Virtual Ray Lights for Rendering Scenes with Participating Media

Jan Novák
Carsten Dachsbacher
Derek Nowrouzezahrai
Wojciech Jarosz

Disney Research, Zurich
Karlsruhe Institute of Technology
Université de Montréal

Motivation

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[Diego Guitierrez]


[http://mev.fopf.mipt.ru]

Motivation

SIGGRAPH2012

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SIGGRAPH2012

Multiple scattering - approaches

SIGGRAPH2012

Multiple scattering - approaches

Diffusion theory

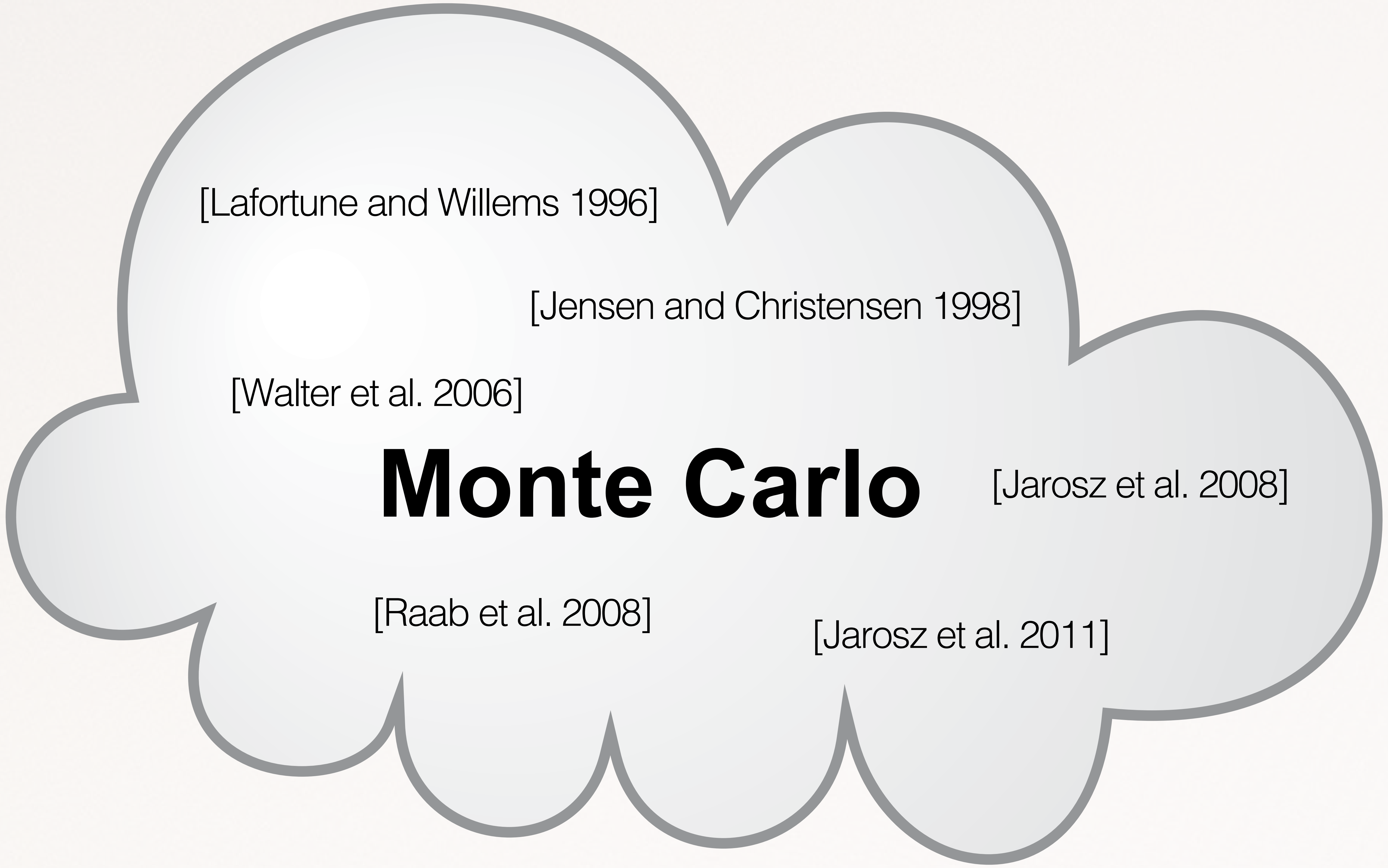
[Stam 1995]
[Jensen et al. 2001]
[Jensen and Buhler 2003]
[Donner and Jensen 2005]
[D'Eon and Irving 2011]

Monte Carlo

[Lafortune and Willems 1996]
[Jensen and Christensen 1998]
[Walter et al. 2006]
[Jarosz et al. 2008]
[Raab et al. 2008]
[Jarosz et al. 2011]

fast, but...
no occlusion
homogeneous only

Multiple scattering - approaches

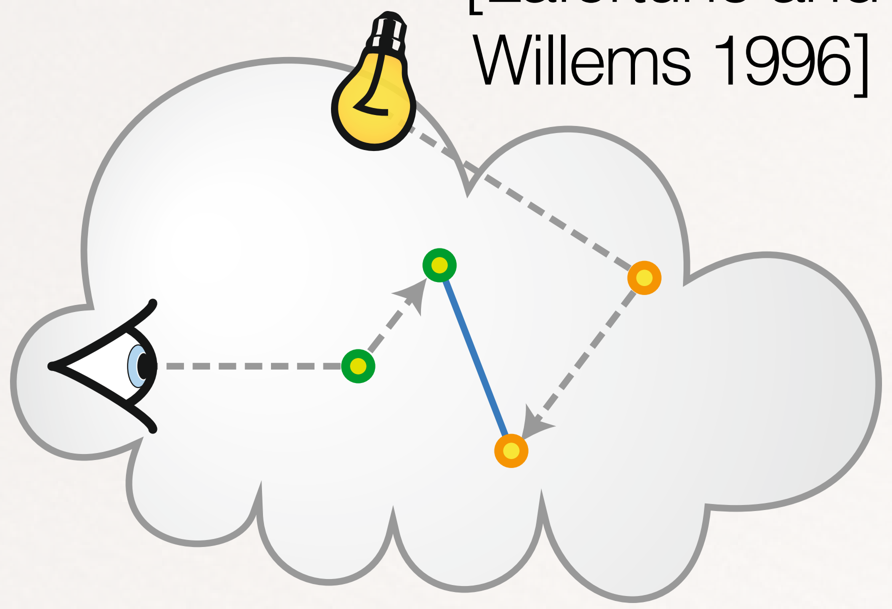


Previous work

SIGGRAPH2012

Bidirectional Path Tracing

[Lafortune and Willems 1996]



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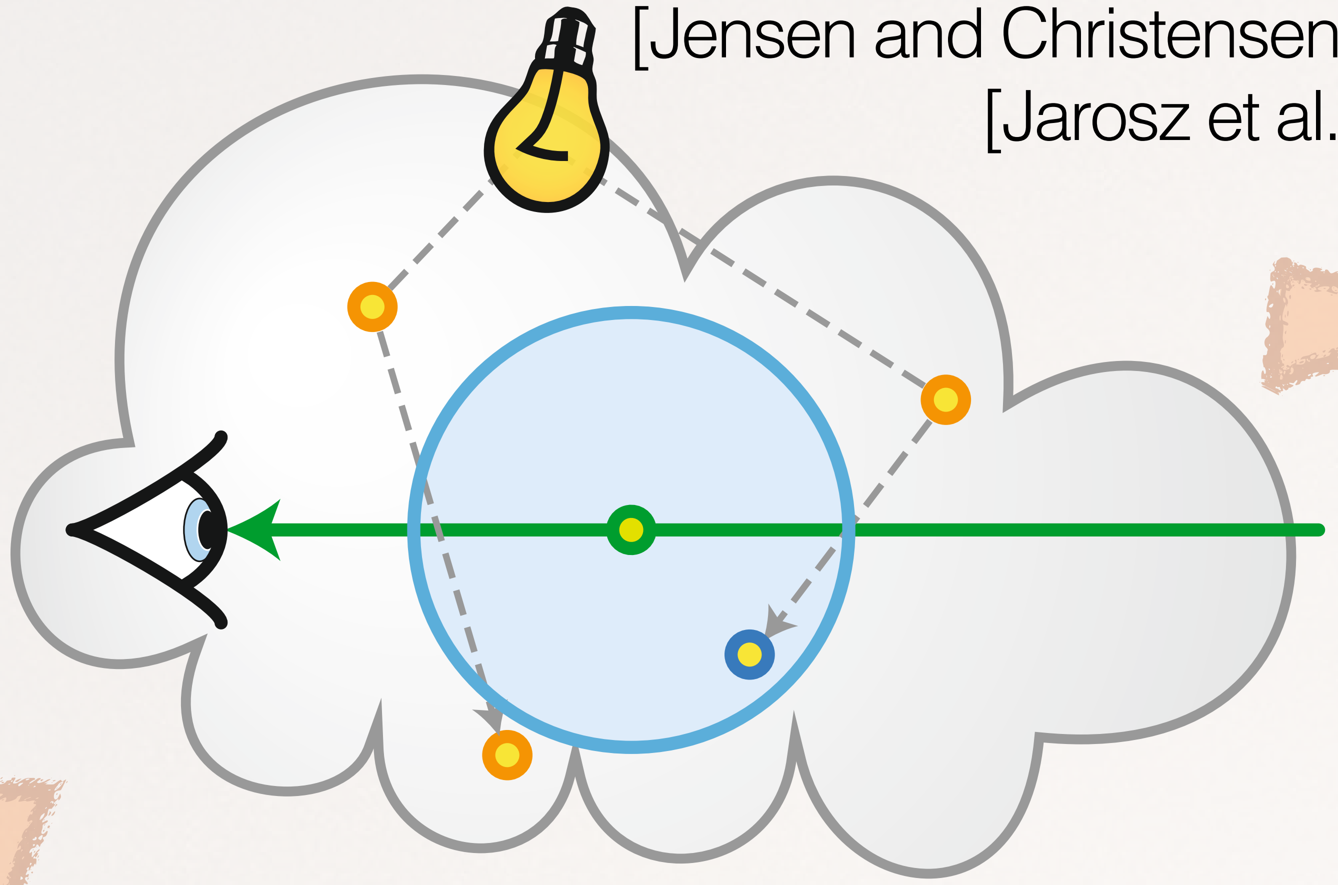

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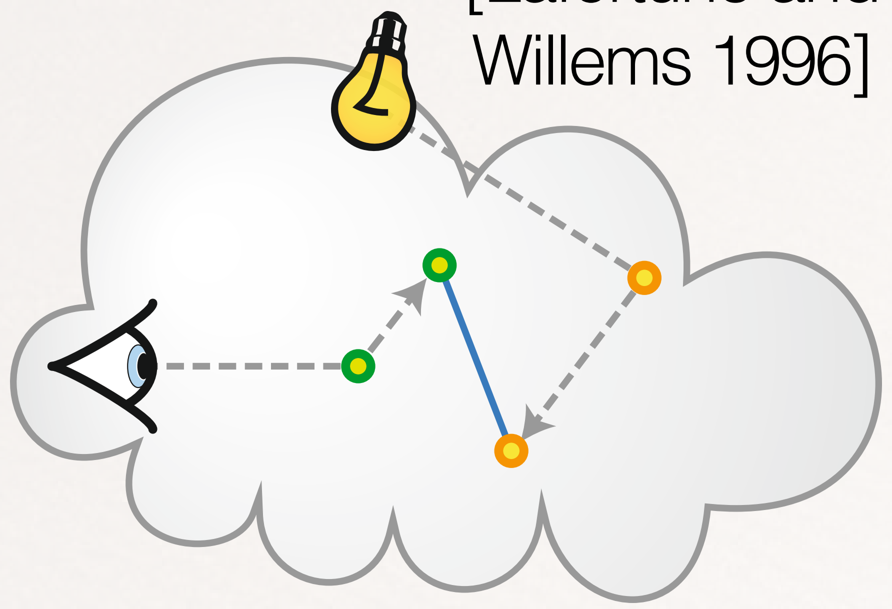

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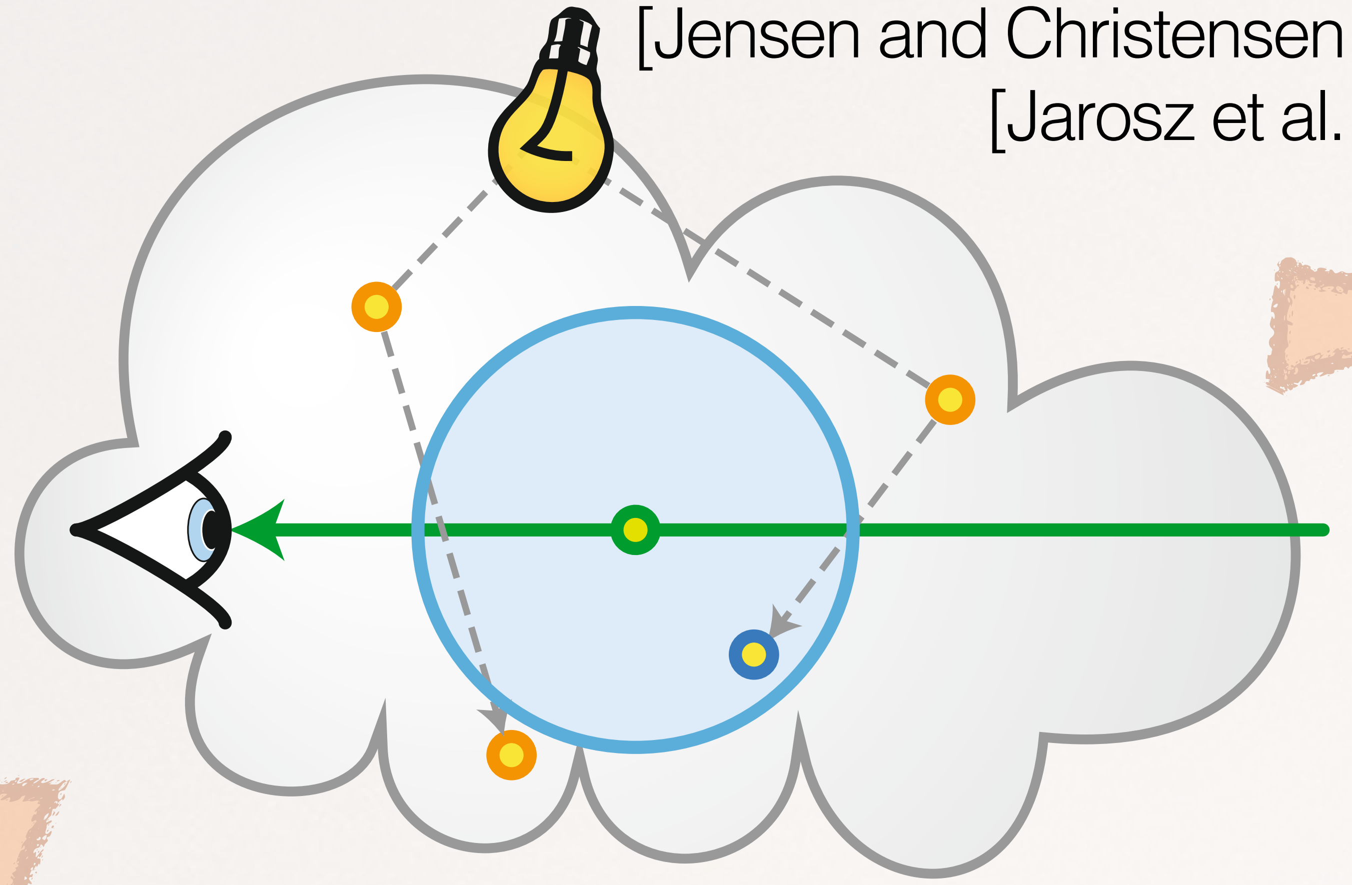

requires a lot of photons

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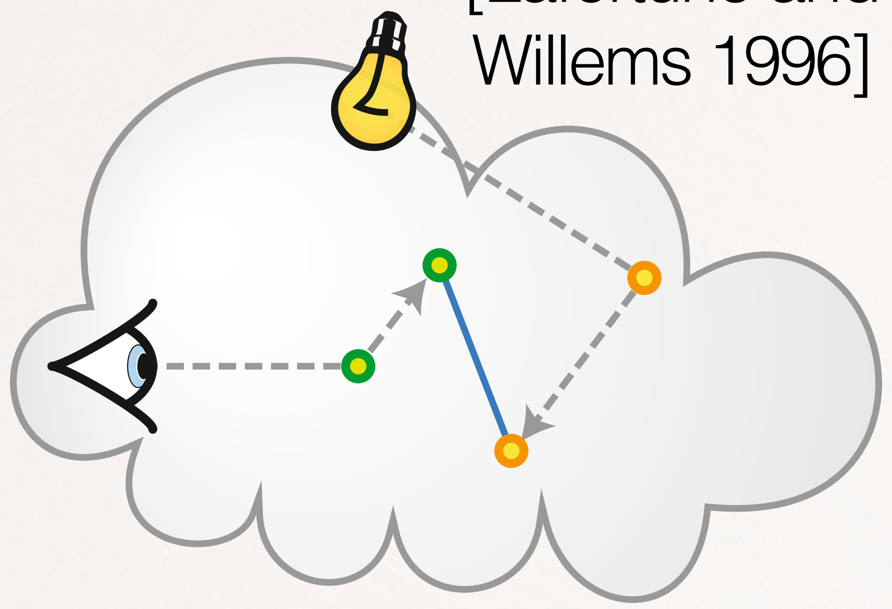

