{1}{4\pi} \phi(\mathbf{p}) + \frac{3}{4\pi} \omega \cdot \mathbf{E}(\mathbf{p})$$

Diffusion approximation through moment matching

$$\nabla \cdot \mathbf{E}(\mathbf{p}) = -\sigma_a \phi(\mathbf{p}) + Q_0(\mathbf{p})$$

$$\frac{1}{3} \nabla \phi(\mathbf{p}) = -\sigma_t \mathbf{E}(\mathbf{p}) + Q_1(\mathbf{p})$$

solve for ϕ

$$\frac{1}{3\sigma_t} \Delta \phi(\mathbf{p}) = \sigma_a \phi(\mathbf{p}) - Q_0(\mathbf{p}) + \frac{1}{\sigma_t} \nabla \cdot Q_1(\mathbf{p})$$

$$Q_0(\mathbf{p}) = \int L_e(\mathbf{p}, \omega') \mathrm{d}\omega' \qquad Q_1(\mathbf{p}) = \int \omega' \cdot L_e(\mathbf{p}, \omega') \mathrm{d}\omega' \qquad L(\mathbf{p}, \omega) \approx \frac{1}{4\pi} \int_{S^2} L(\mathbf{p}, \omega') \mathrm{d}\omega' + \frac{3}{4\pi} \omega \cdot \int_{S^2} \omega' L(\mathbf{p}, \omega') \mathrm{d}\omega' = \frac{1}{4\pi} \phi(\mathbf{p}) + \frac{3}{4\pi} \omega \cdot \mathbf{E}(\mathbf{p})$$

Diffusion approximation through moment matching

$$\nabla \cdot \mathbf{E}(\mathbf{p}) = -\sigma_a \phi(\mathbf{p}) + Q_0(\mathbf{p})$$

$$\frac{1}{3} \nabla \phi(\mathbf{p}) = -\sigma_t \mathbf{E}(\mathbf{p}) + Q_1(\mathbf{p})$$

solve for ϕ

$$\boxed{\frac{1}{3\sigma_t} \Delta \phi(\mathbf{p}) = \sigma_a \phi(\mathbf{p}) - Q_0(\mathbf{p}) + \frac{1}{\sigma_t} \nabla \cdot Q_1(\mathbf{p})}$$

$\mathbf{E}$ can be computed from ϕ and Q

$$L(\mathbf{p}, \omega) \approx \frac{1}{4\pi} \int_{S^2} L(\mathbf{p}, \omega') \mathrm{d}\omega' + \frac{3}{4\pi} \omega \cdot \int_{S^2} \omega' L(\mathbf{p}, \omega') \mathrm{d}\omega' = \frac{1}{4\pi} \phi(\mathbf{p}) + \frac{3}{4\pi} \omega \cdot \mathbf{E}(\mathbf{p})$$

What is the connection between radiative transfer equation & Poisson equation?

$$\frac{\mathrm{d}}{\mathrm{d}t}L(\mathbf{p}(t),\omega) = -\sigma_t L(\mathbf{p}(t),\omega) + L_e(\mathbf{p}(t),\omega) + \sigma_s \int_{S^2} \rho(\omega,\omega')L(\mathbf{p}(t),\omega')\mathrm{d}\omega'$$

v.s.

$$\Delta u + Q = 0$$

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$$\frac{1}{3\sigma_t}\Delta\phi(\mathbf{p}) = \sigma_a\phi(\mathbf{p}) - Q_0(\mathbf{p}) + \frac{1}{\sigma_t}\nabla \cdot Q_1(\mathbf{p})$$

v.s.

$$\Delta u + Q = 0$$

What is the connection between radiative transfer equation & Poisson equation?

$$\frac{1}{3\sigma_t}\Delta\phi(\mathbf{p}) = \boxed{\sigma_a\phi(\mathbf{p})} - Q_0(\mathbf{p}) + \frac{1}{\sigma_t}\nabla\cdot Q_1(\mathbf{p})$$

energy loss due to absorption

v.s.

$$\Delta u + Q = 0$$

aka "screened Poisson equation" or
Yukawa equation
https://en.wikipedia.org/wiki/Screened_Poisson_equation

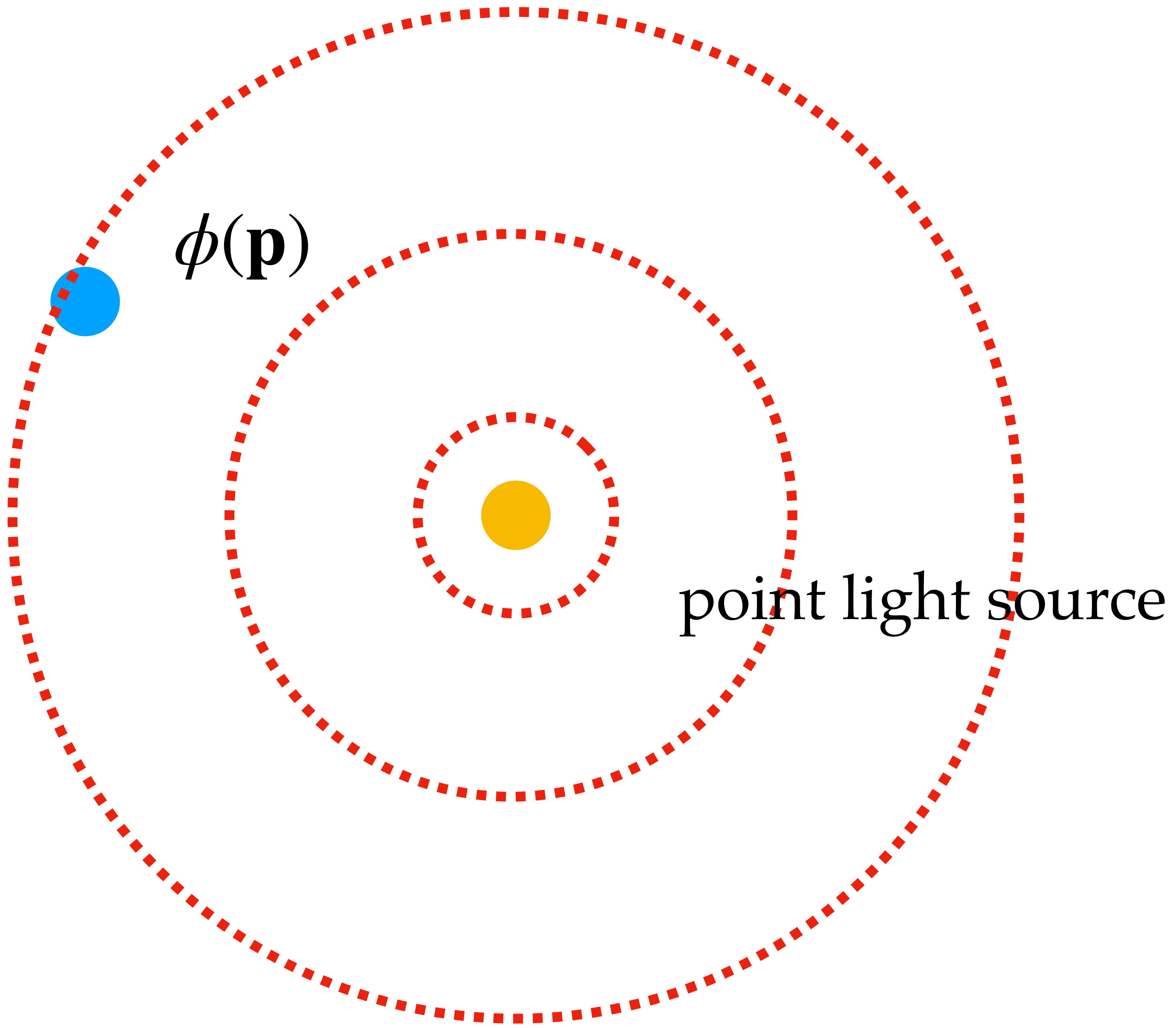
Solving for ϕ in diffusion approximation

- ϕ depends on the choice of Q & boundary condition
- goal: setup Q & boundary conditions so that we have efficient solutions

$$\frac{1}{3\sigma_t}\Delta\phi(\mathbf{p}) = \sigma_a\phi(\mathbf{p}) - Q_0(\mathbf{p}) + \frac{1}{\sigma_t}\nabla\cdot Q_1(\mathbf{p})$$

Monopole solution: a single point light source without boundary

$$\frac{1}{3\sigma_t}\Delta\phi(\mathbf{p}) = \sigma_a\phi(\mathbf{p}) - Q_0(\mathbf{p}) + \frac{1}{\sigma_t}\nabla\cdot Q_1(\mathbf{p})$$