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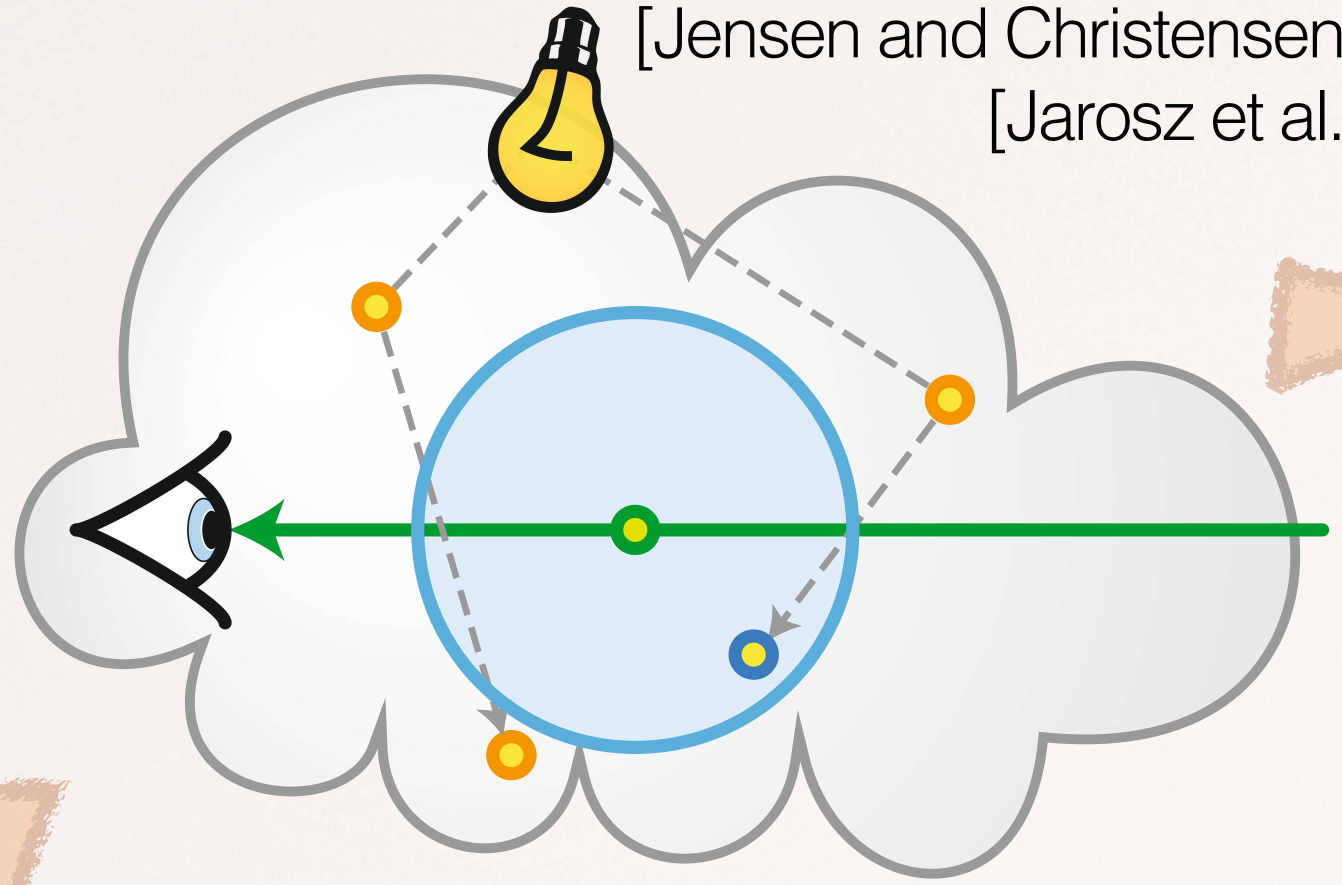

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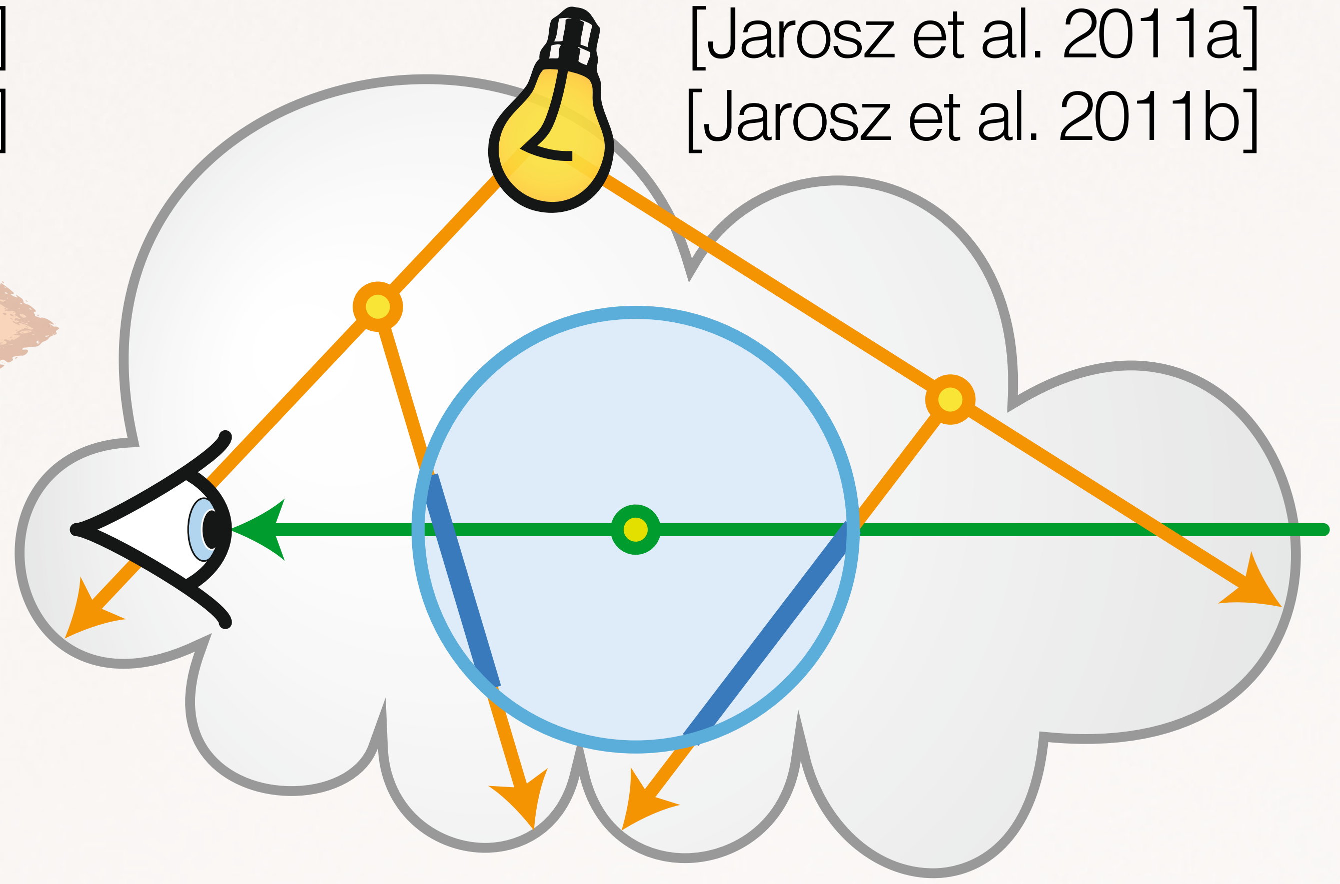
Photon Beams



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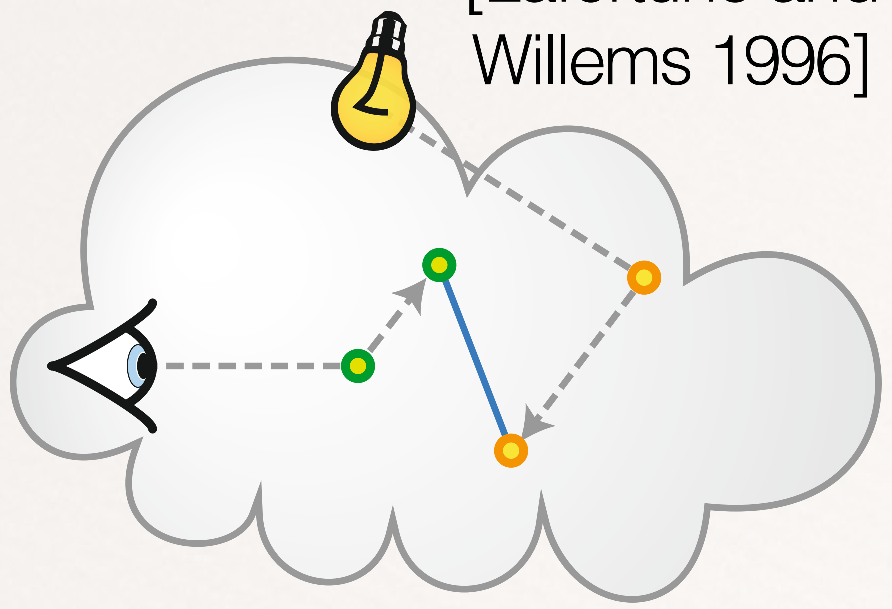

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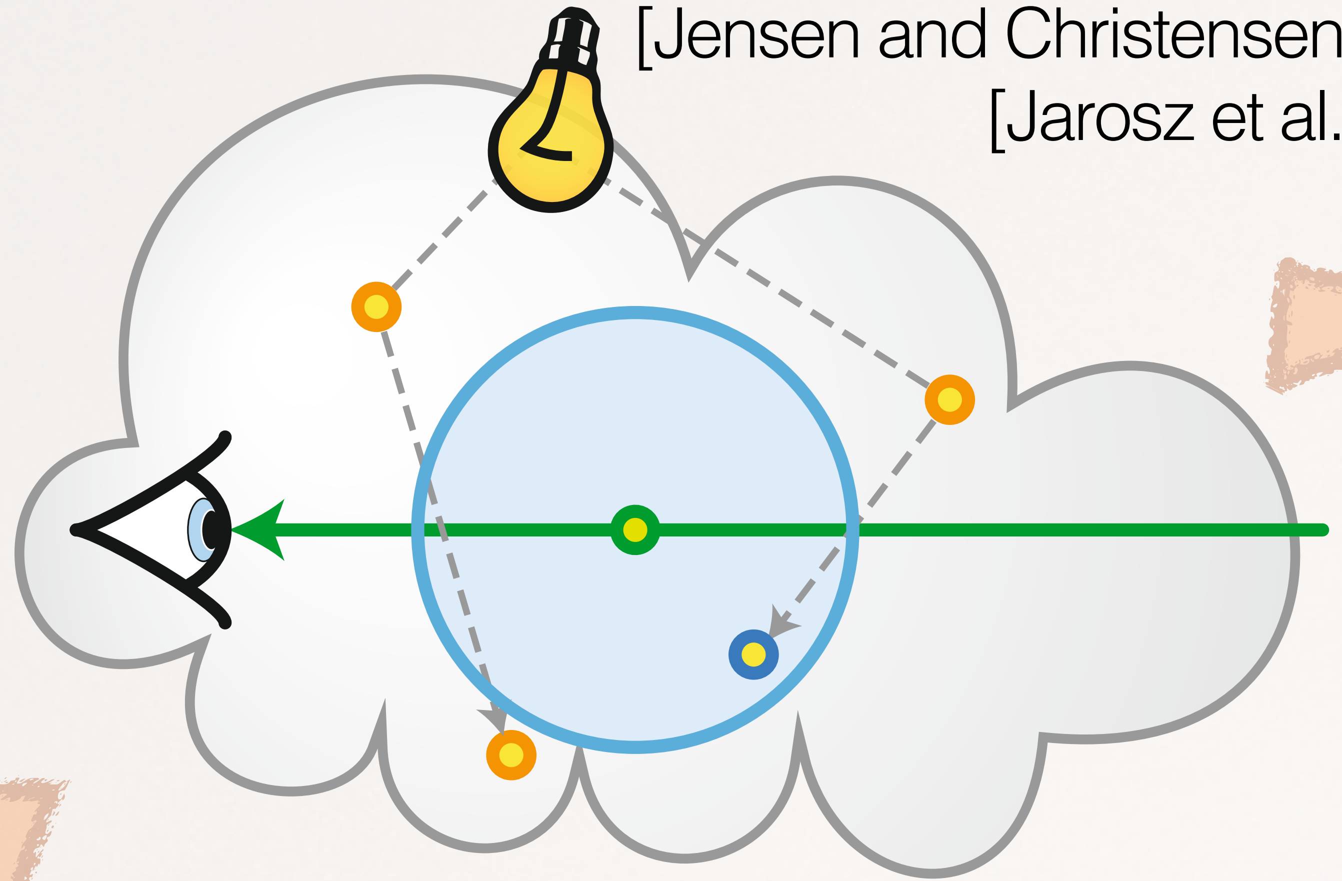

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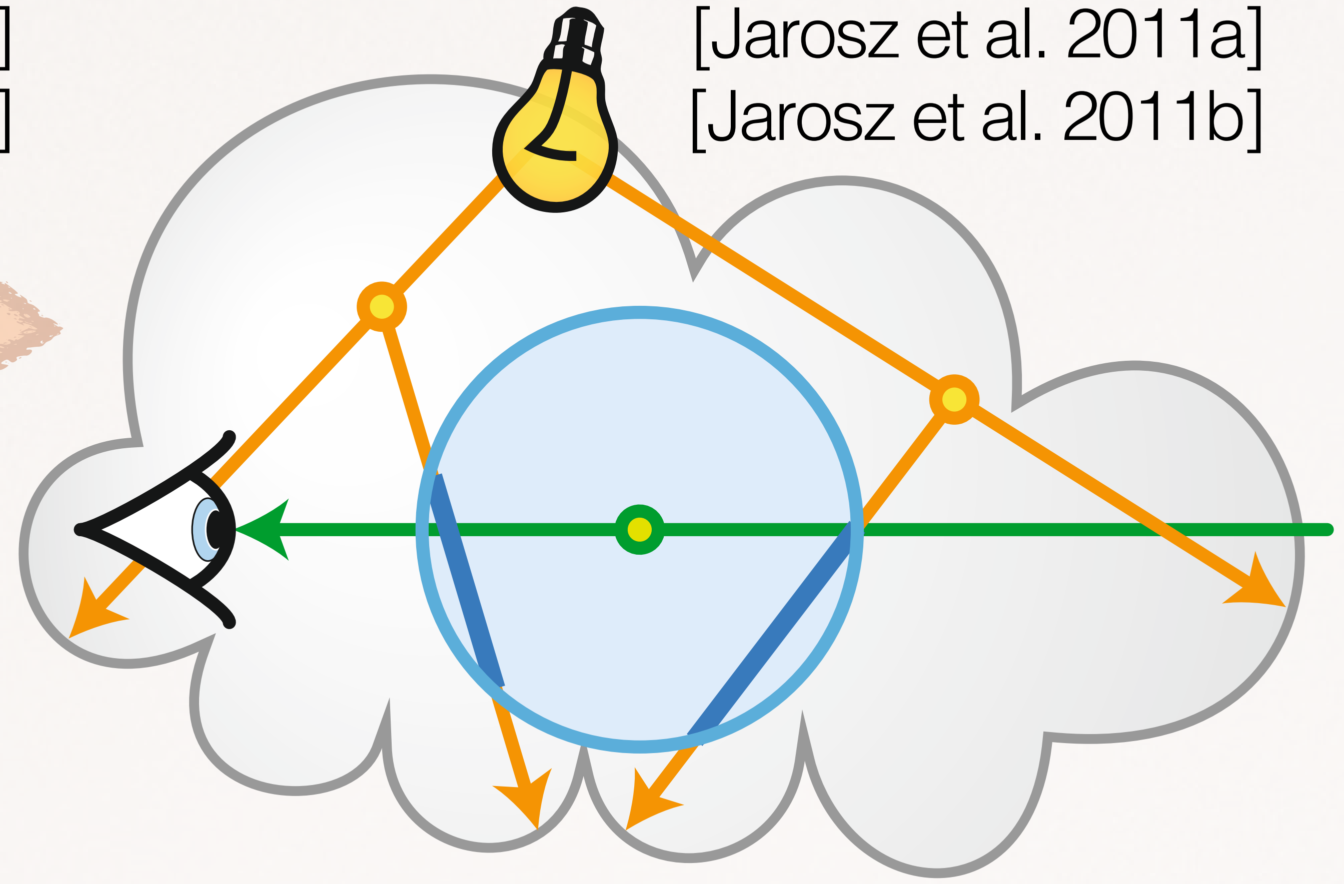

great caustics,
MS not so...

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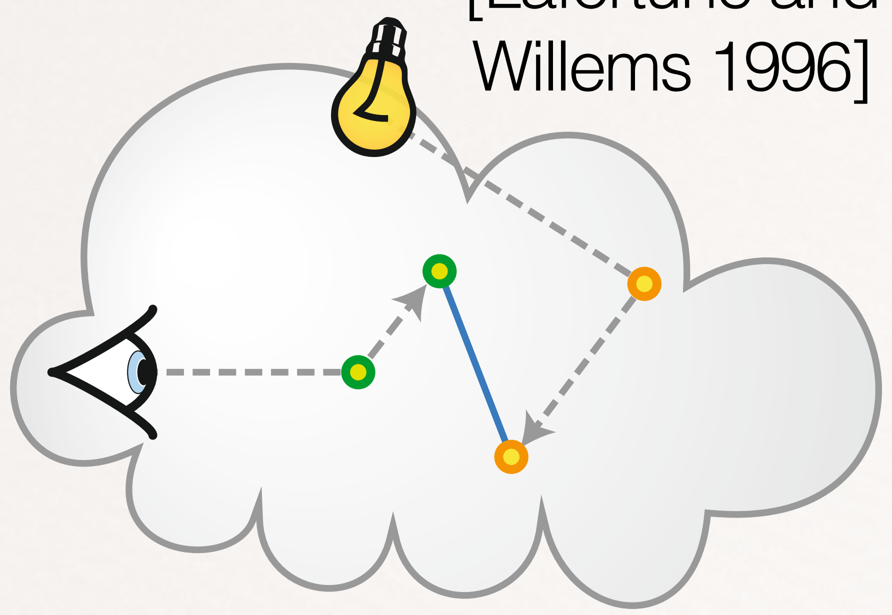

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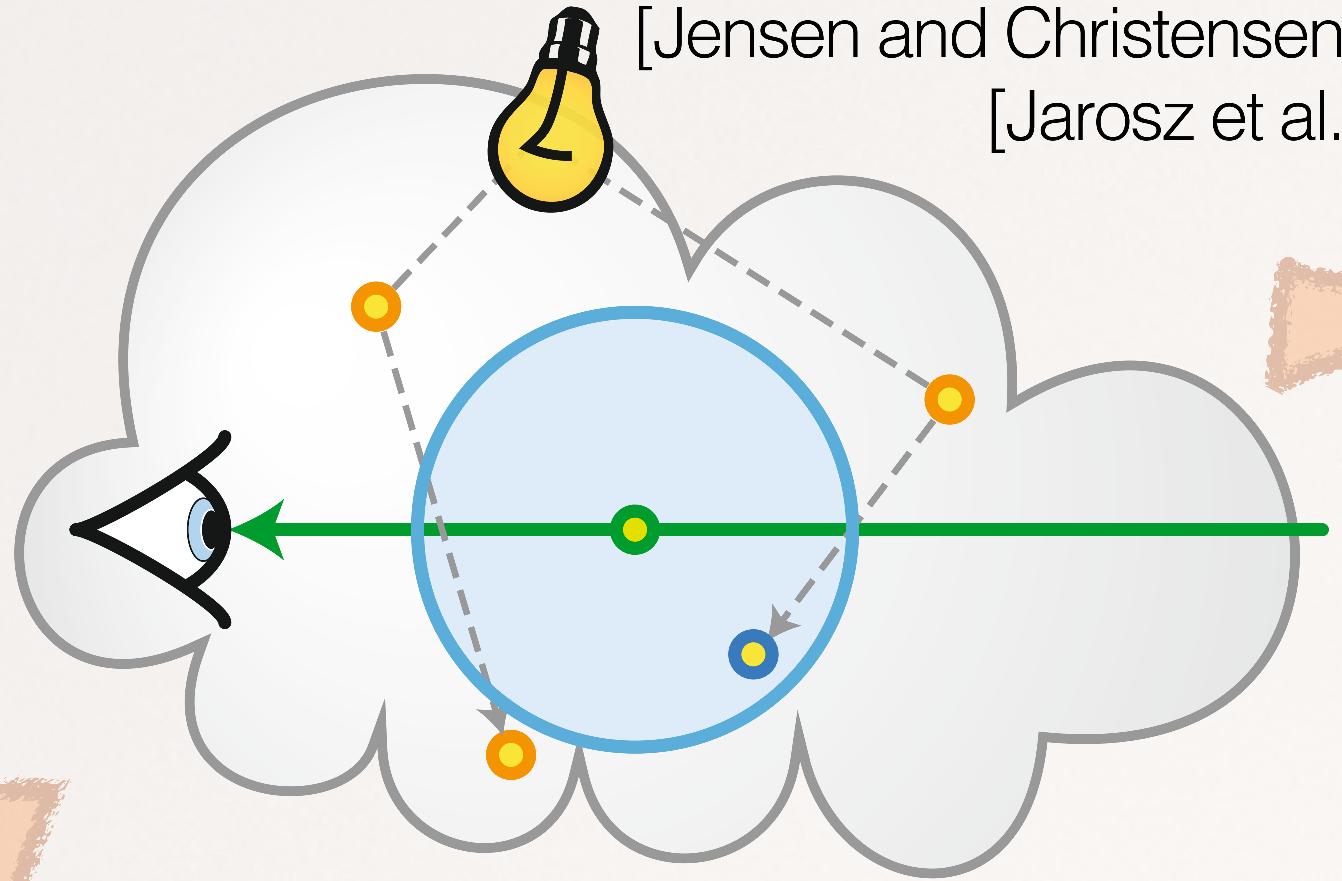

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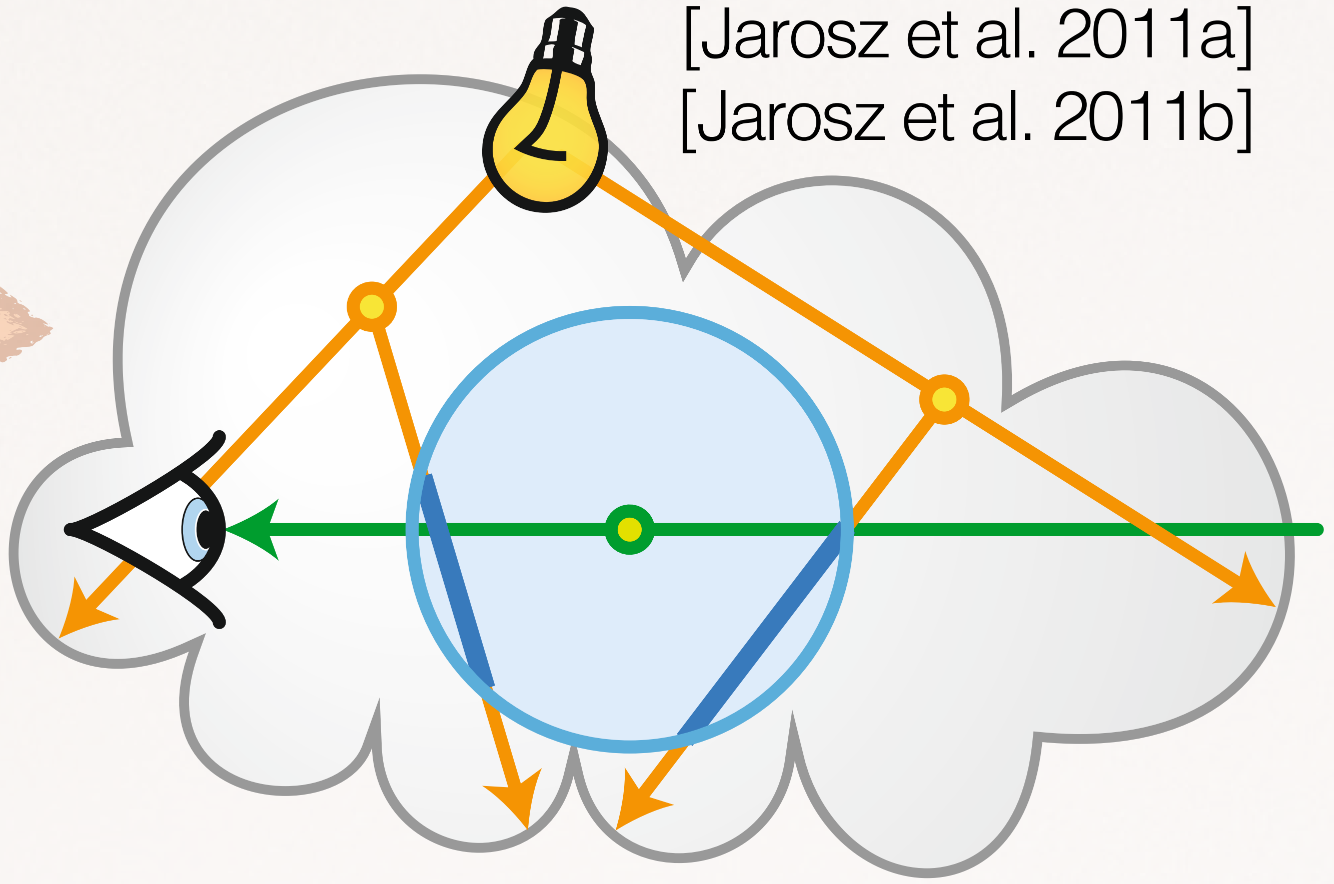

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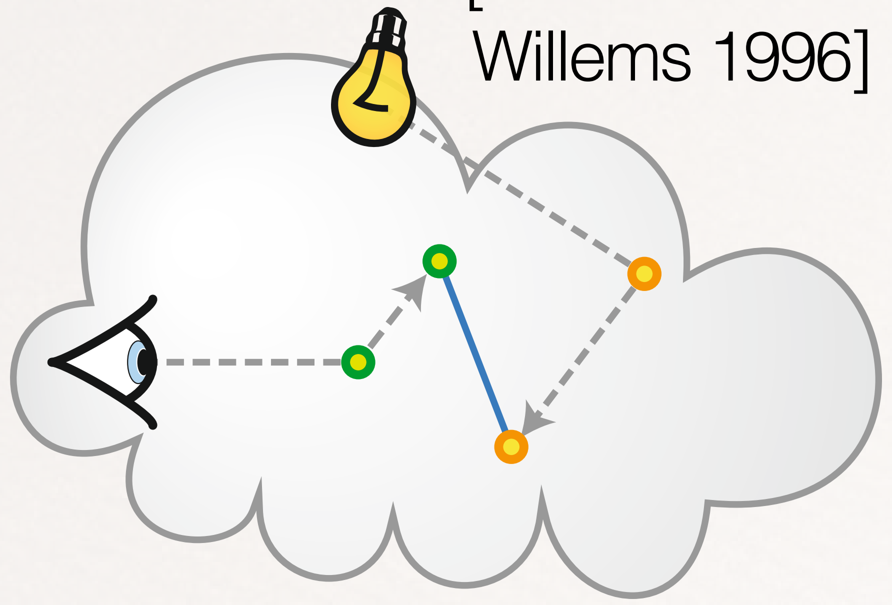

Virtual Point Lights

[Keller 1997]
[Walter et al. 2005]
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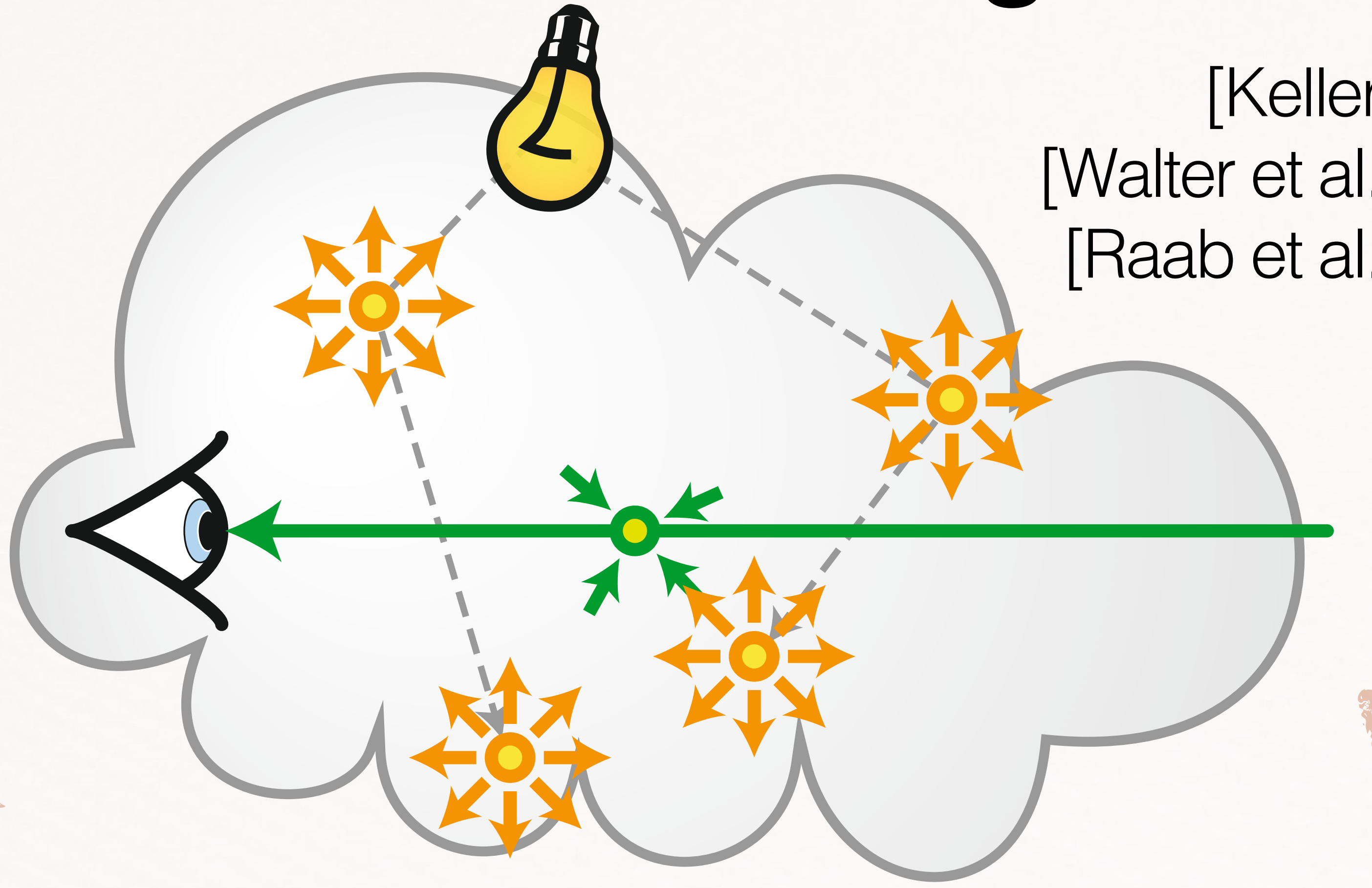

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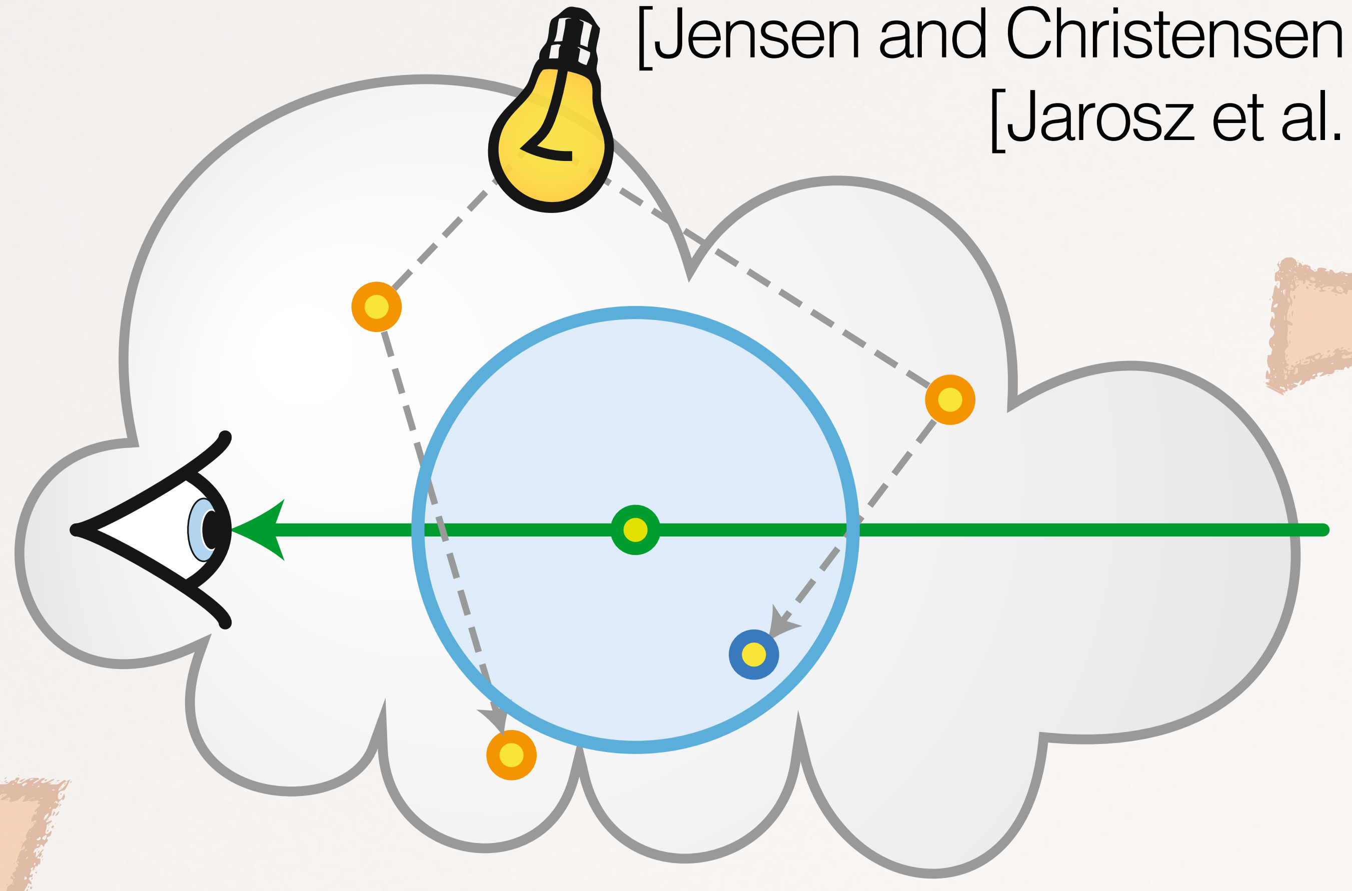