$$Q_0 = \delta(\mathbf{p})$$

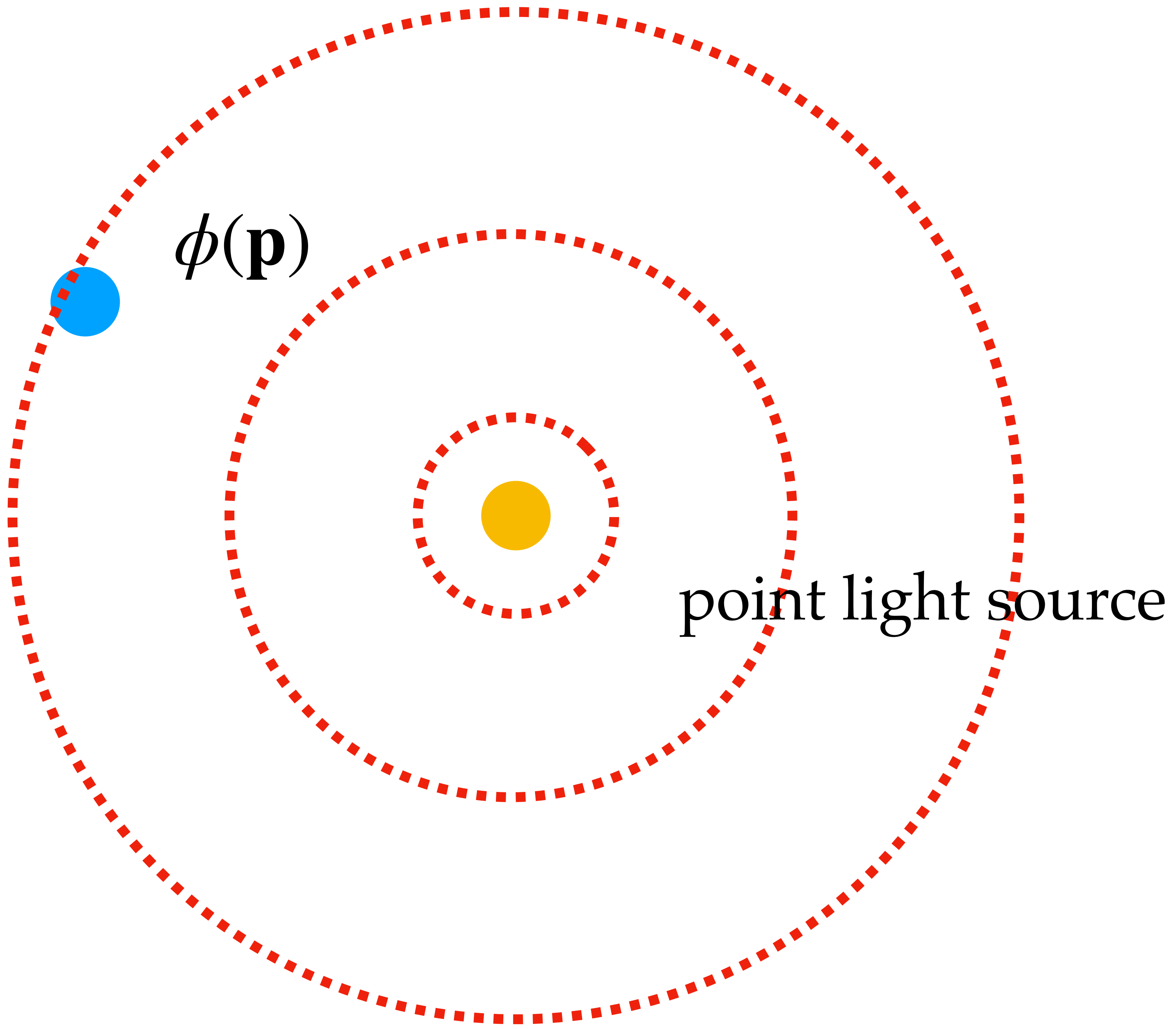
$$Q_1 = 0$$

Monopole solution: a single point light source without boundary

$$\frac{1}{3\sigma_t}\Delta\phi(\mathbf{p}) = \sigma_a\phi(\mathbf{p}) - Q_0(\mathbf{p}) + \frac{1}{\sigma_t}\nabla\cdot Q_1(\mathbf{p})$$

$$\phi_m(\mathbf{p}) = \frac{3\sigma_t}{4\pi}\frac{e^{-\sqrt{3\sigma_a\sigma_t}\|\mathbf{p}\|}}{\|\mathbf{p}\|}$$

"Green's function"



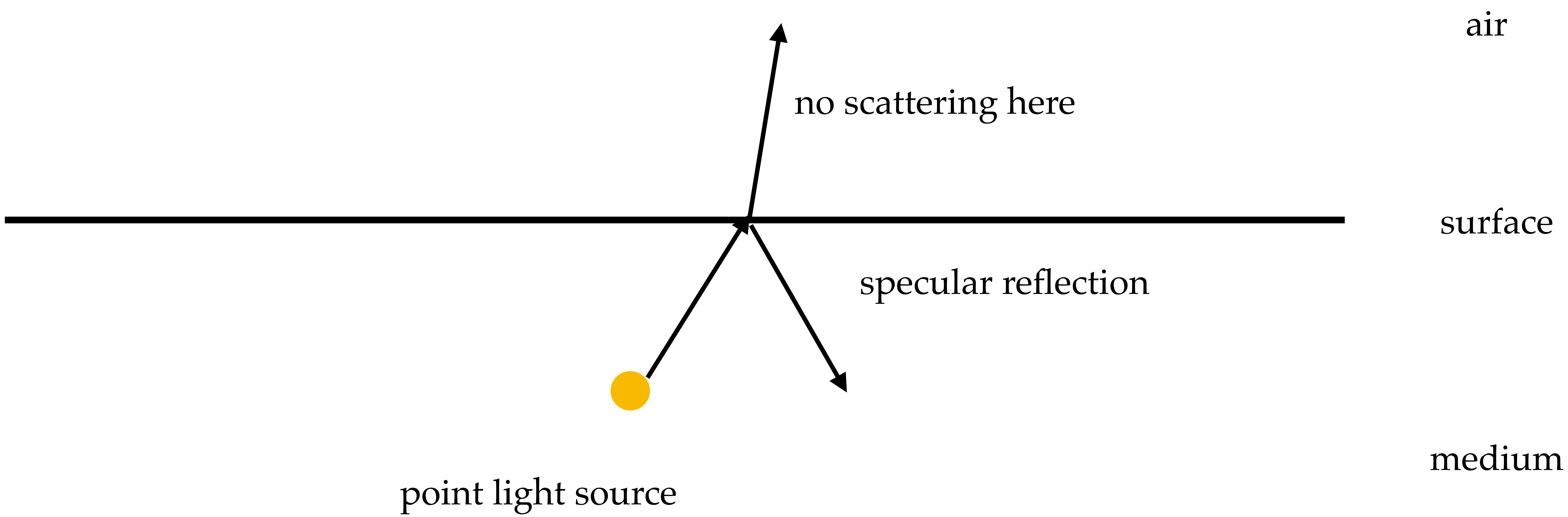
$$Q_0 = \delta(\mathbf{p})$$

$$Q_1 = 0$$

https://en.wikipedia.org/wiki/Green%27s_function

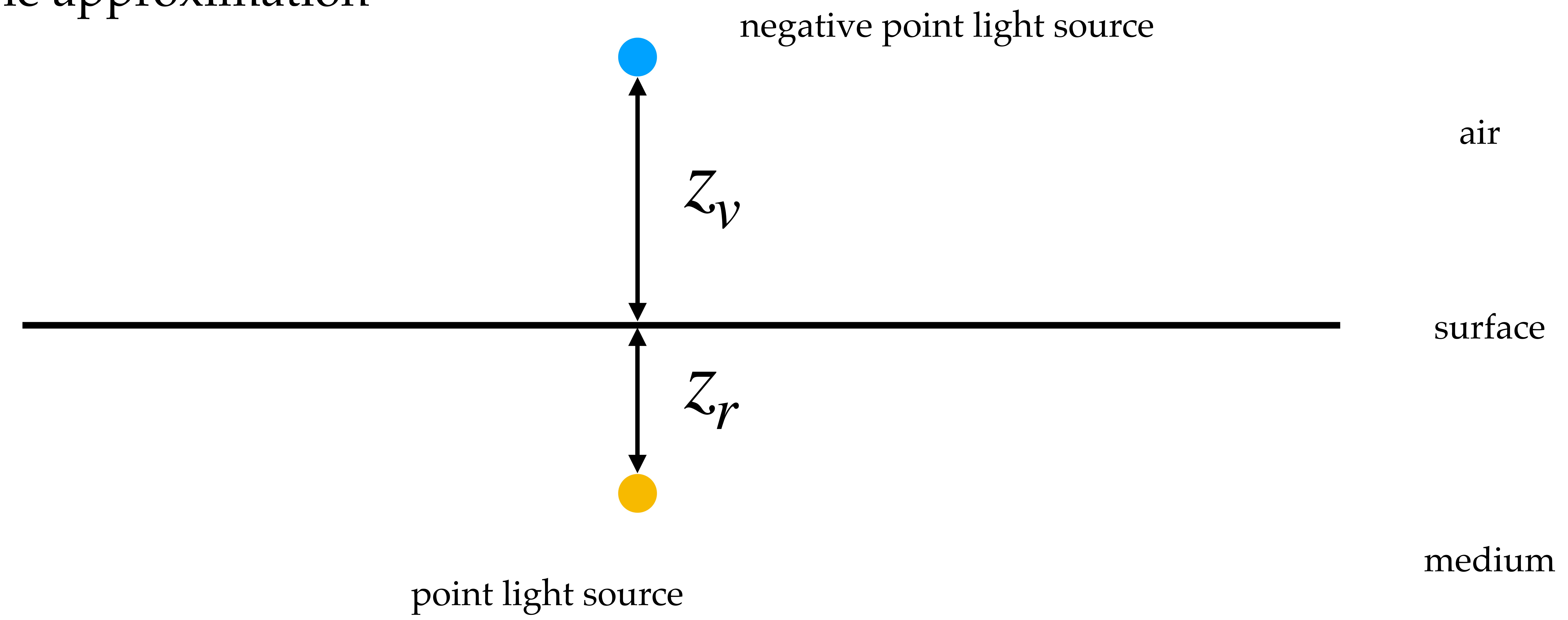
https://www.youtube.com/watch?v=ism2SfZgFJg (super cool video about Green's function)

Monopole fails to account for the boundary



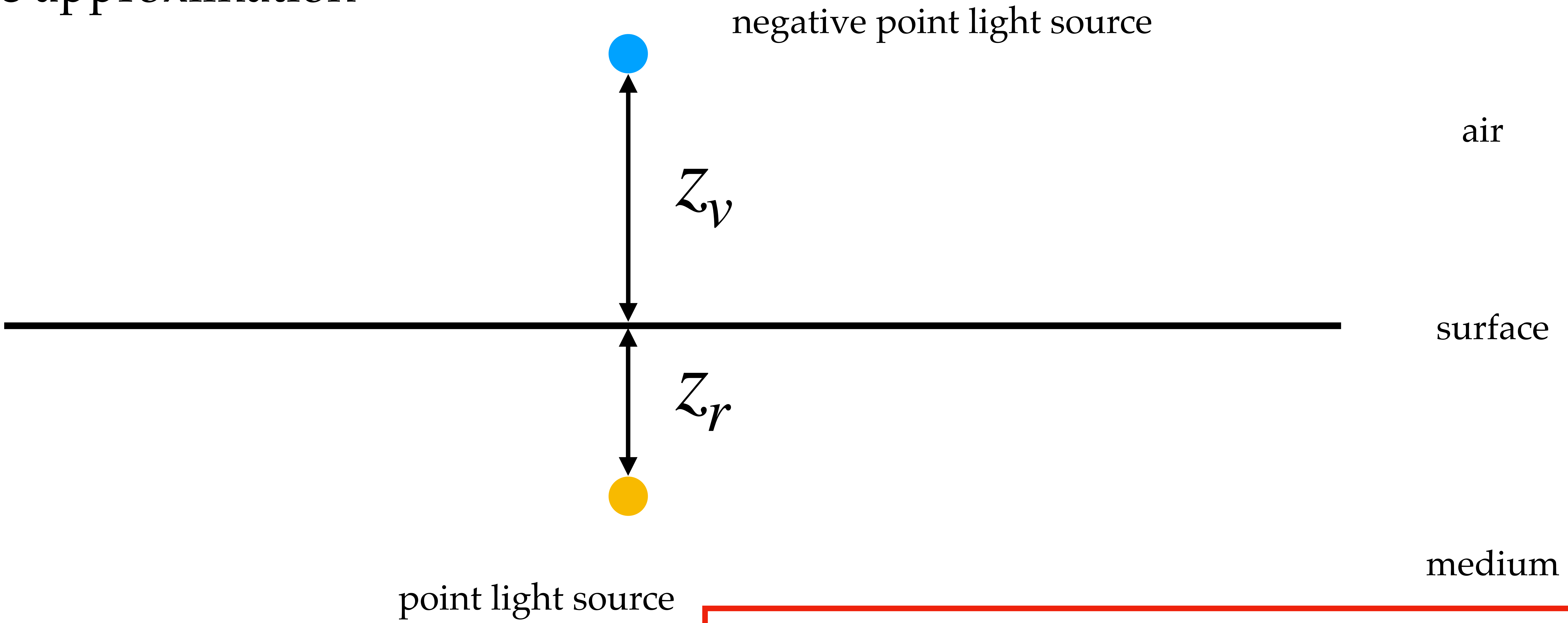
Idea: put a **negative** light source to cancel out contribution