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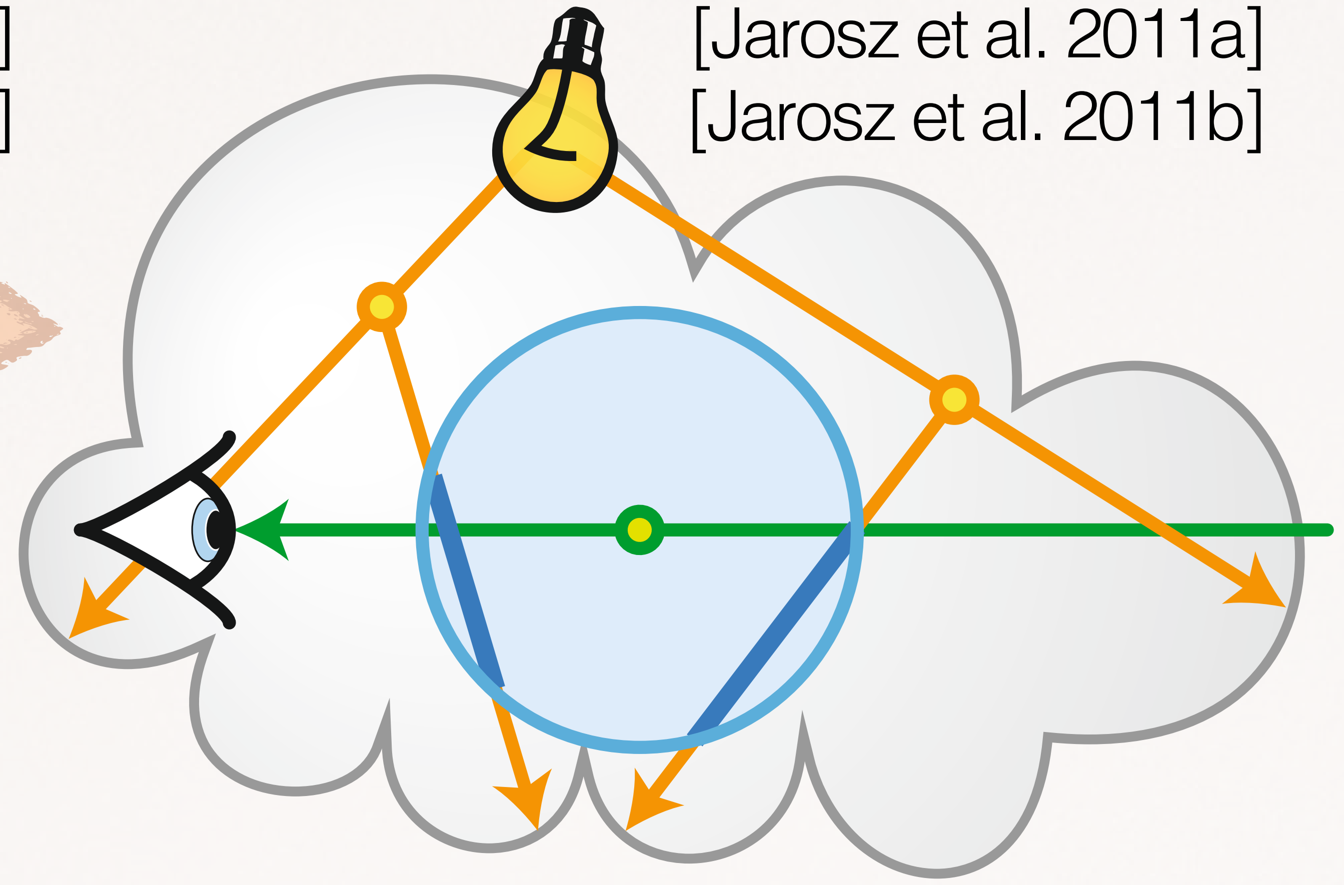

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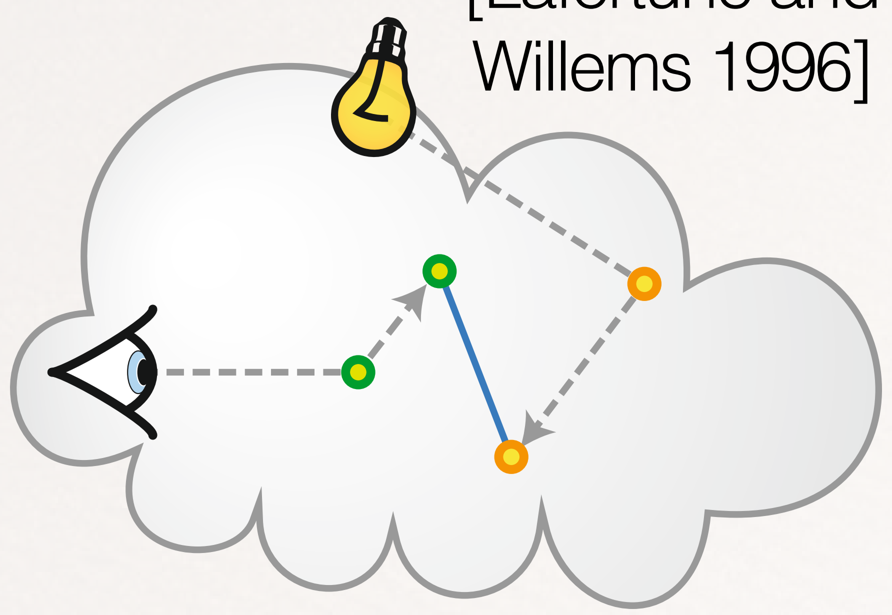

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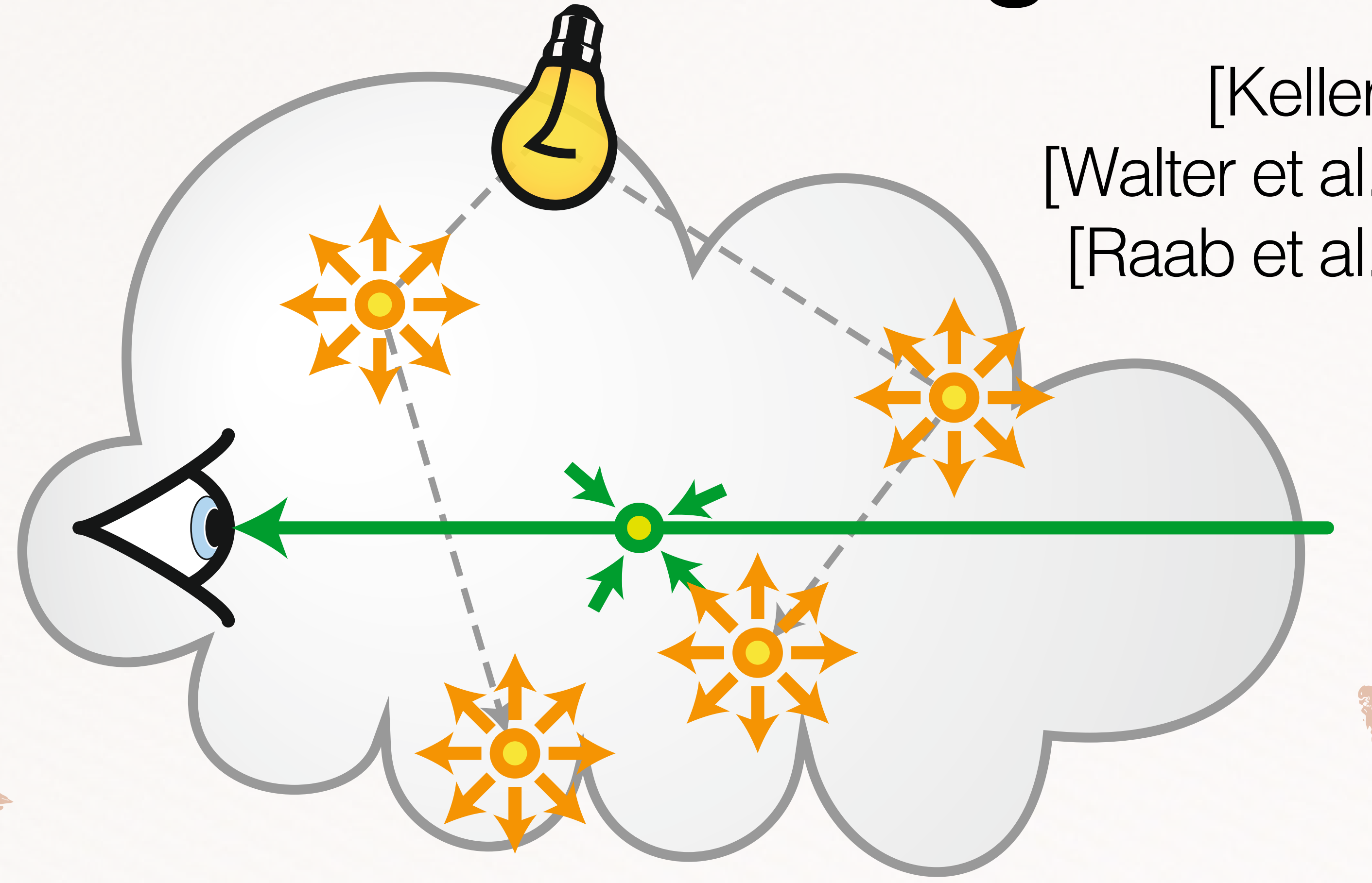

suffers from singularities

Previous work

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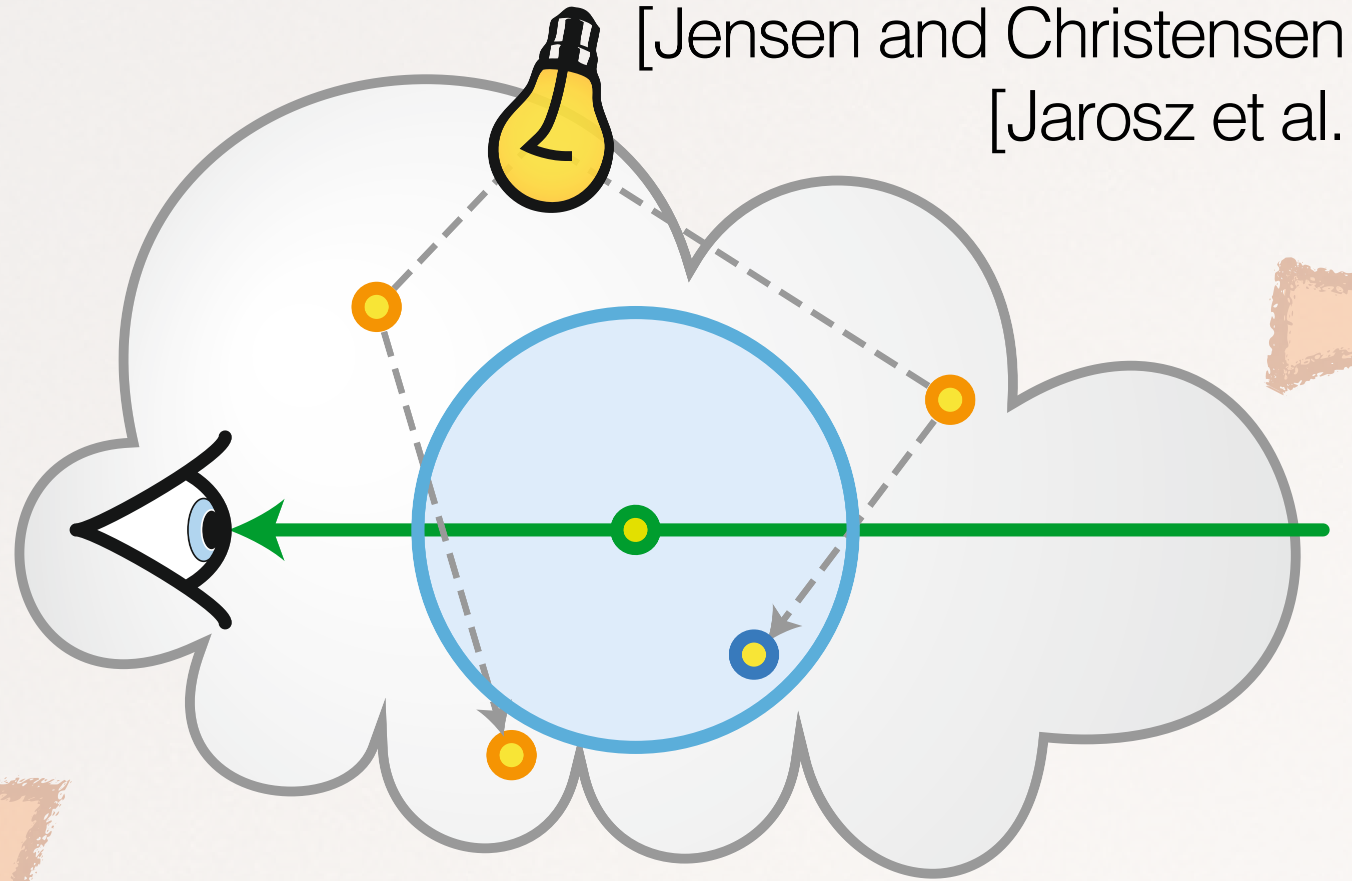

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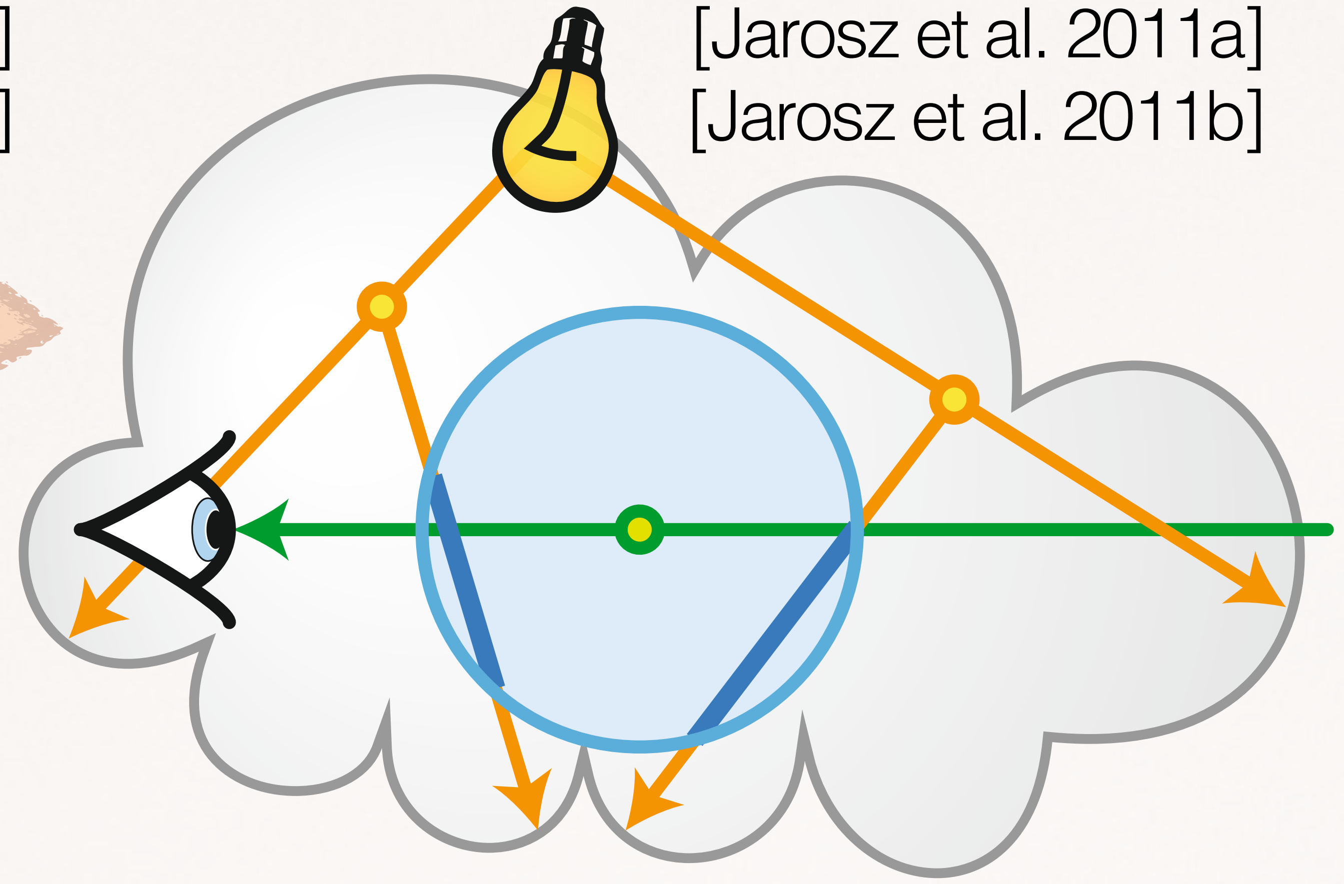

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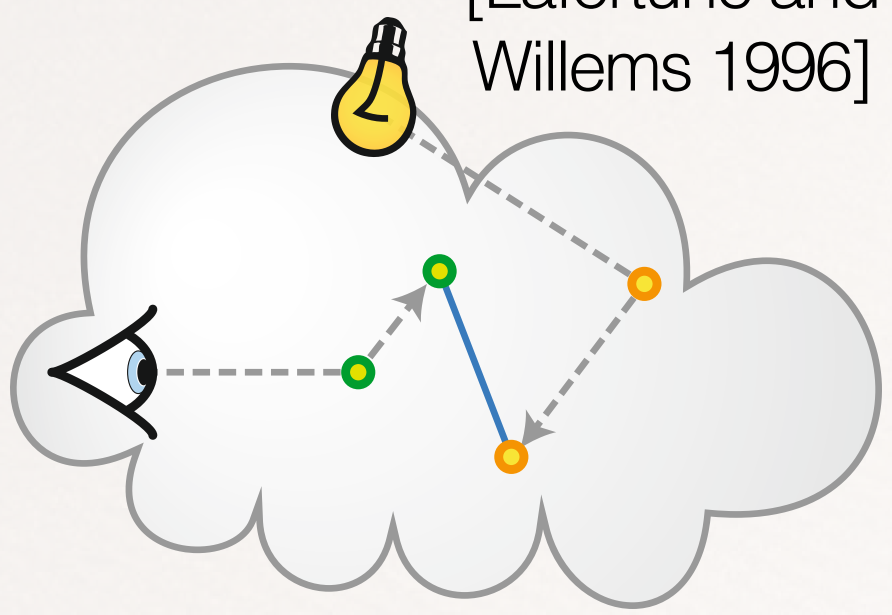

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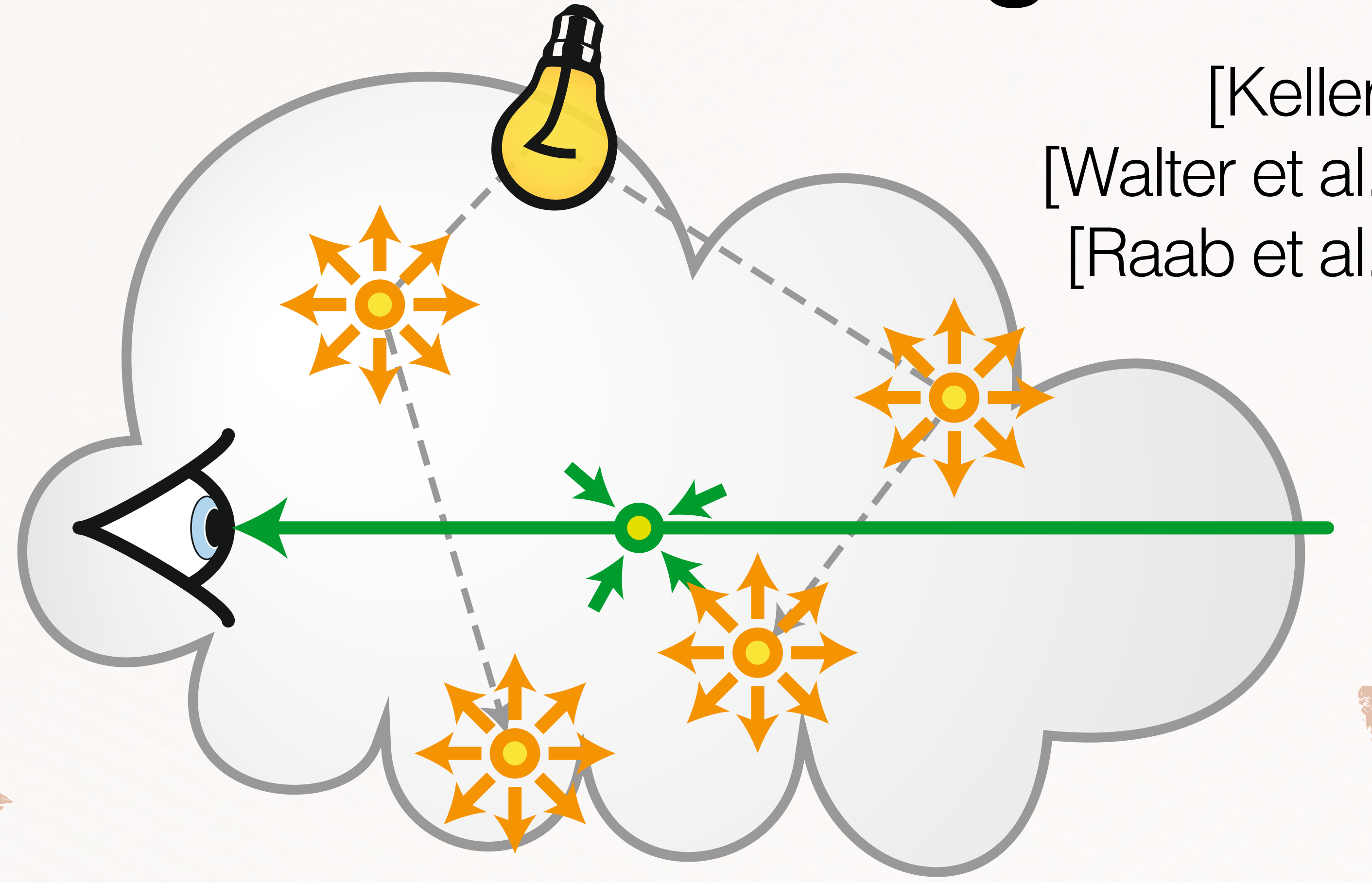

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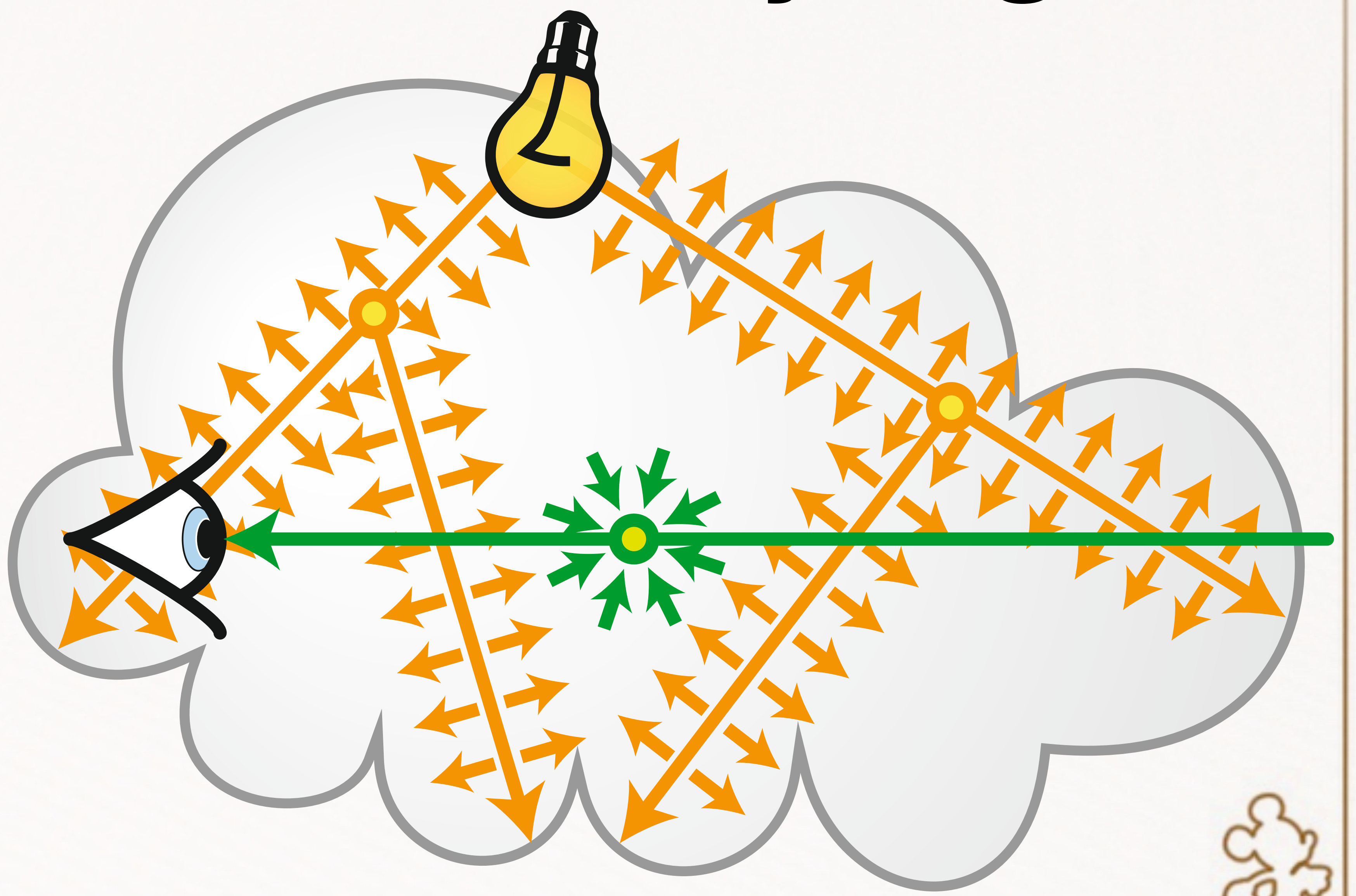
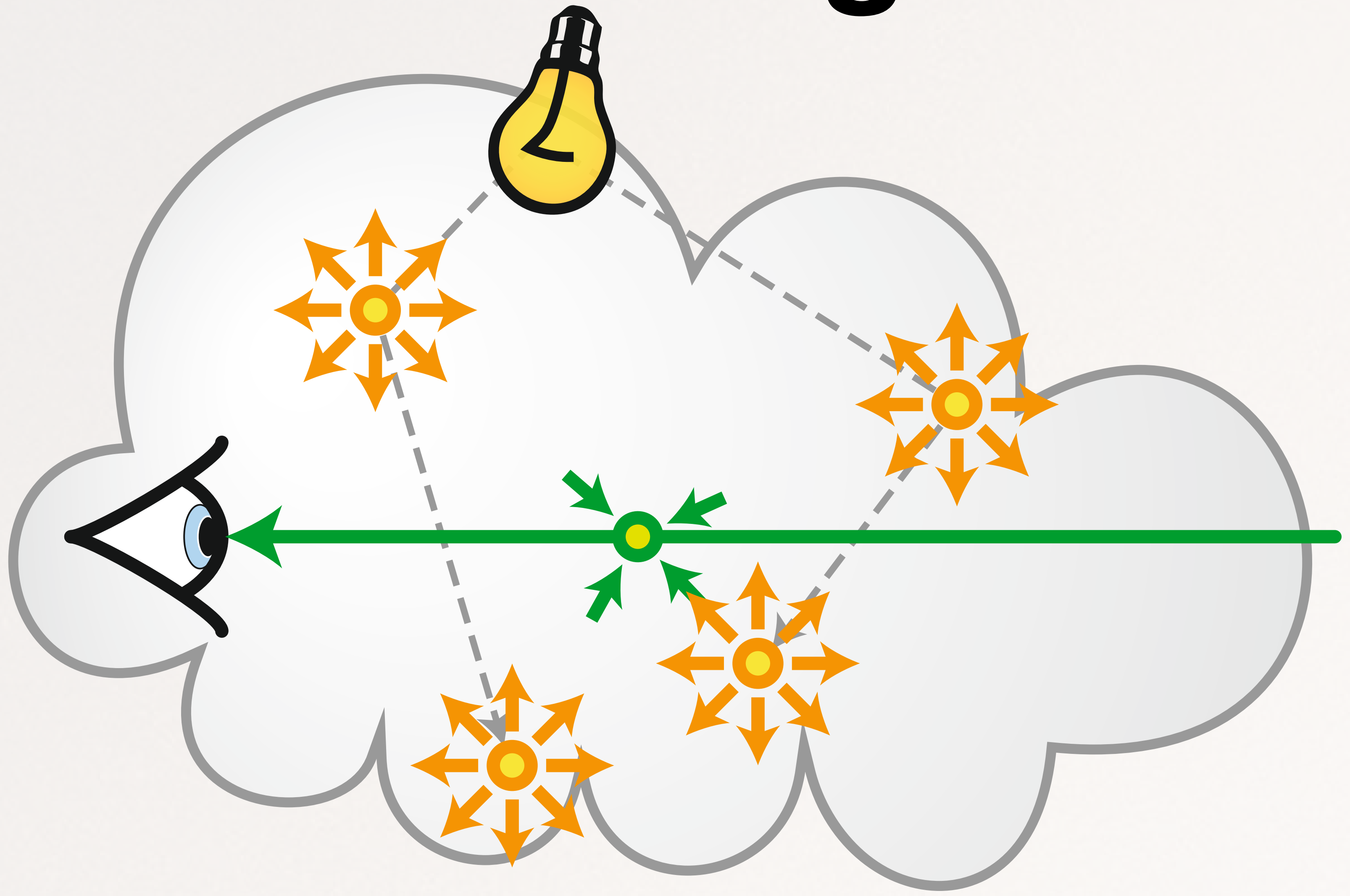


From points to rays

Point Lights



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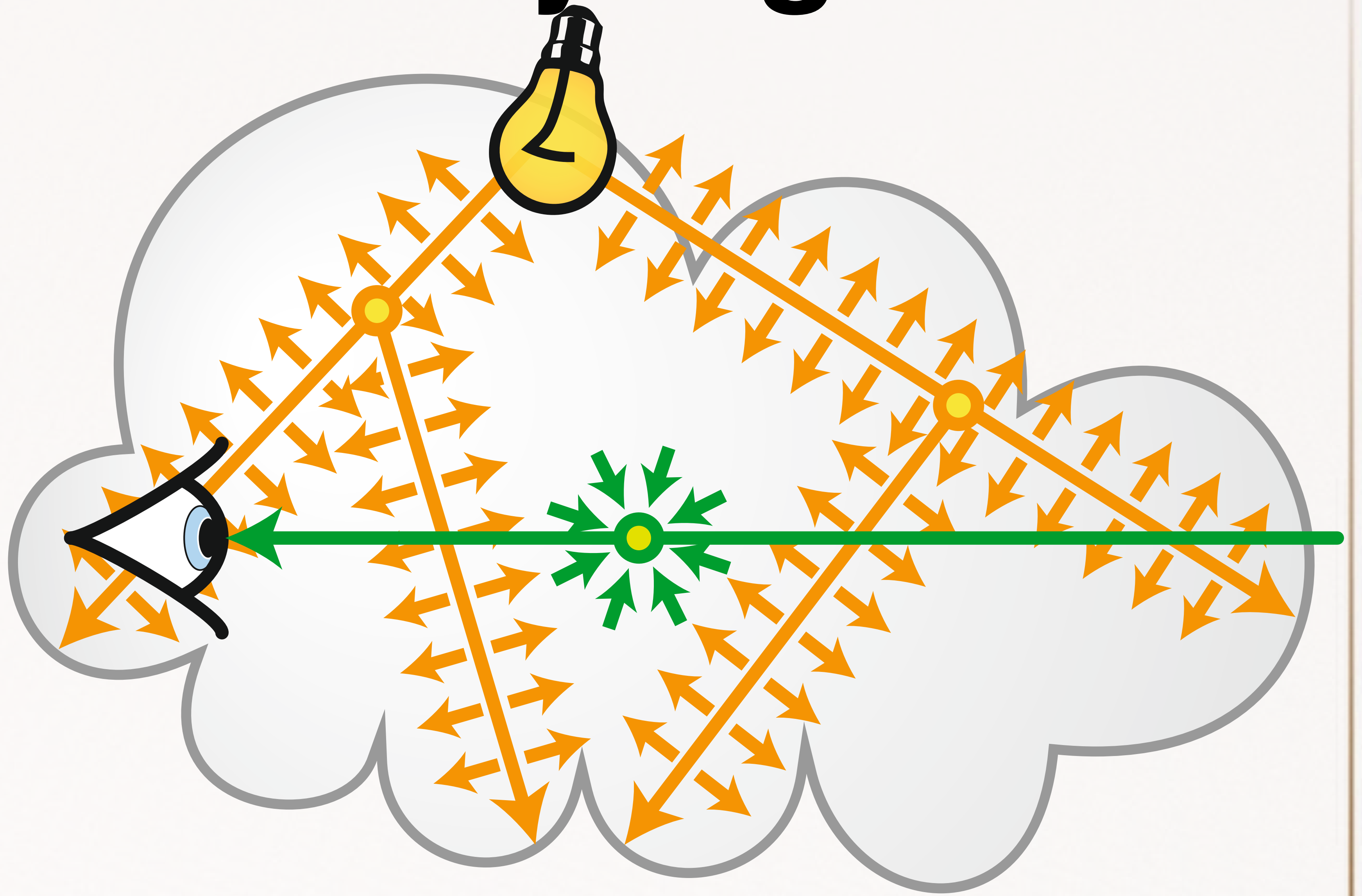