- "dipole approximation"



Idea: put a **negative** light source to cancel out contribution

- "dipole approximation"

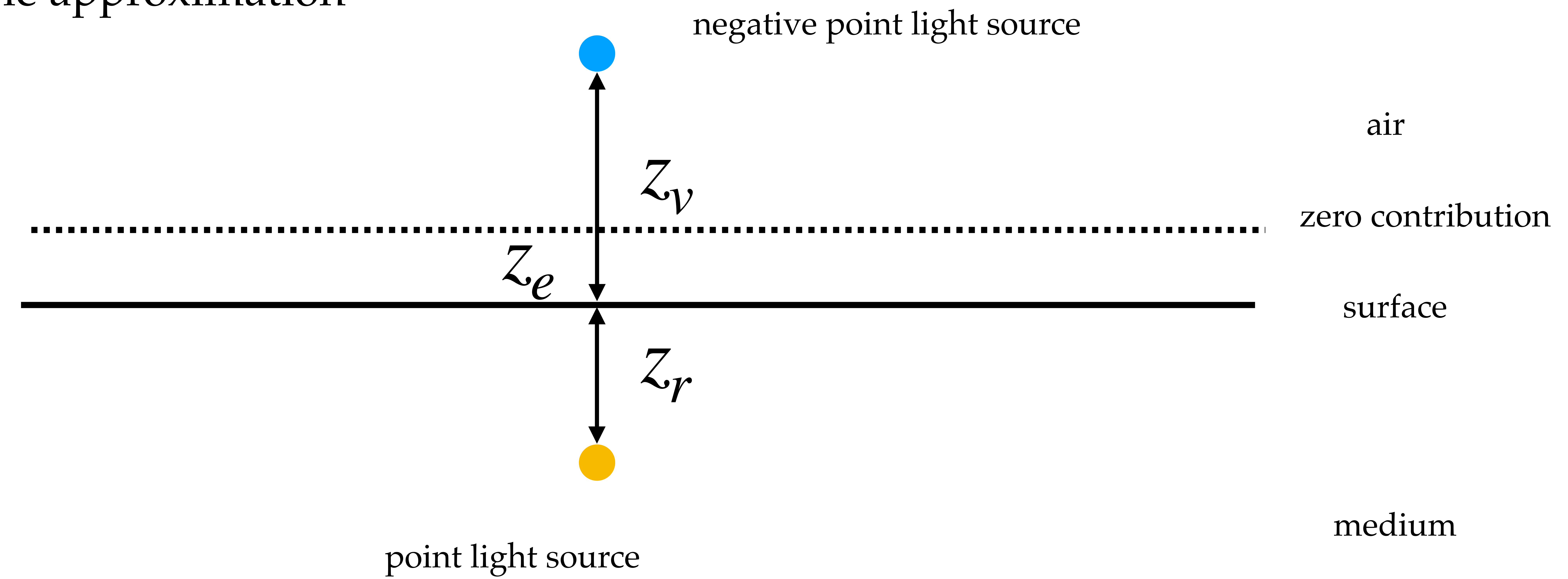


$$\boxed{\phi_d(\mathbf{p}) = \frac{3\sigma_t}{4\pi}\frac{e^{-\sqrt{3\sigma_a\sigma_t}\|\mathbf{p}-\mathbf{p}_r\|}}{\|\mathbf{p}-\mathbf{p}_r\|} - \frac{3\sigma_t}{4\pi}\frac{e^{-\sqrt{3\sigma_a\sigma_t}\|\mathbf{p}-\mathbf{p}_v\|}}{\|\mathbf{p}-\mathbf{p}_v\|}}$$

Choose z_v to cancel out contribution at z_e

read pbrt for how z_e is chosen

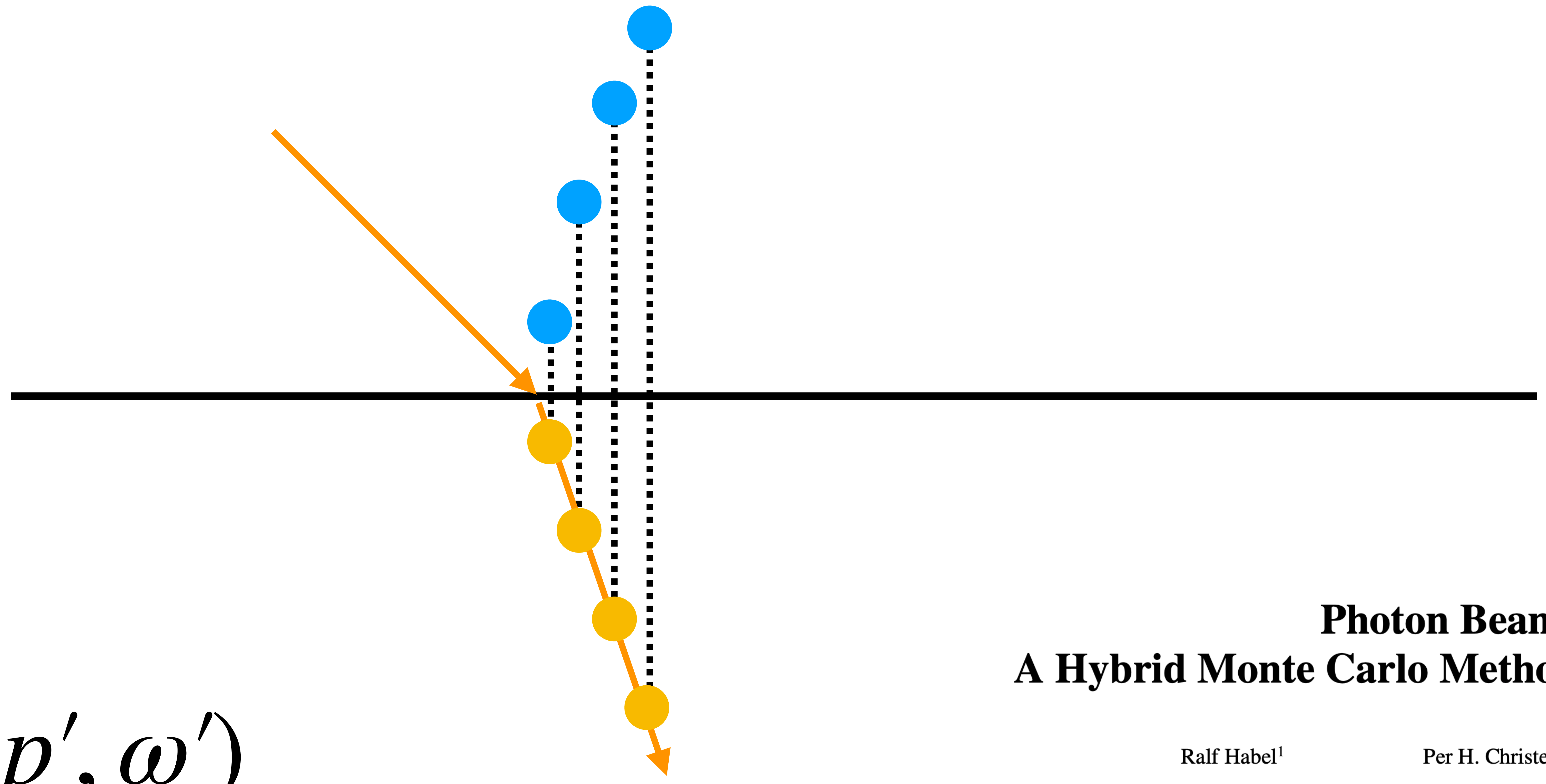
- "dipole approximation"



$$\phi_d(\mathbf{p}) = \frac{3\sigma_t}{4\pi}\frac{e^{-\sqrt{3\sigma_a\sigma_t}\|\mathbf{p}-\mathbf{p}_r\|}}{\|\mathbf{p}-\mathbf{p}_r\|} - \frac{3\sigma_t}{4\pi}\frac{e^{-\sqrt{3\sigma_a\sigma_t}\|\mathbf{p}-\mathbf{p}_v\|}}{\|\mathbf{p}-\mathbf{p}_v\|}$$

Using dipole solutions for BSSRDF

- place point “light sources” along the incoming ray (using reciprocity of light transport)



$$f(p, \omega, p', \omega')$$

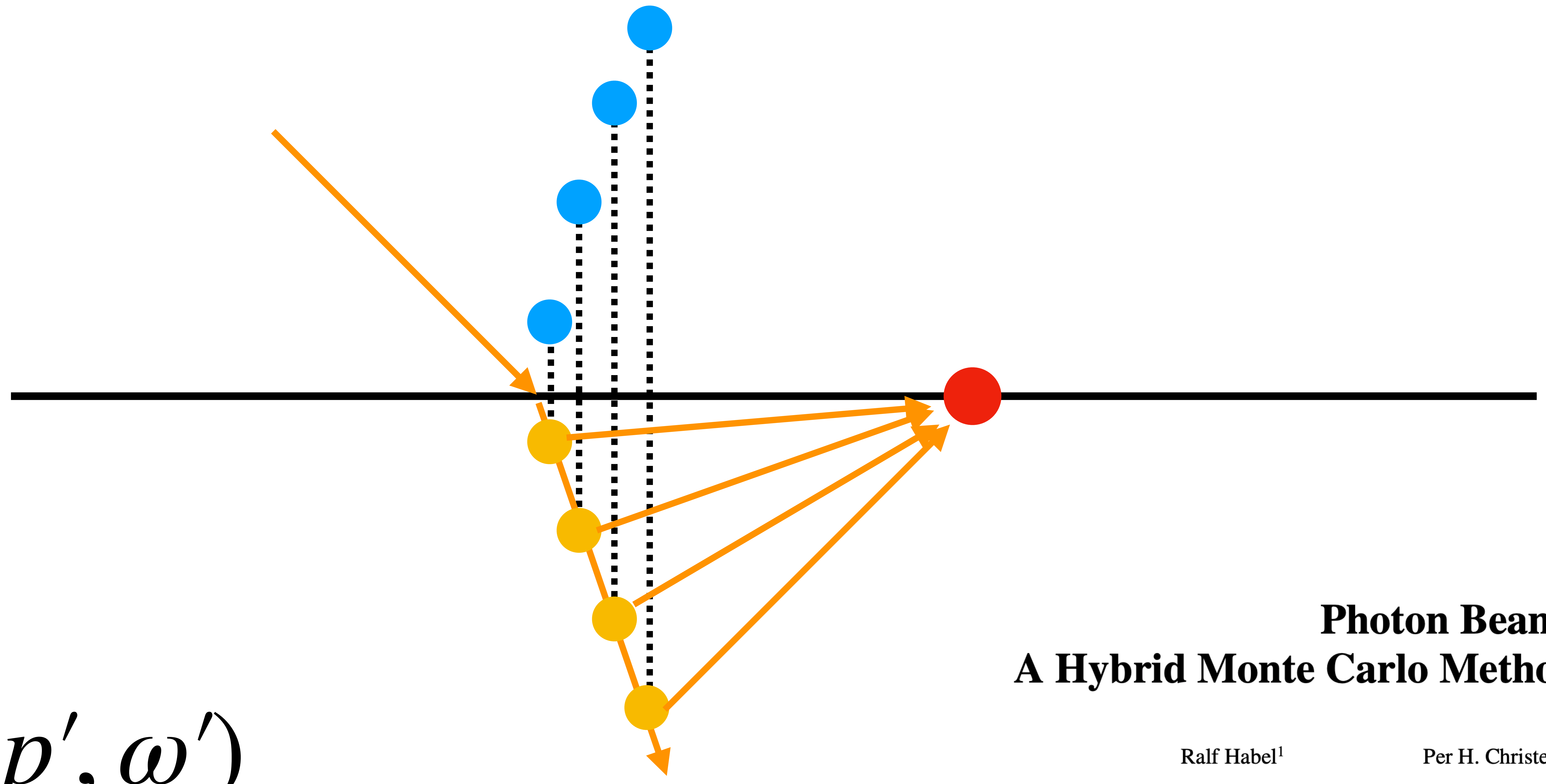
Photon Beam Diffusion:
A Hybrid Monte Carlo Method for Subsurface Scattering

Ralf Habel[1] Per H. Christensen[2] Wojciech Jarosz[1]

[1]Disney Research Zürich [2]Pixar Animation Studios

Using dipole solutions for BSSRDF

- place point “light sources” along the incoming ray (using reciprocity of light transport)
  - BSSRDF is defined as the sum of dipoles to all of them (multiply with Fresnel)



$$f(p, \omega, p', \omega')$$

Photon Beam Diffusion:
A Hybrid Monte Carlo Method for Subsurface Scattering

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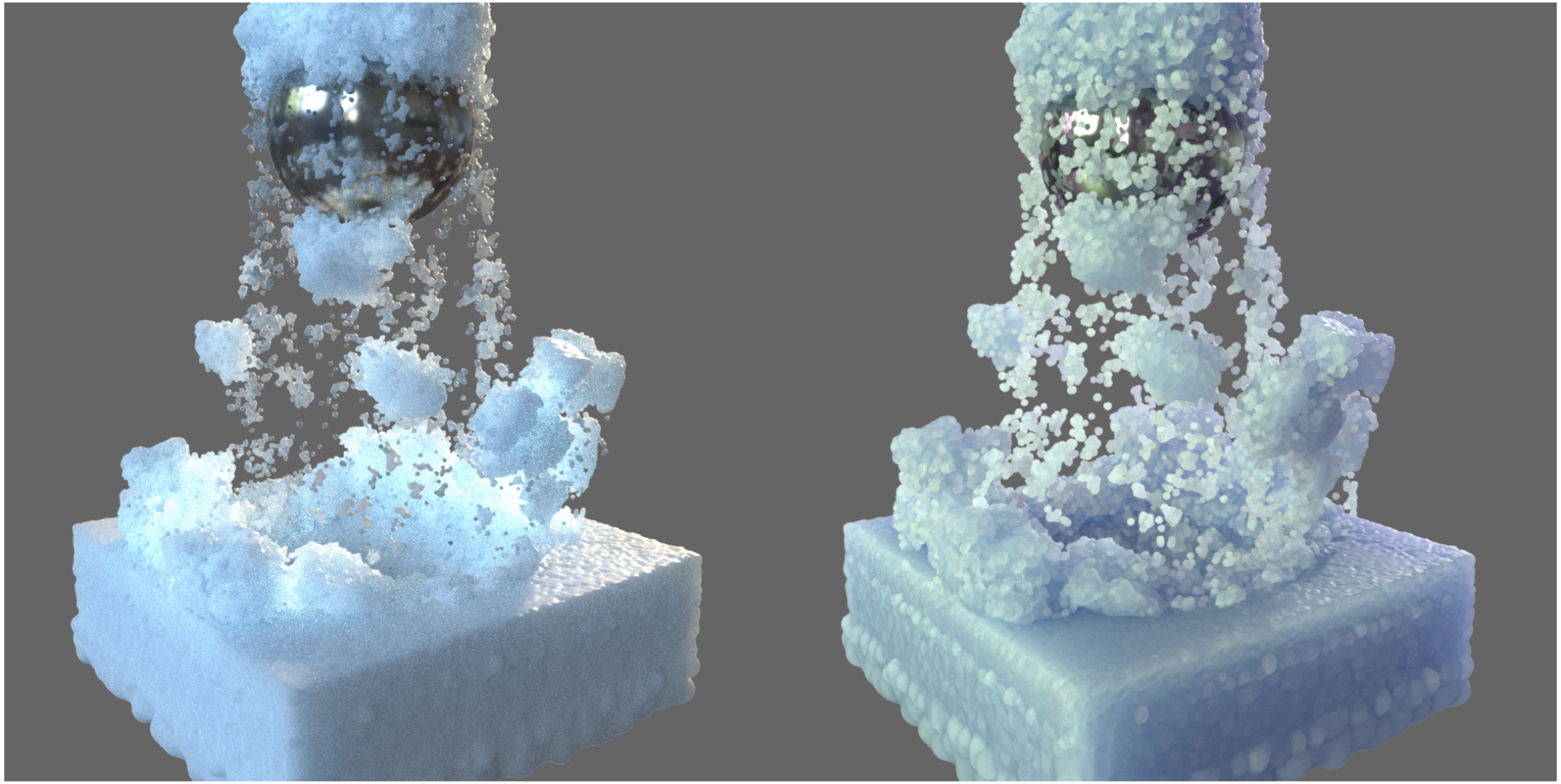
Dipole vs volumetric path tracing

dipole (photon beam diffusion)

path tracing

https://cs.dartmouth.edu/~wjarosz/publications/habel13pbd.html

Dipole vs volumetric path tracing



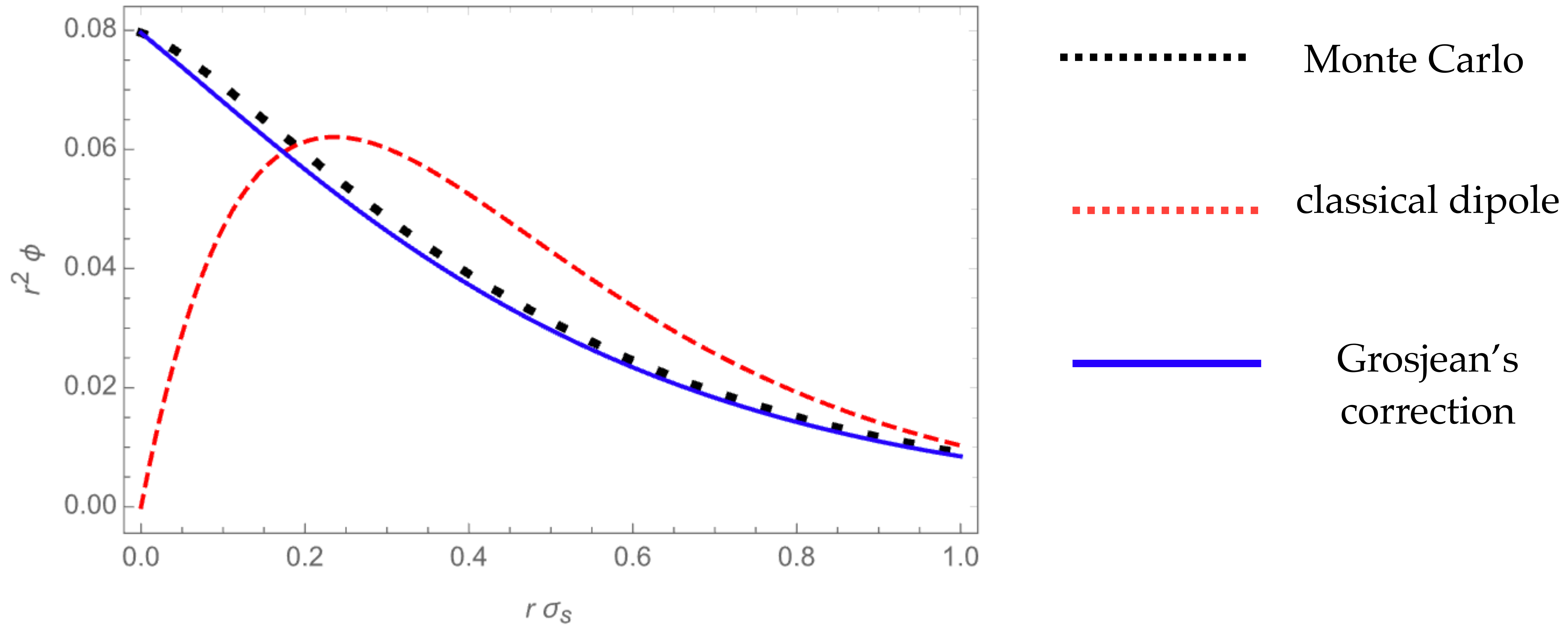
dipole   path tracing

"Hacks" to improve dipoles

$$\phi_m(\mathbf{p}) = \frac{3\sigma_t}{4\pi} \frac{e^{-\sqrt{3\sigma_a\sigma_t}\|\mathbf{p}\|}}{\|\mathbf{p}\|}$$

$$\phi_g(\mathbf{p}) = \frac{e^{-\sigma_t\|p\|}}{4\pi\|p\|^2} - \phi_m(\mathbf{p})$$

Grosjean's correction [1956]



https://www.pbr-book.org/3ed-2018/Light_Transport_II_Volume_Rendering/Subsurface_Scattering_Using_the_Diffusion_Equation#Non-classicalDiffusion