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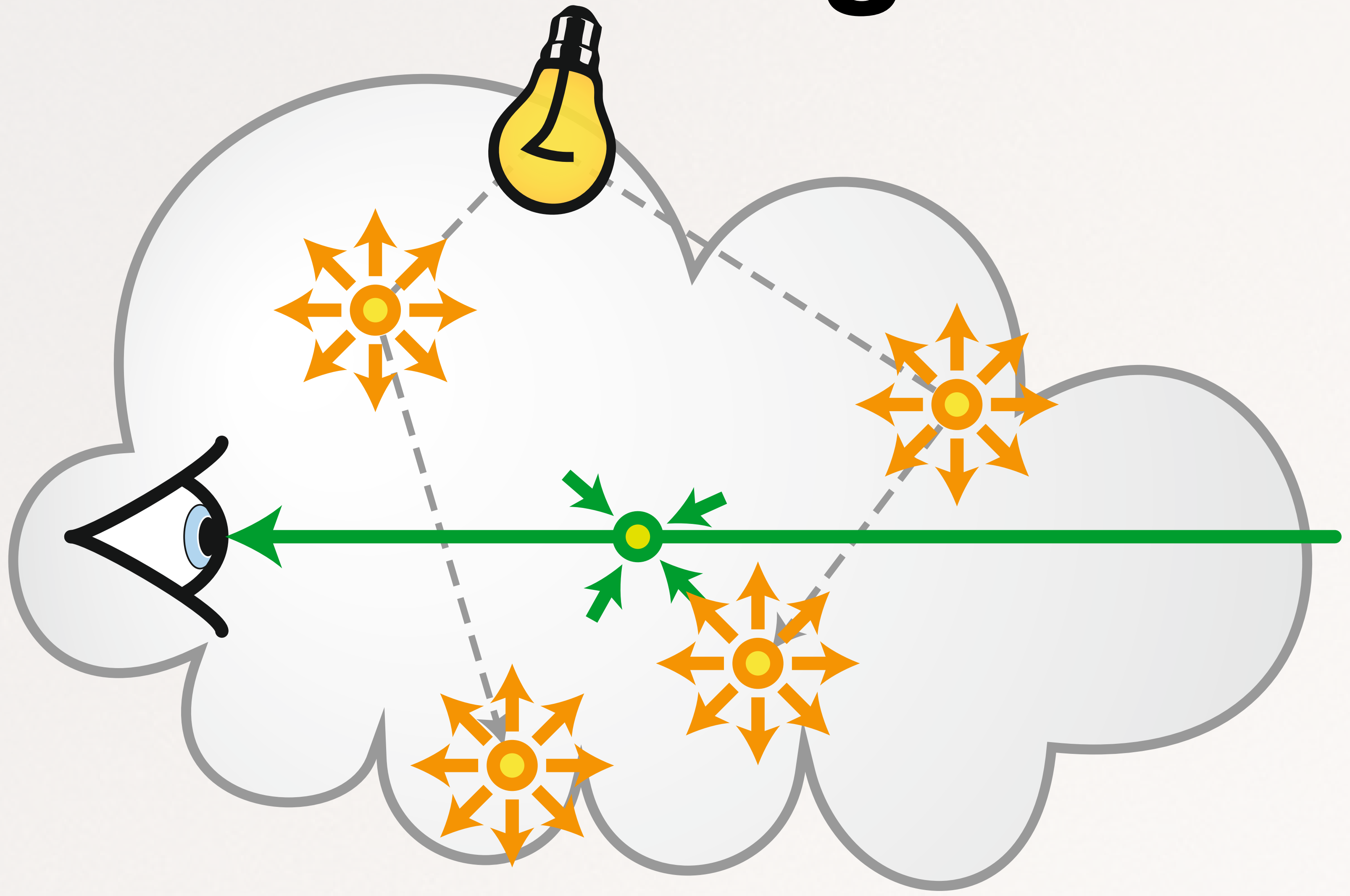
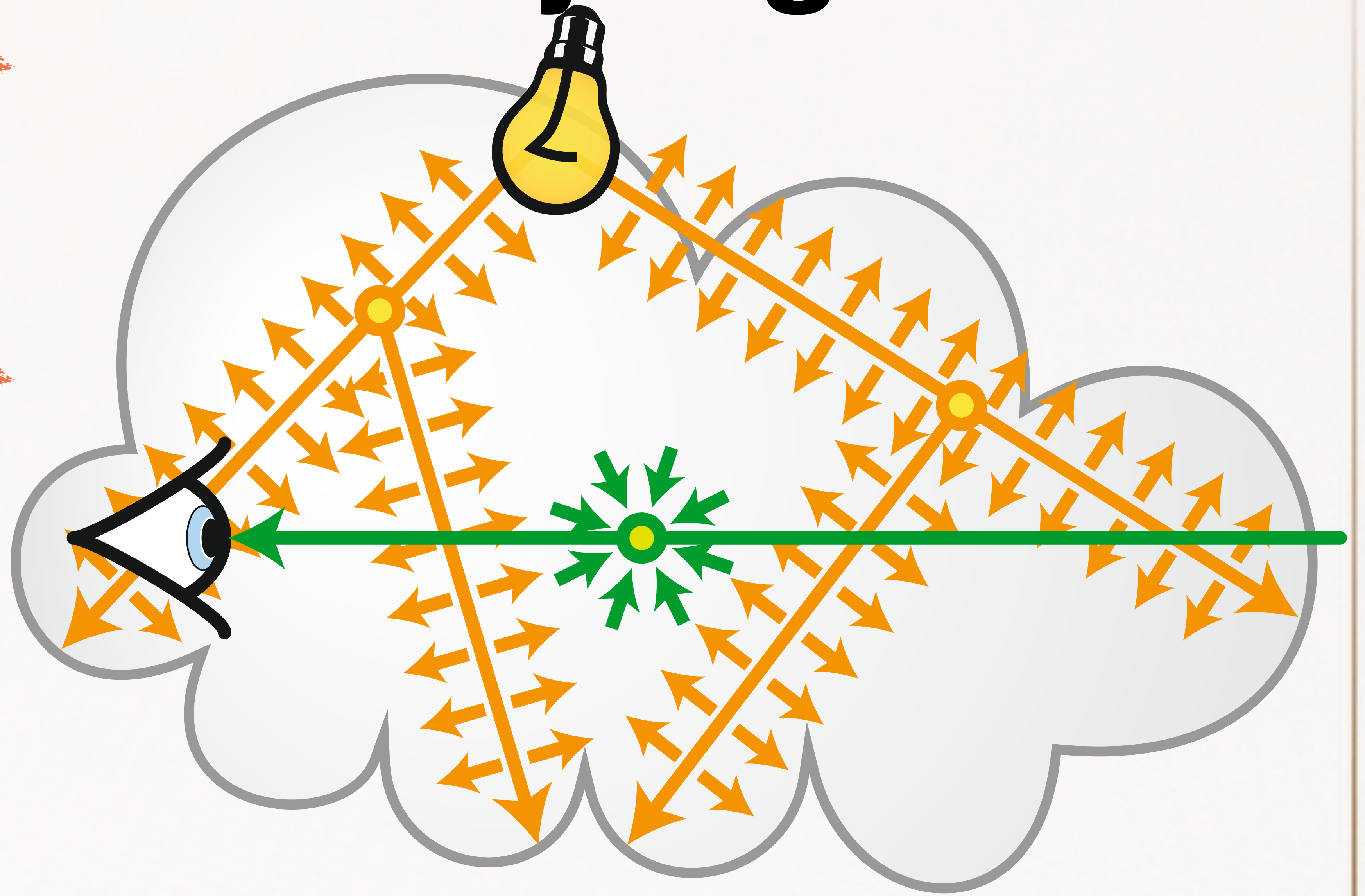


provably reduce singularities

no need to clamp, unbiased

Ray Lights



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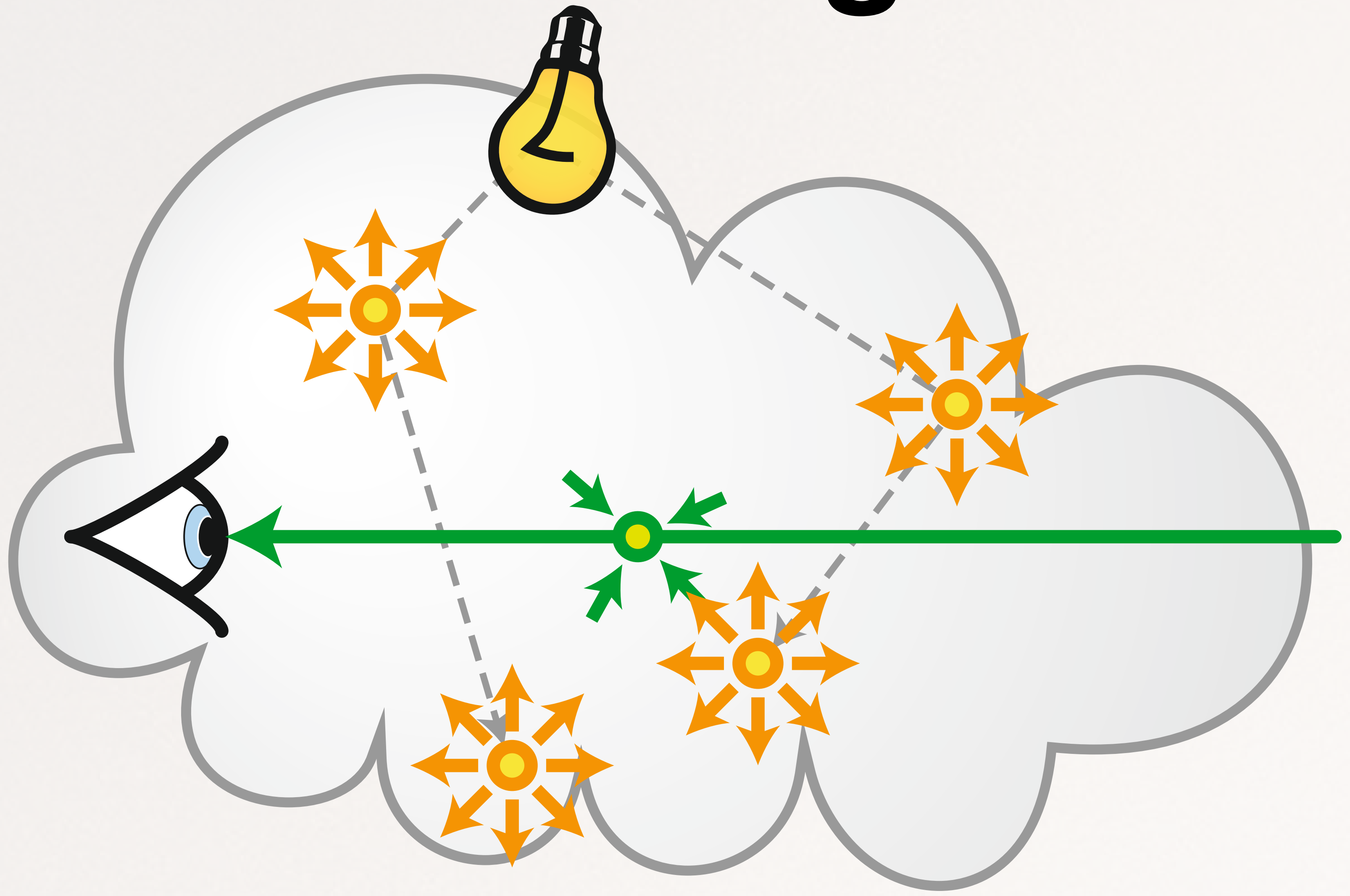

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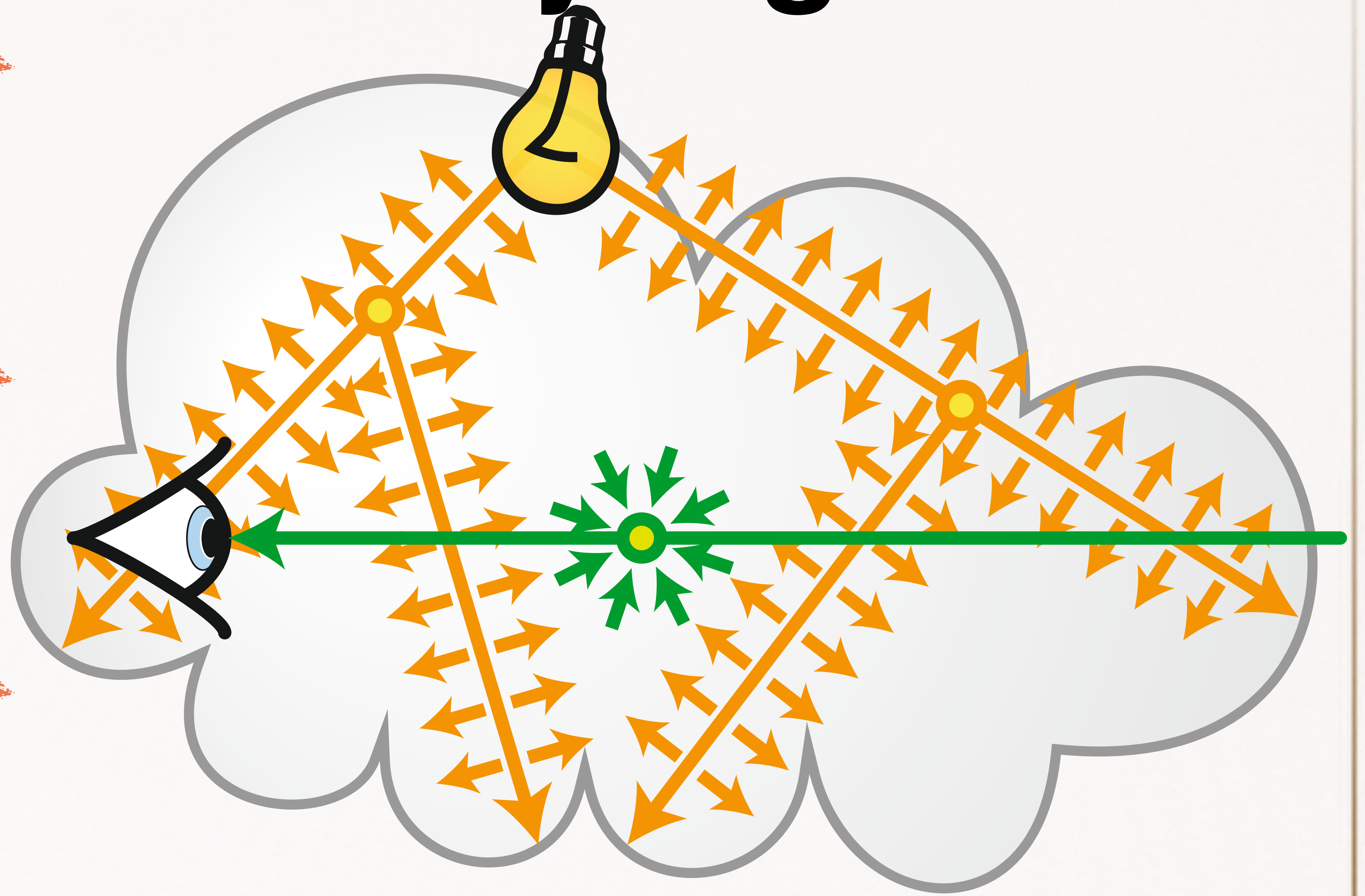
increase sampling of path space