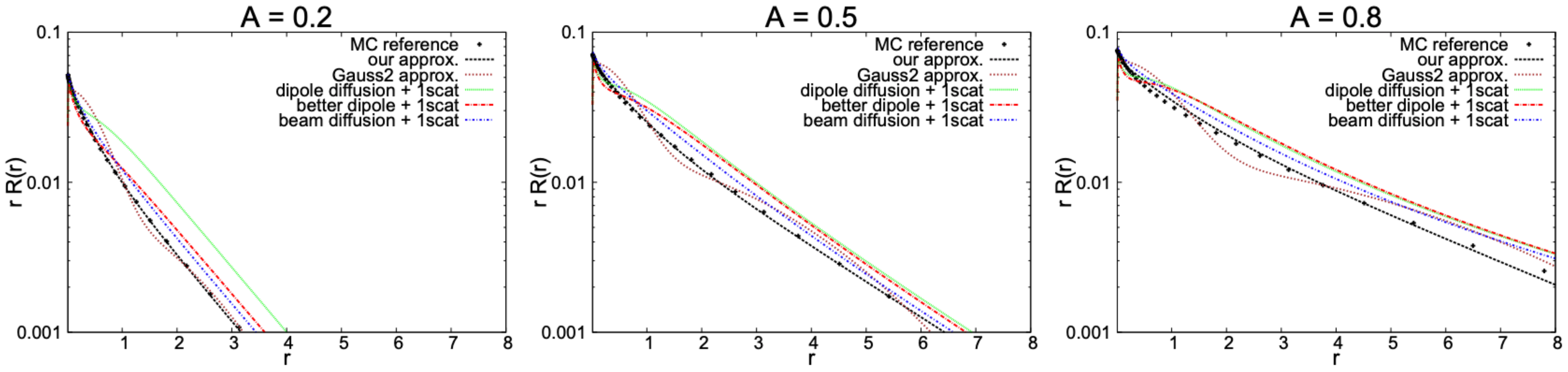
“Hacks” to improve dipoles

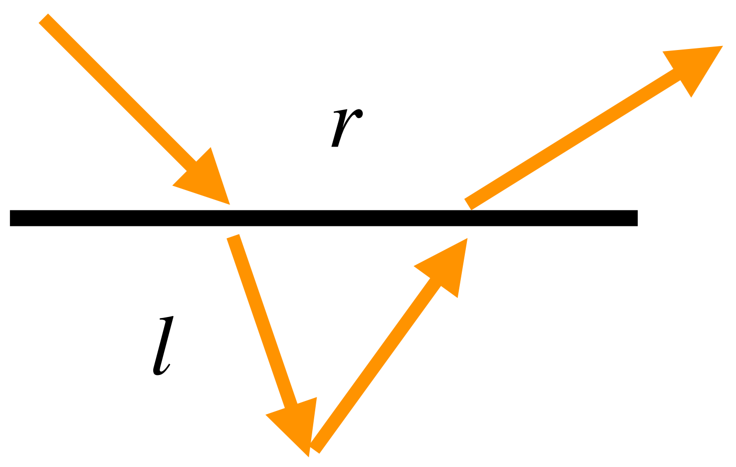
Christensen & Burley’s
empirical model

$$\phi_d(\mathbf{p}) = A\frac{e^{-\frac{sr}{l}} - e^{-\frac{sr}{3l}}}{8\pi l r}$$

A: albedo $\frac{\sigma_s}{\sigma_t}$

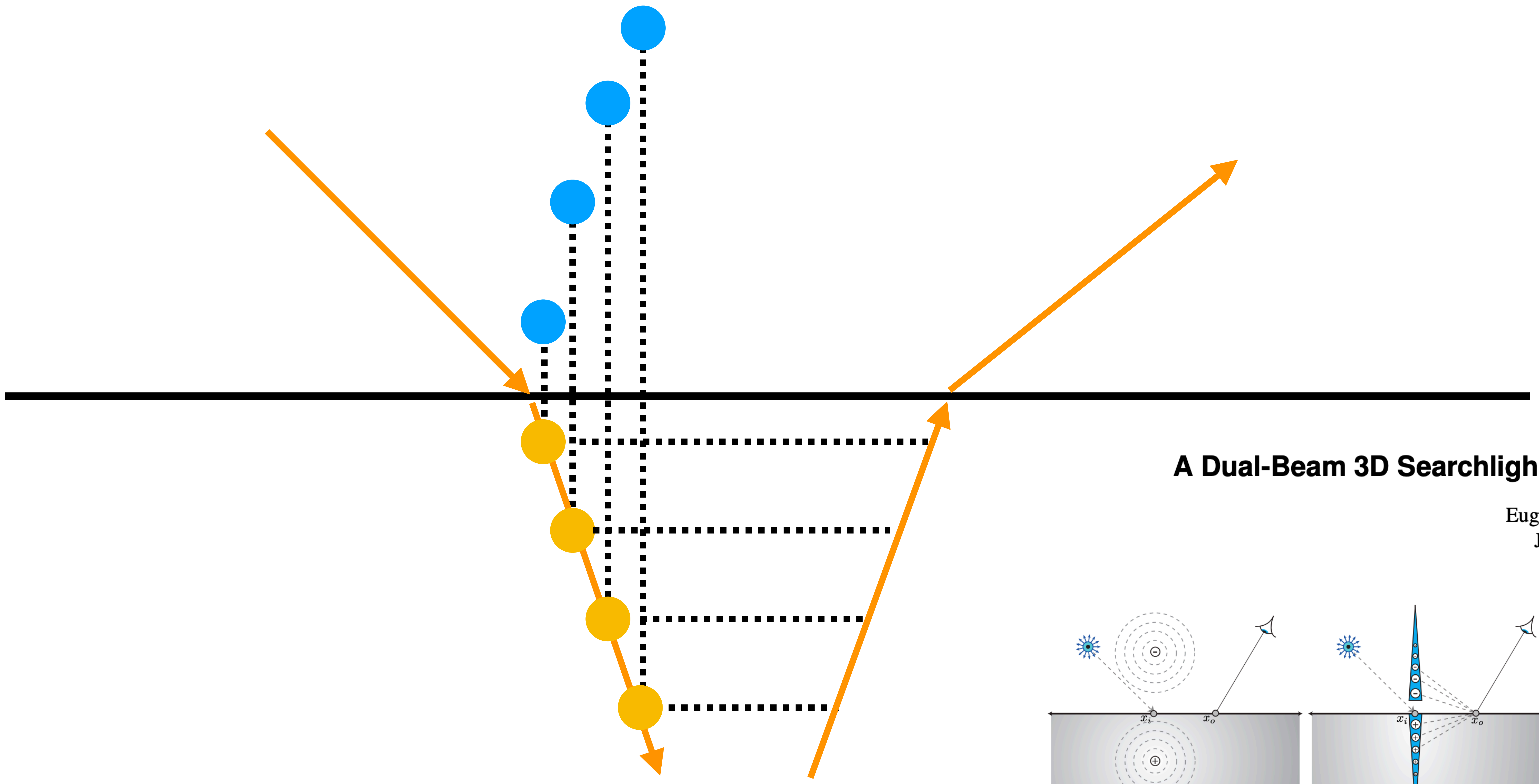
$s = 1.85 - A + 7|A - 0.8|^3$





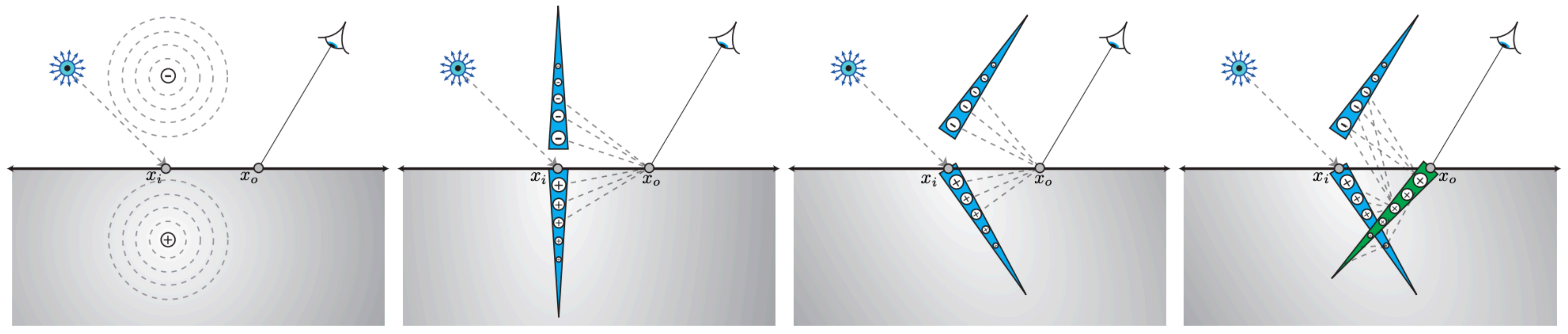
https://graphics.pixar.com/library/ApproxBSSRDF/paper.pdf

Dual-beam diffusion



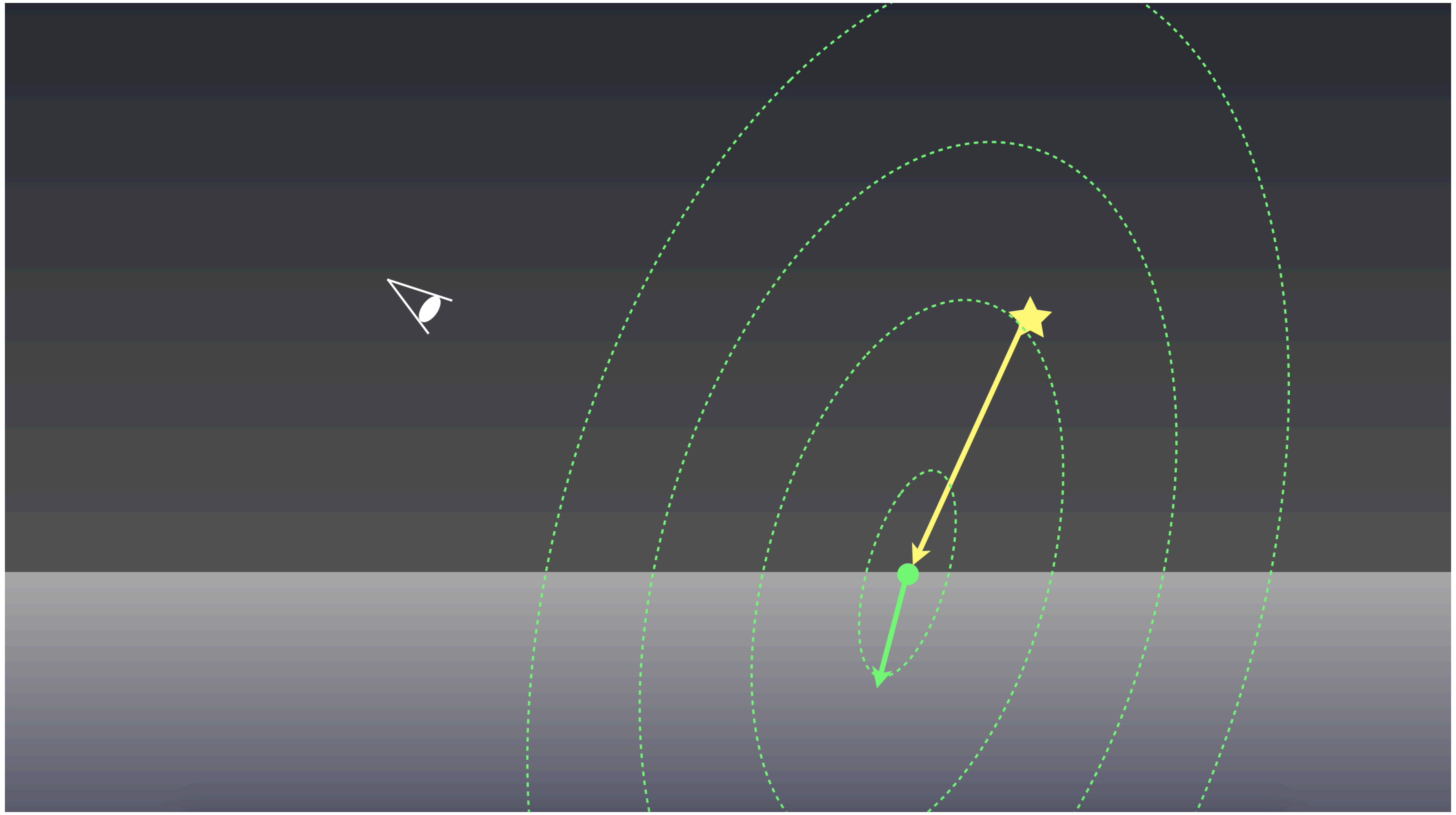
A Dual-Beam 3D Searchlight BSSRDF (Supplementary Doc)

Eugene d'Eon
Jig Lab



(a) Dipole (b) Quantized Diffusion (c) Photon Beam Diffusion (d) Dual-Beam BSSRDF

Directional dipole [Frisvad 2014]



(highly recommend Toshiya (UCSD phd!)'s slides!!)
https://cs.uwaterloo.ca/~thachisu/dirpole_slides.pdf

Data-driven BSSRDFs

An Empirical BSSRDF Model

Craig Donner* Jason Lawrence† Ravi Ramamoorthi ‡
Toshiya Hachisuka§ Henrik Wann Jensen§ Shree Nayar*
*Columbia University †University of Virginia ‡UC Berkeley §UC San Diego

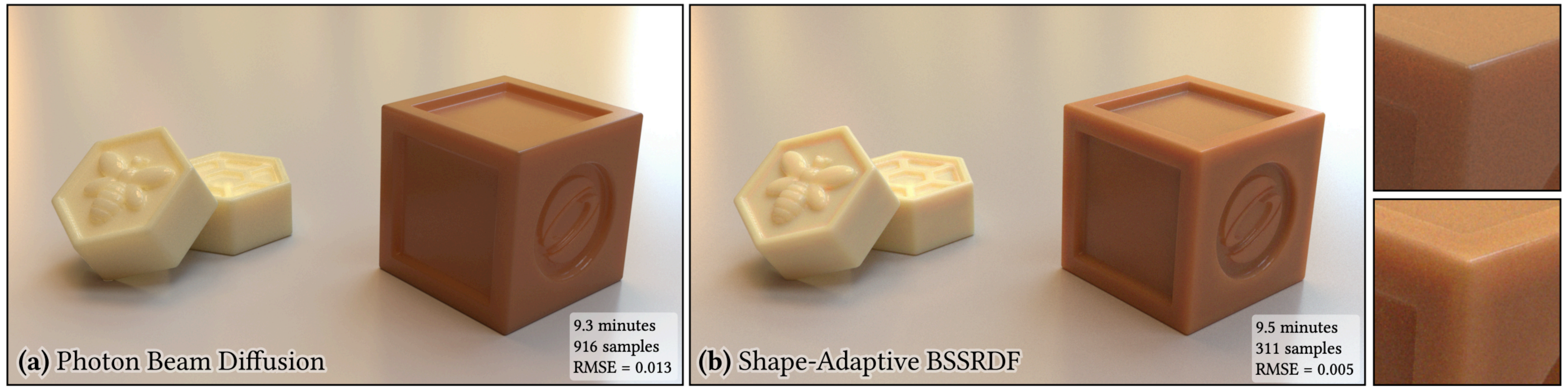
Monte Carlo Path Tracing (30 hours)

Diffusion Dipole + Single Scattering (10 min) Our Model + Single Scattering (30 min) Single Scattering Only

tabular solution

A Learned Shape-Adaptive Subsurface Scattering Model

DELIO VICINI, Ecole Polytechnique Fédérale de Lausanne (EPFL)
VLADLEN KOLTUN, Intel Labs
WENZEL JAKOB, Ecole Polytechnique Fédérale de Lausanne (EPFL)



neural net solution

Similarity relation for converting non-isotropic phase functions to isotropic ones

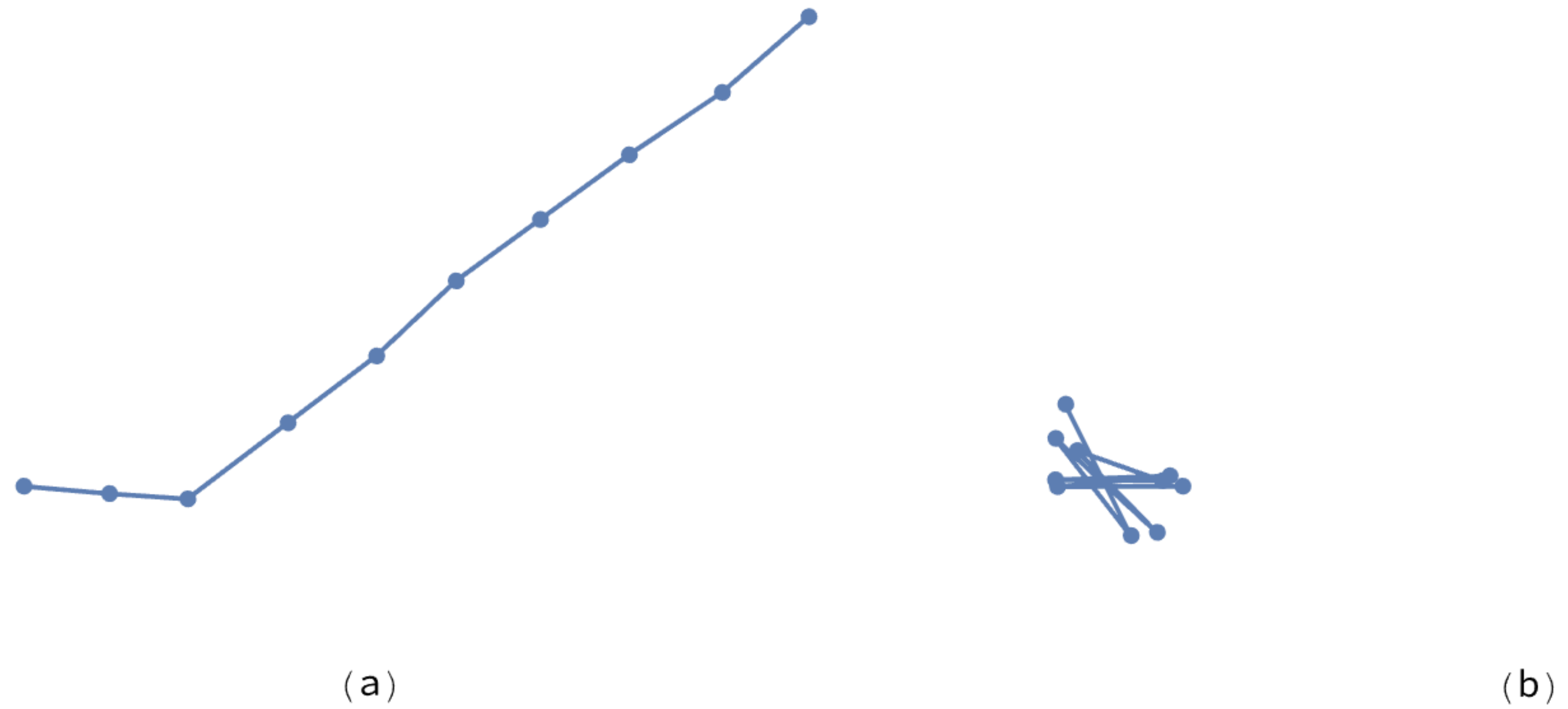


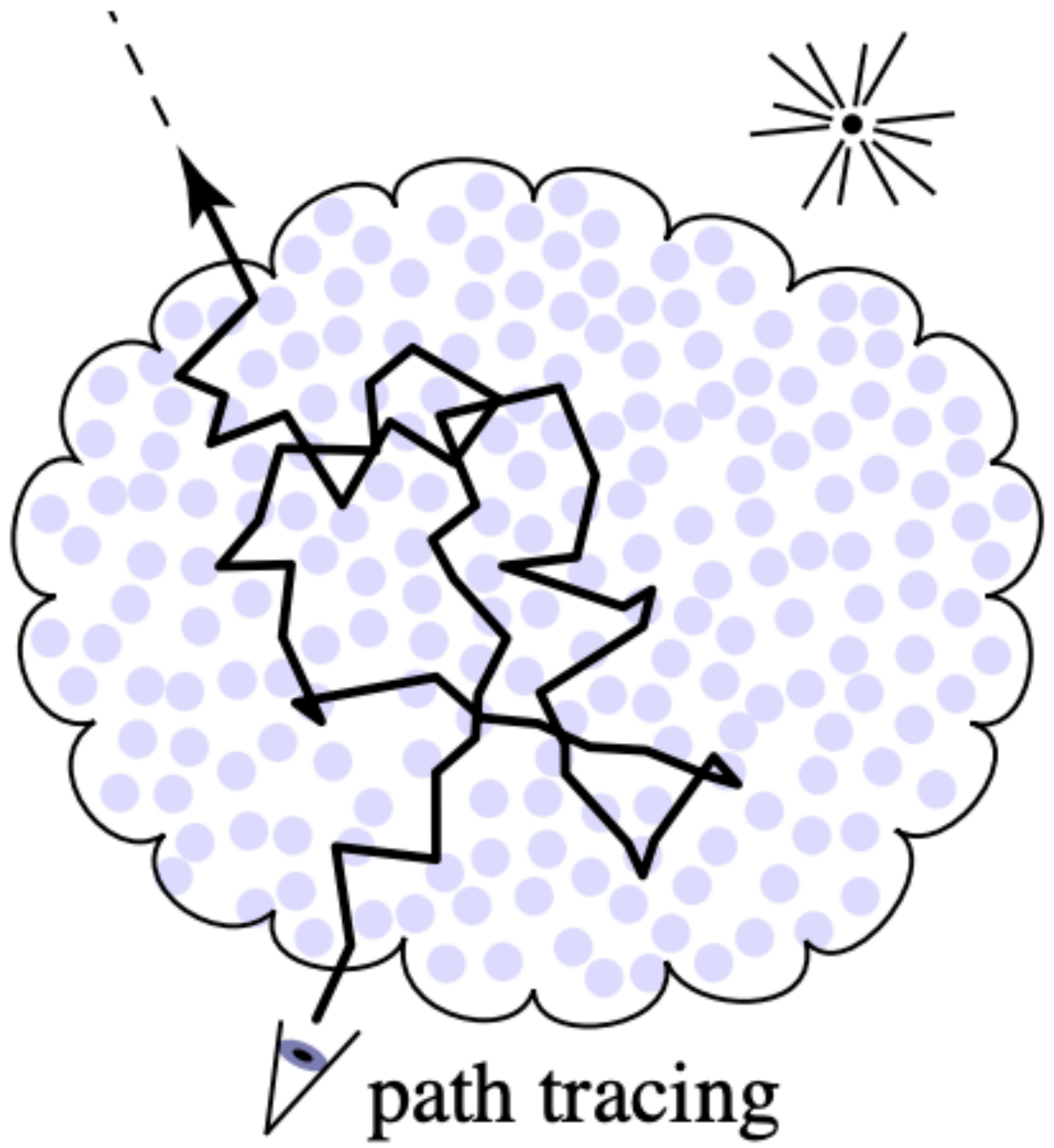
Figure 15.15: Representative Light Paths for Highly Anisotropic Scattering Media. (a) Forward-scattering medium, with $g = 0.9$. Light generally scatters in the same direction it was originally traveling. (b) Backward-scattering medium, with $g = -0.9$. Light frequently bounces back and forth, making relatively little forward progress with respect to its original direction.