Ray Lights



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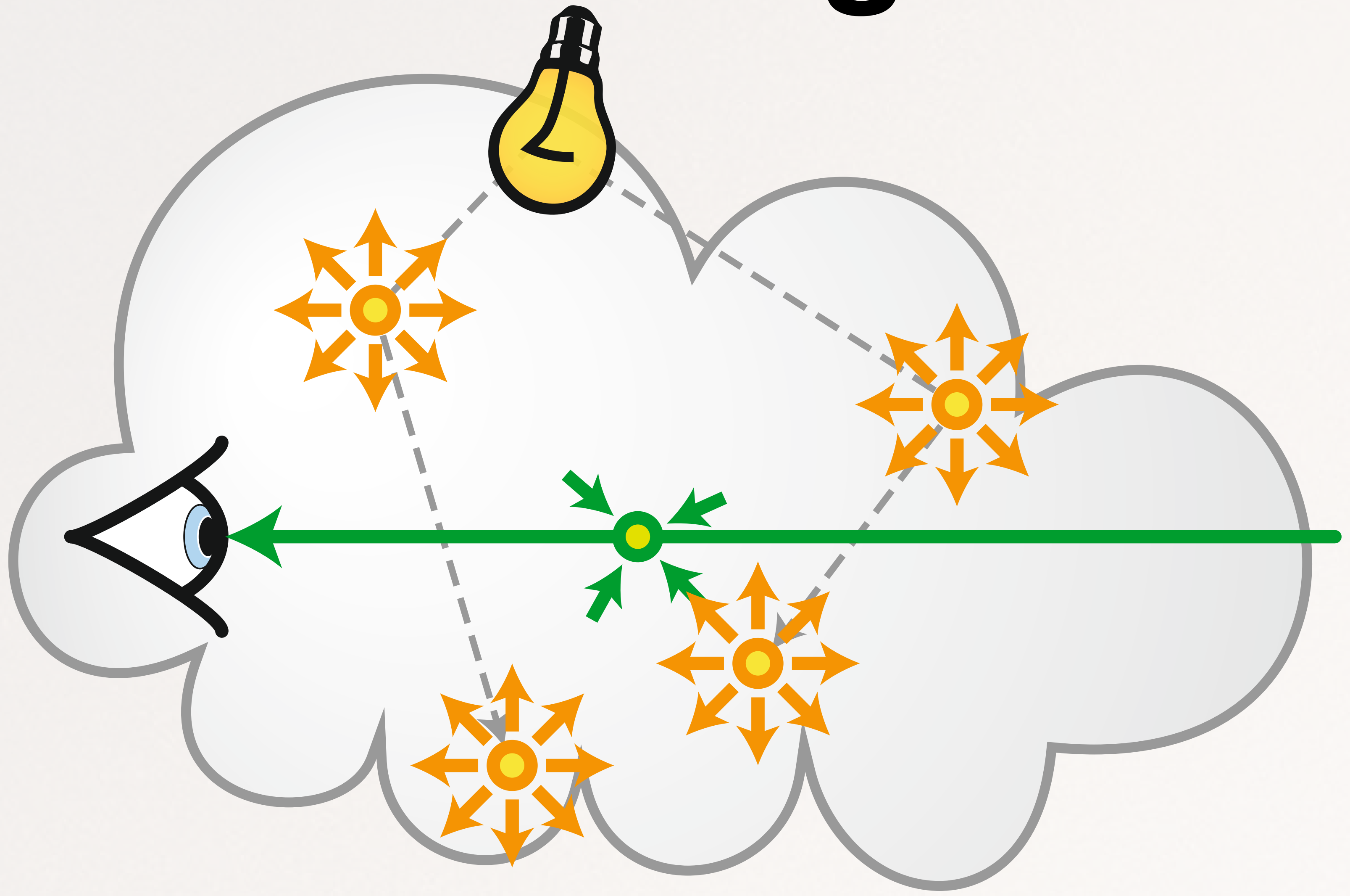
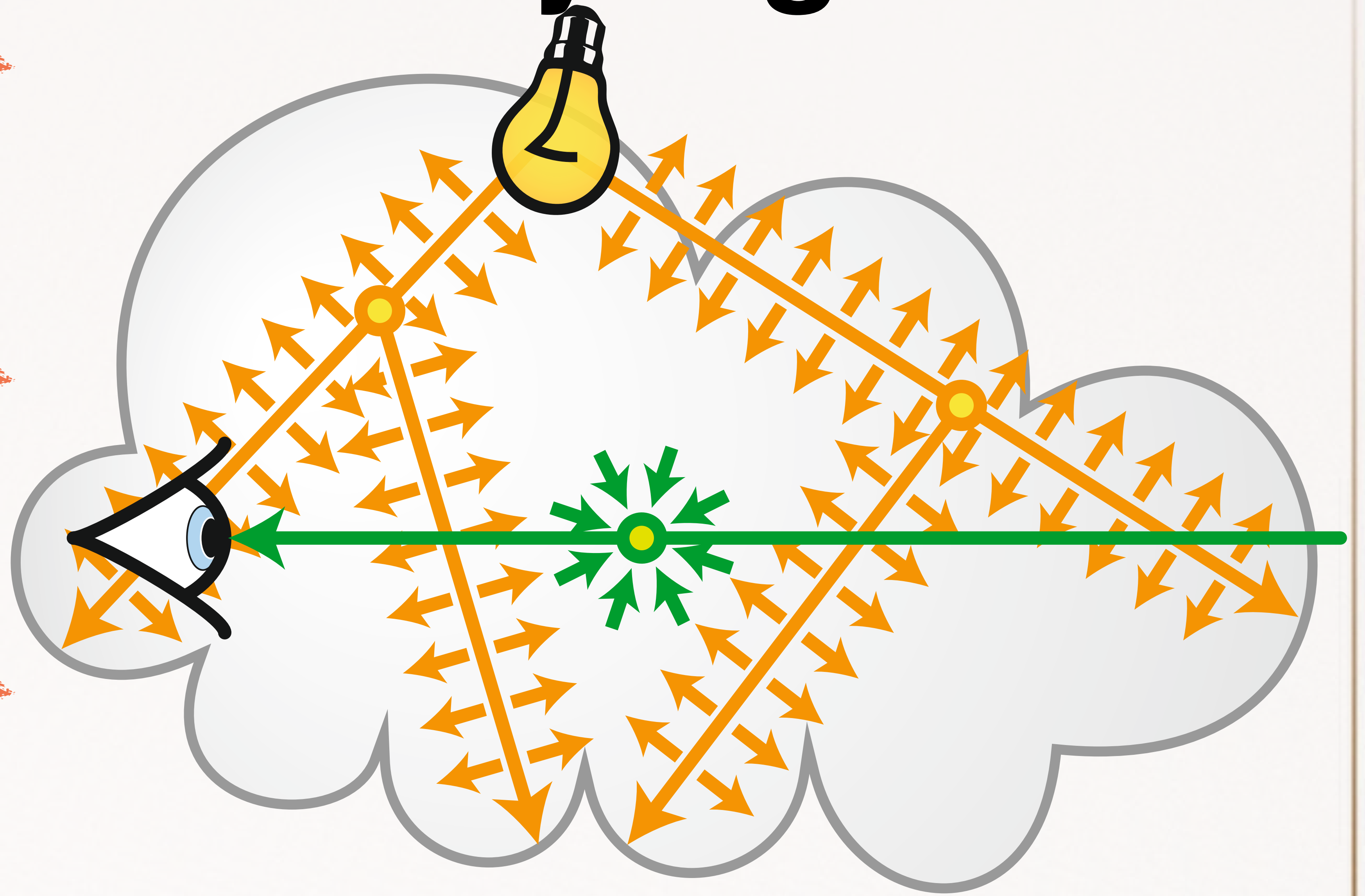


- provably reduce singularities
- no need to clamp, unbiased
- increase sampling of path space
- handle anisotropic “glossy” media

Ray Lights



Quick demo

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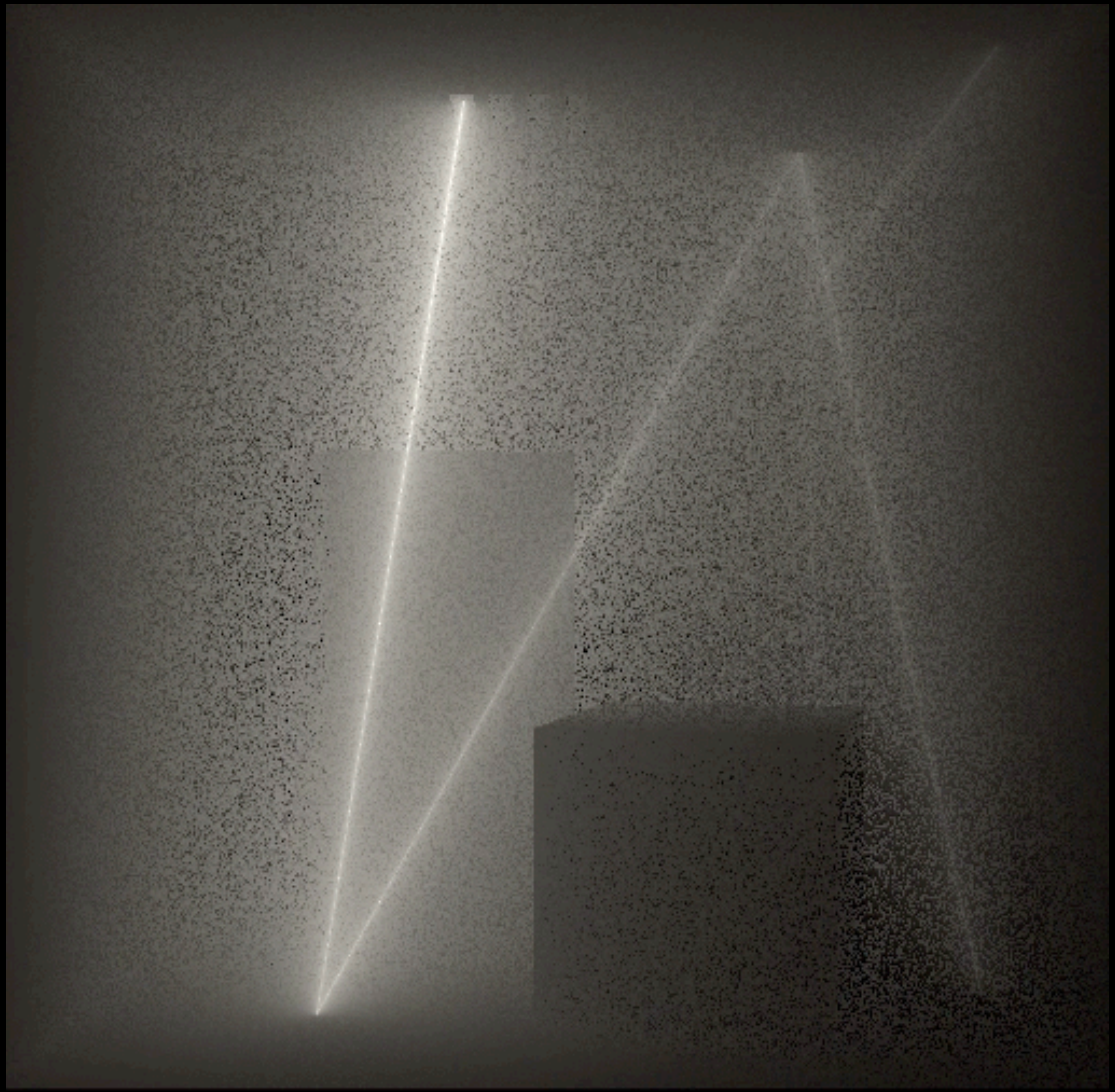
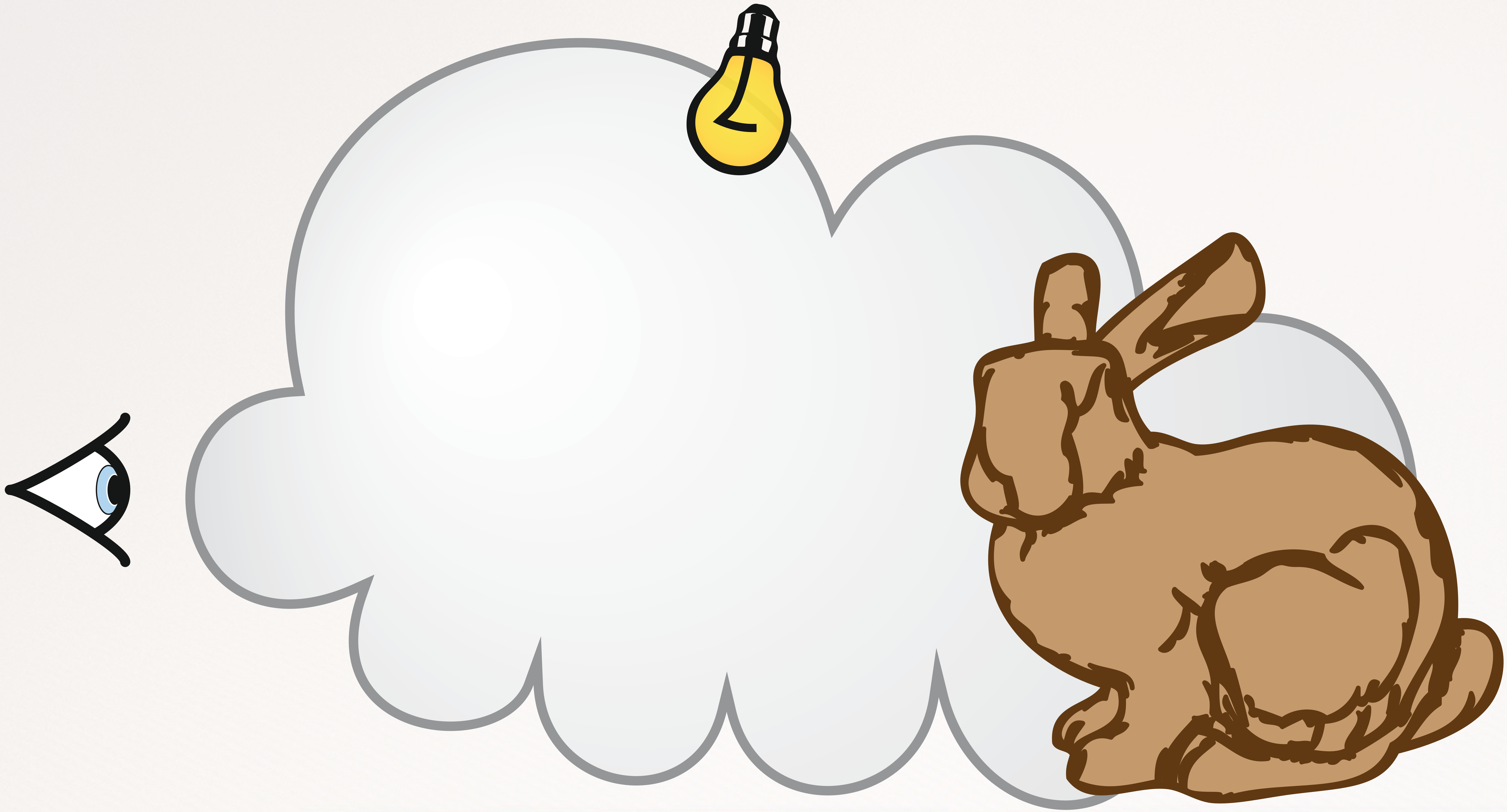


6 VRLs

Algorithm overview



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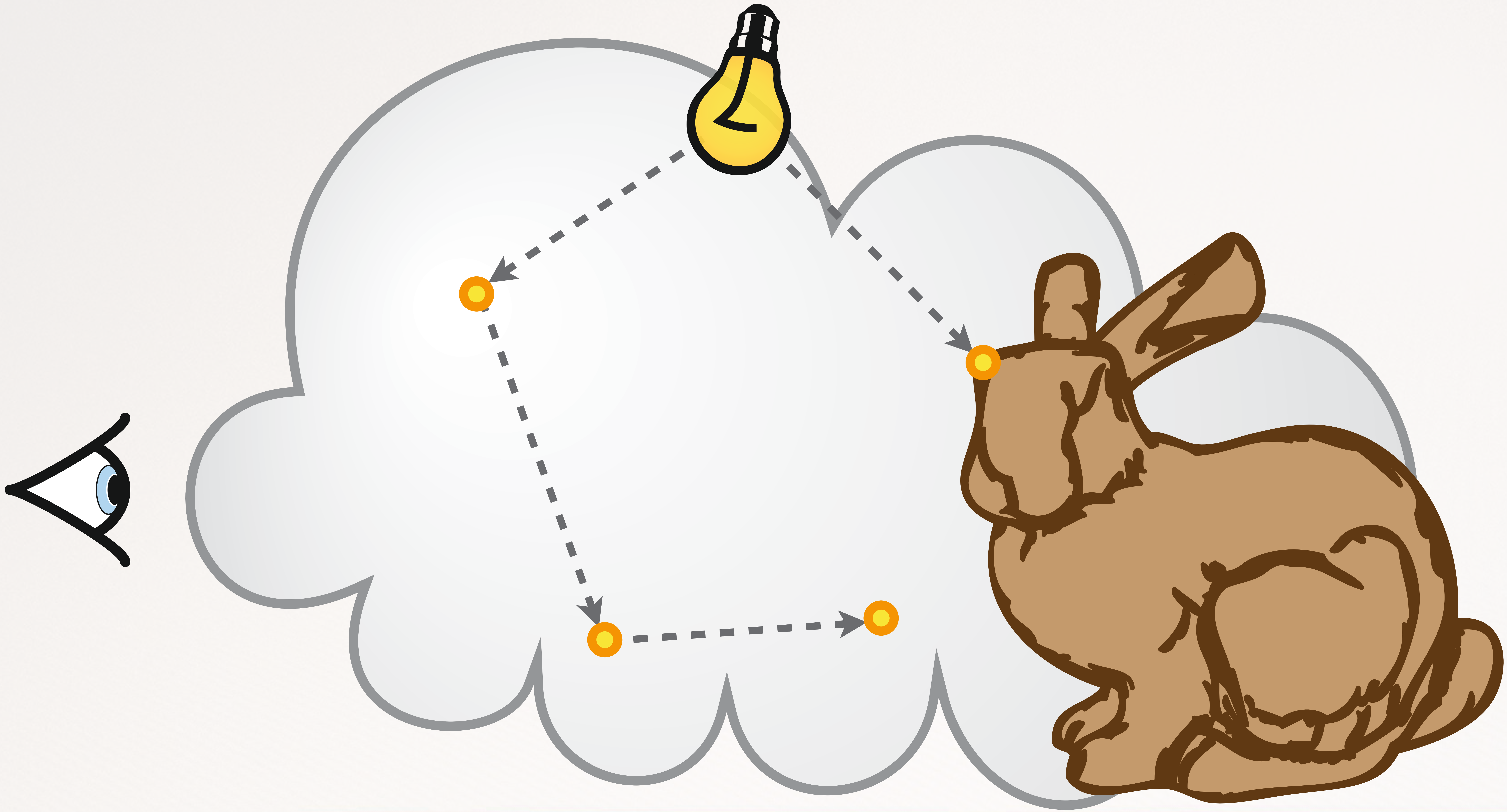