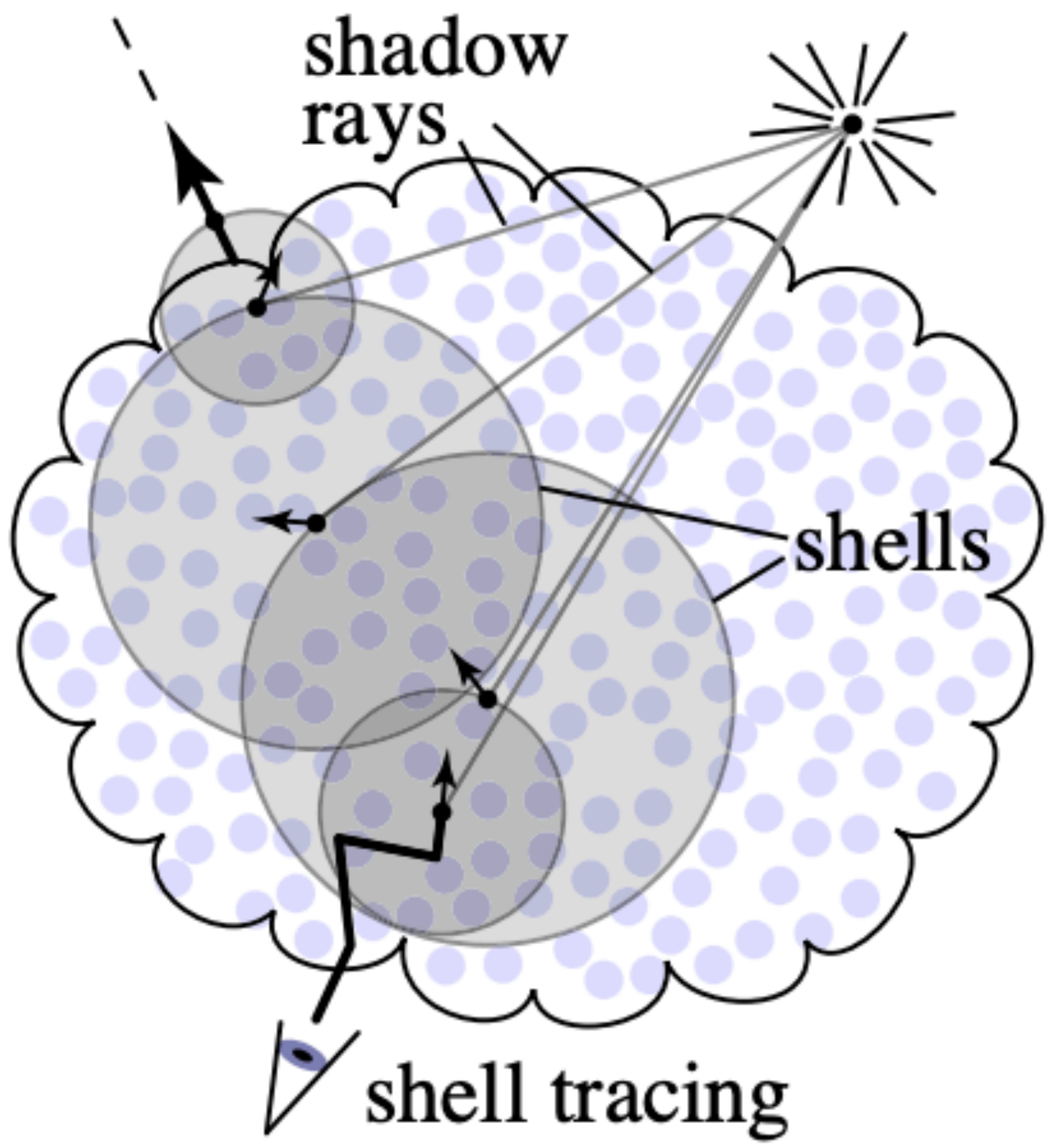
High-Order Similarity Relations in Radiative Transfer

Shuang Zhao, Cornell University
Ravi Ramamoorthi, University of California, Berkeley
Kavita Bala, Cornell University

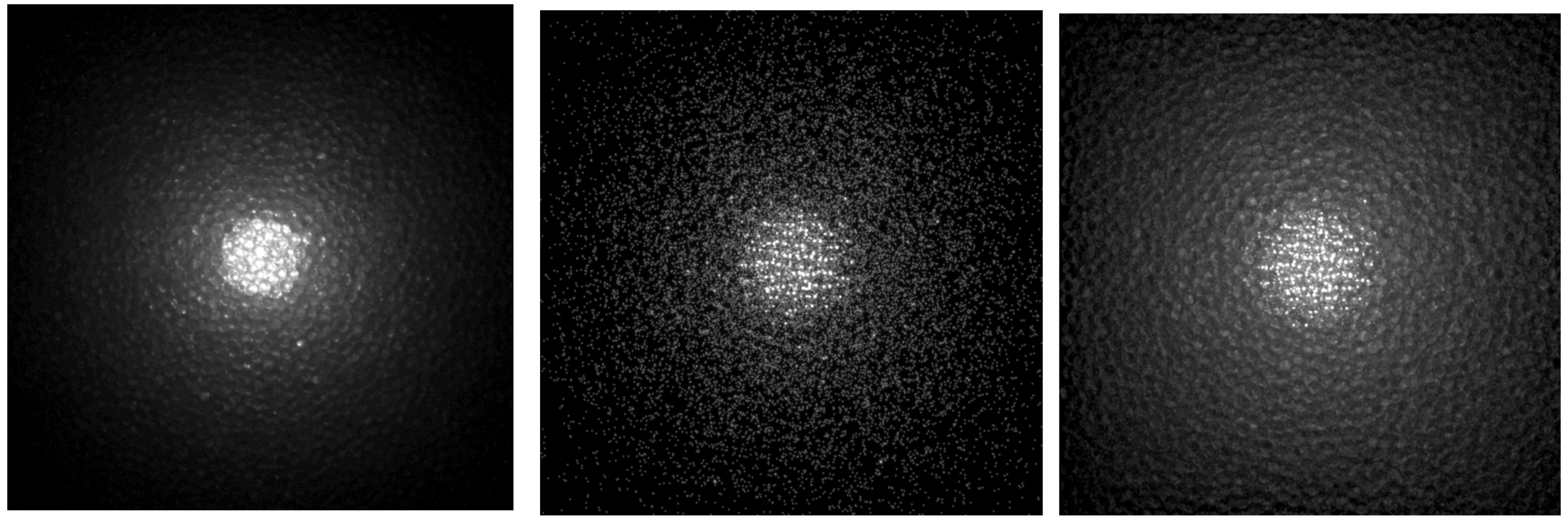
https://www.pbr-book.org/3ed-2018/Light_Transport_II_Volume_Rendering/Subsurface_Scattering_Using_the_Diffusion_Equation#Non-classicalDiffusion

Shell tracing: BSSRDF for discrete media





$$f(x, \omega, x', \omega')$$



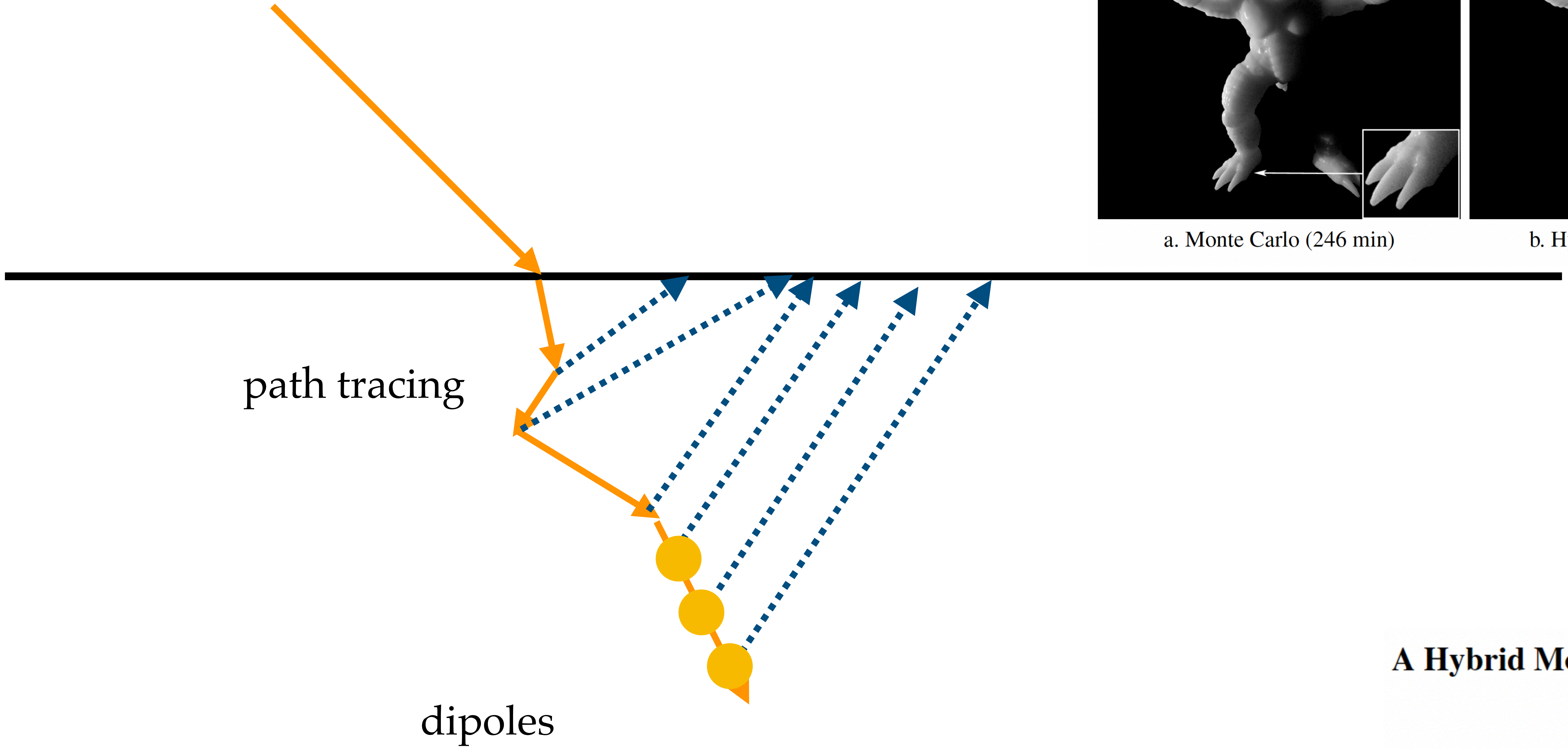
photograph | path tracing (28 hours) | shell tracing (1 hour)

Rendering Discrete Random Media Using Precomputed Scattering Solutions

Jonathan T. Moon, Bruce Walter, and Stephen R. Marschner

Department of Computer Science and Program of Computer Graphics, Cornell University

Hybrid method: combining volumetric path tracing & BSSRDF



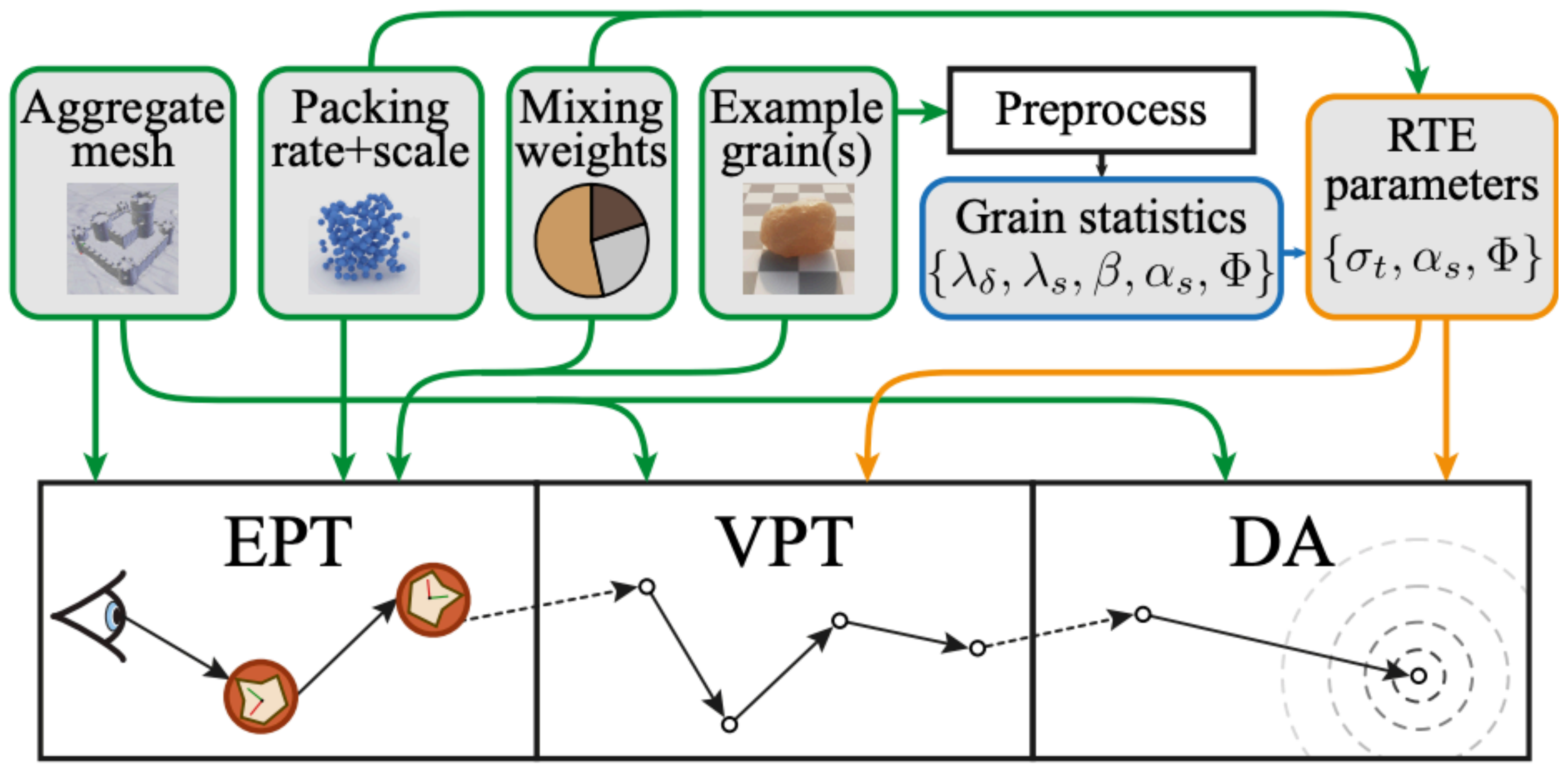
a. Monte Carlo (246 min) b. Hybrid method (33 min) c. Jensen et al. (10 min)

A Hybrid Monte Carlo Method for Accurate and Efficient Subsurface Scattering

Hongsong Li † Fabio Pellacini† Kenneth Torrance†

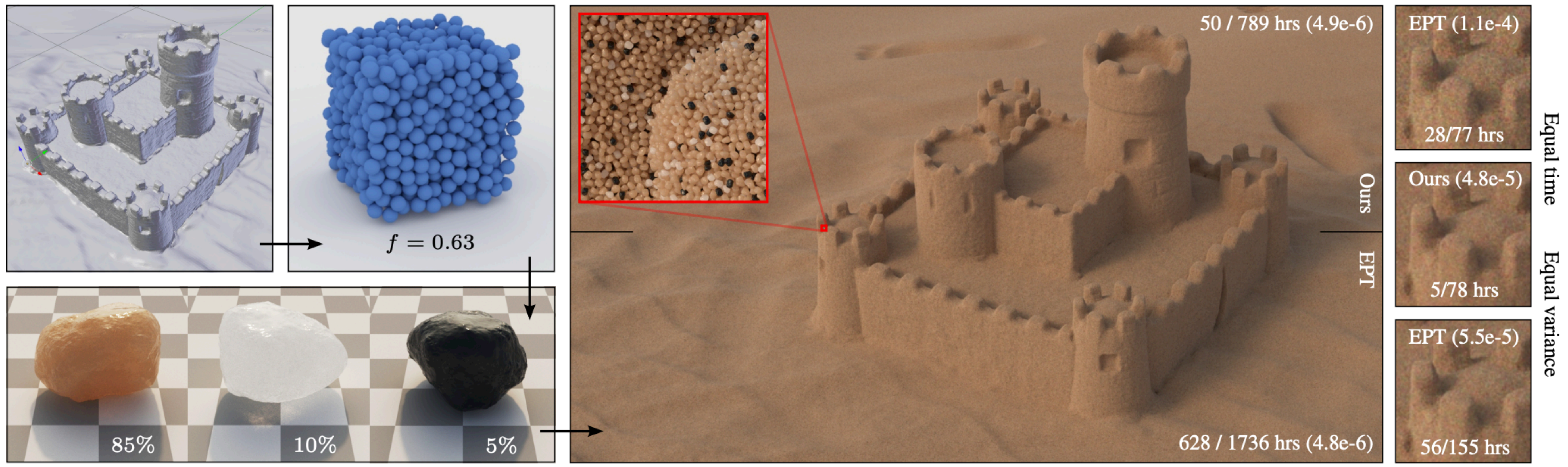
Program of Computer Graphics, Rhodes Hall, Cornell University, Ithaca, NY 14853, U.S.A.

Multi-scale methods: granular media rendering



Multi-Scale Modeling and Rendering of Granular Materials

Johannes Meng[2,1] Marios Papas[1,3] Ralf Habel[1]
Carsten Dachsbacher[2] Steve Marschner[4] Markus Gross[1,3] Wojciech Jarosz[1,5]*
[1]Disney Research Zürich [2]Karlsruhe Institute of Technology [3]ETH Zürich [4]Cornell University [5]Dartmouth College

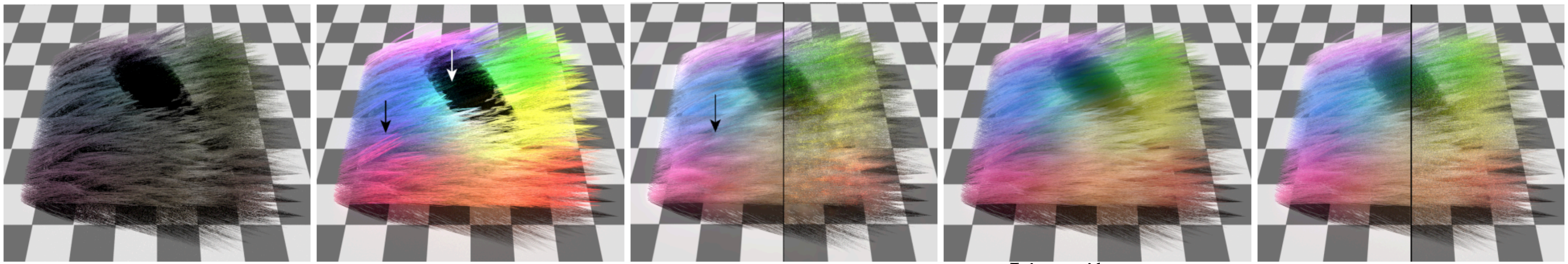


Multi-scale methods: granular media rendering

BSSRDF for fur rendering

A BSSRDF Model for Efficient Rendering of Fur with Global Illumination

LING-QI YAN, University of California, Berkeley
WEILUN SUN, University of California, Berkeley
HENRIK WANN JENSEN, University of California, San Diego
RAVI RAMAMOORTHI, University of California, San Diego



(a) Local illumination + Classic dual scattering
16spp, 54s

(b) Local illumination + Extended dual scattering
87spp, 7.2min

(c) Photon mapped
Left: equal quality, 174.1min
Right: equal time, 6.8min

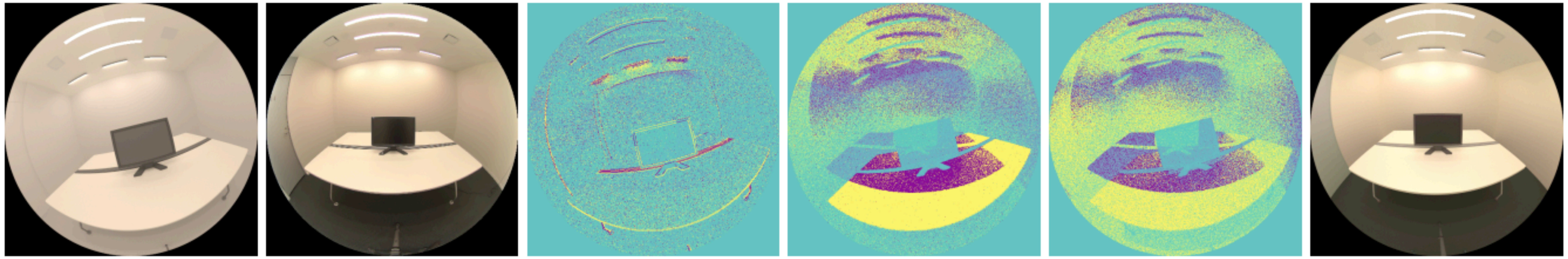
(d) Lingqi's ~~Our~~ method
42spp, 7.0min

(e) Path traced reference
Left: 1200spp, 72.9min
Right: 85spp, 7.6min

Next: differentiable rendering

Differentiable Monte Carlo Ray Tracing through Edge Sampling

TZU-MAO LI, MIT CSAIL
MIIKA AITTALA, MIT CSAIL
FRÉDO DURAND, MIT CSAIL
JAAKKO LEHTINEN, Aalto University & NVIDIA



(a) initial guess (b) real photograph (c) camera gradient (per-pixel contribution) (d) table albedo gradient (per-pixel contribution) (e) light gradient (per-pixel contribution) (f) our fitted result