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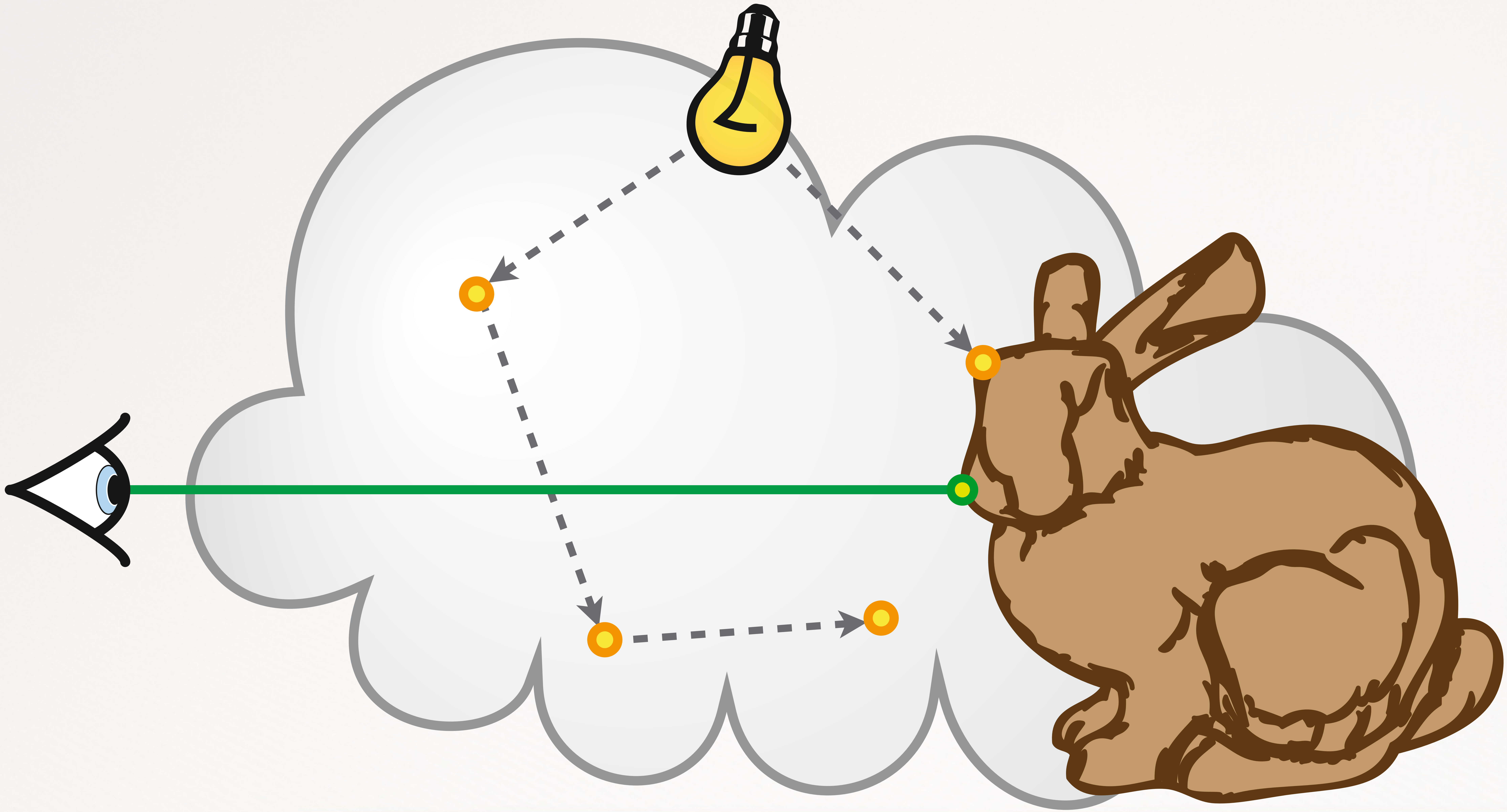

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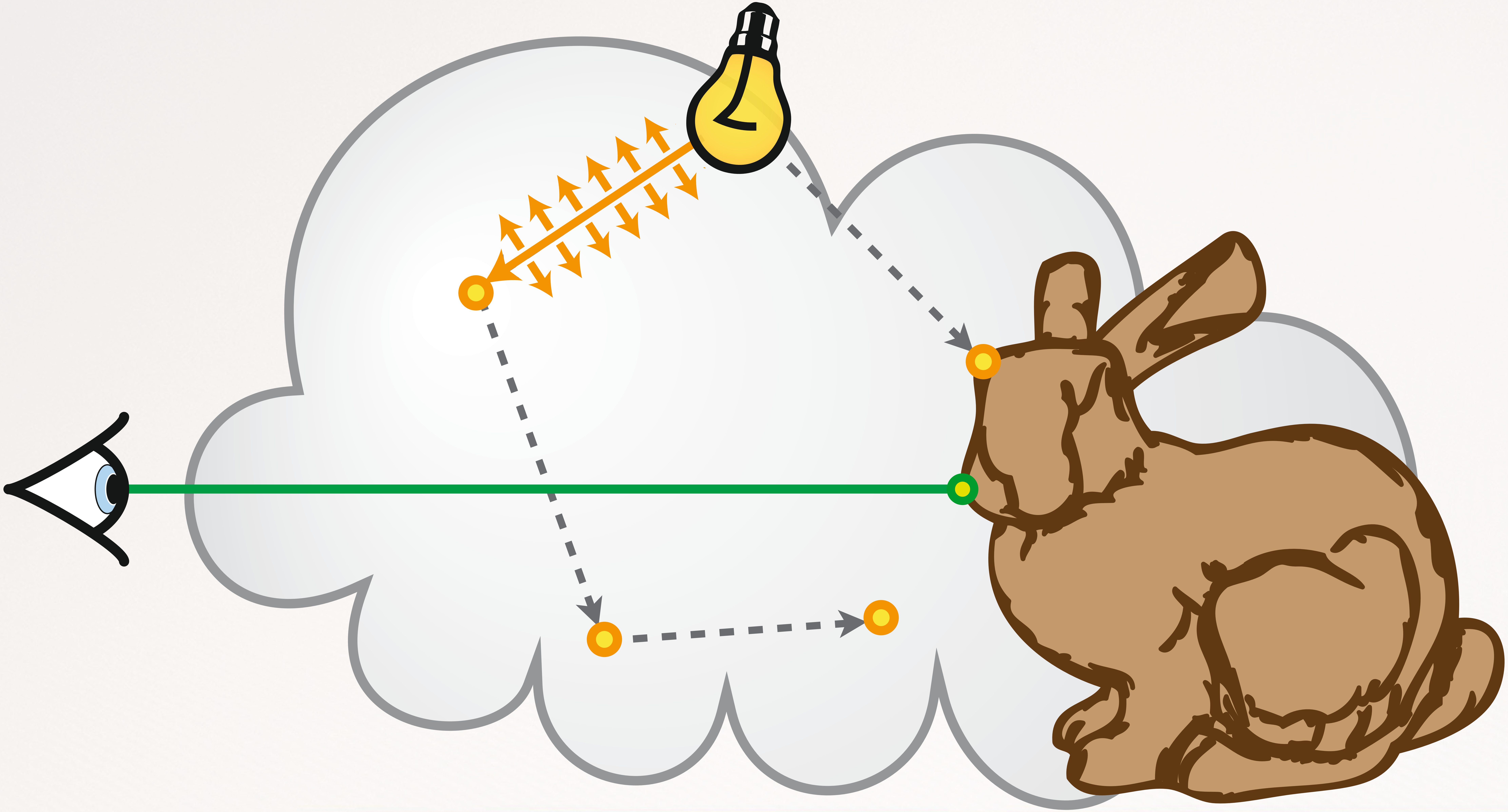

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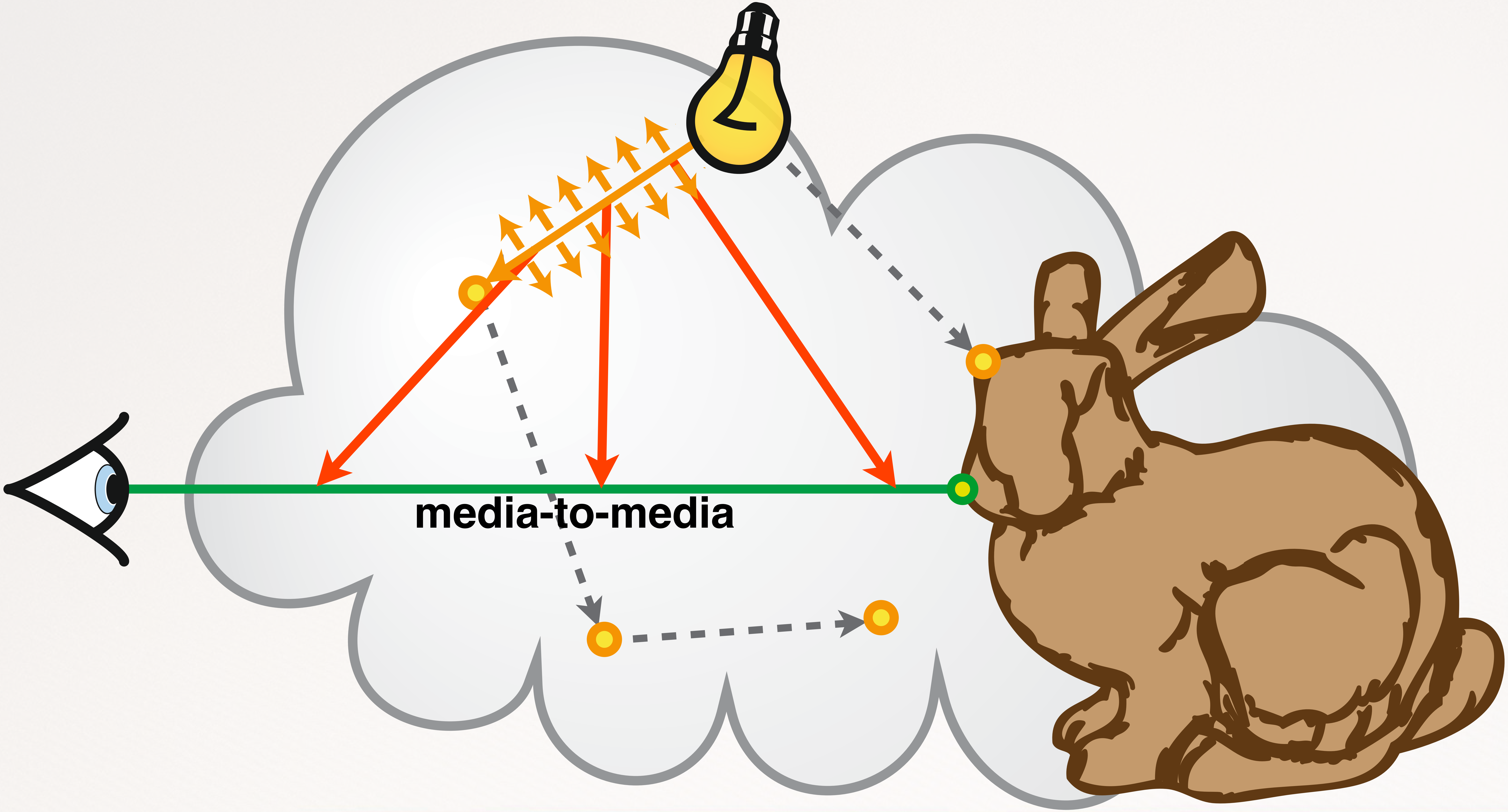

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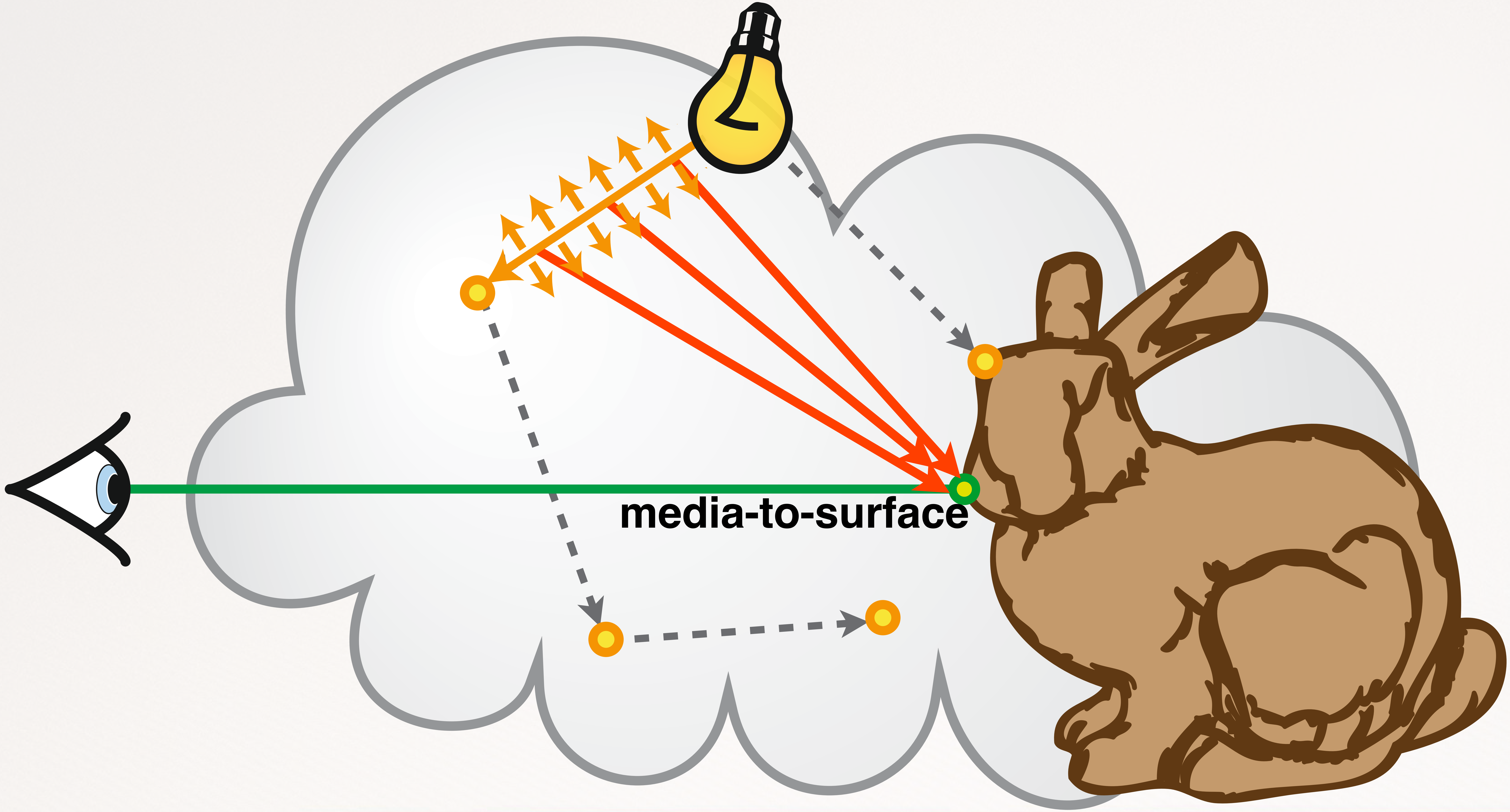

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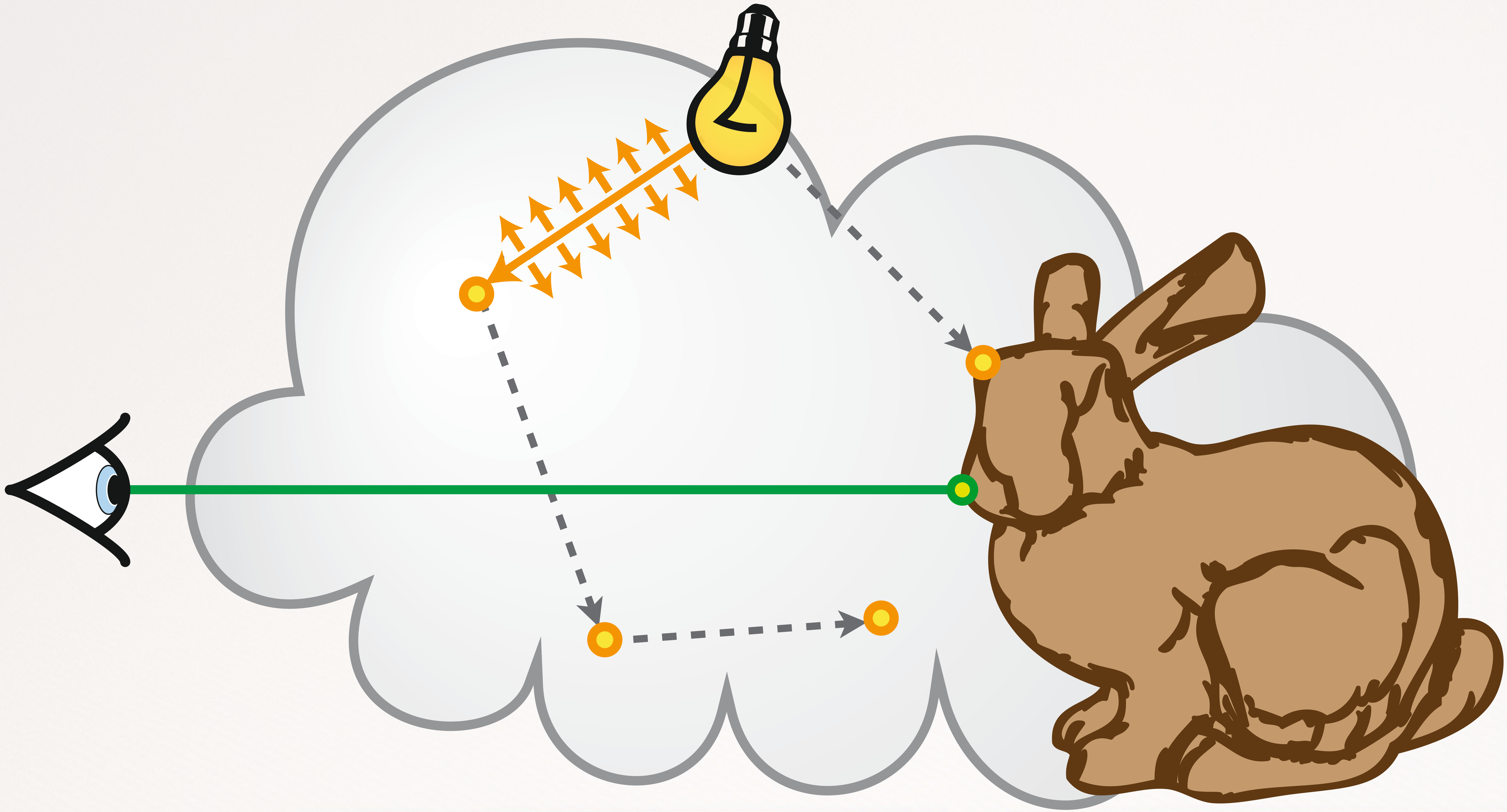

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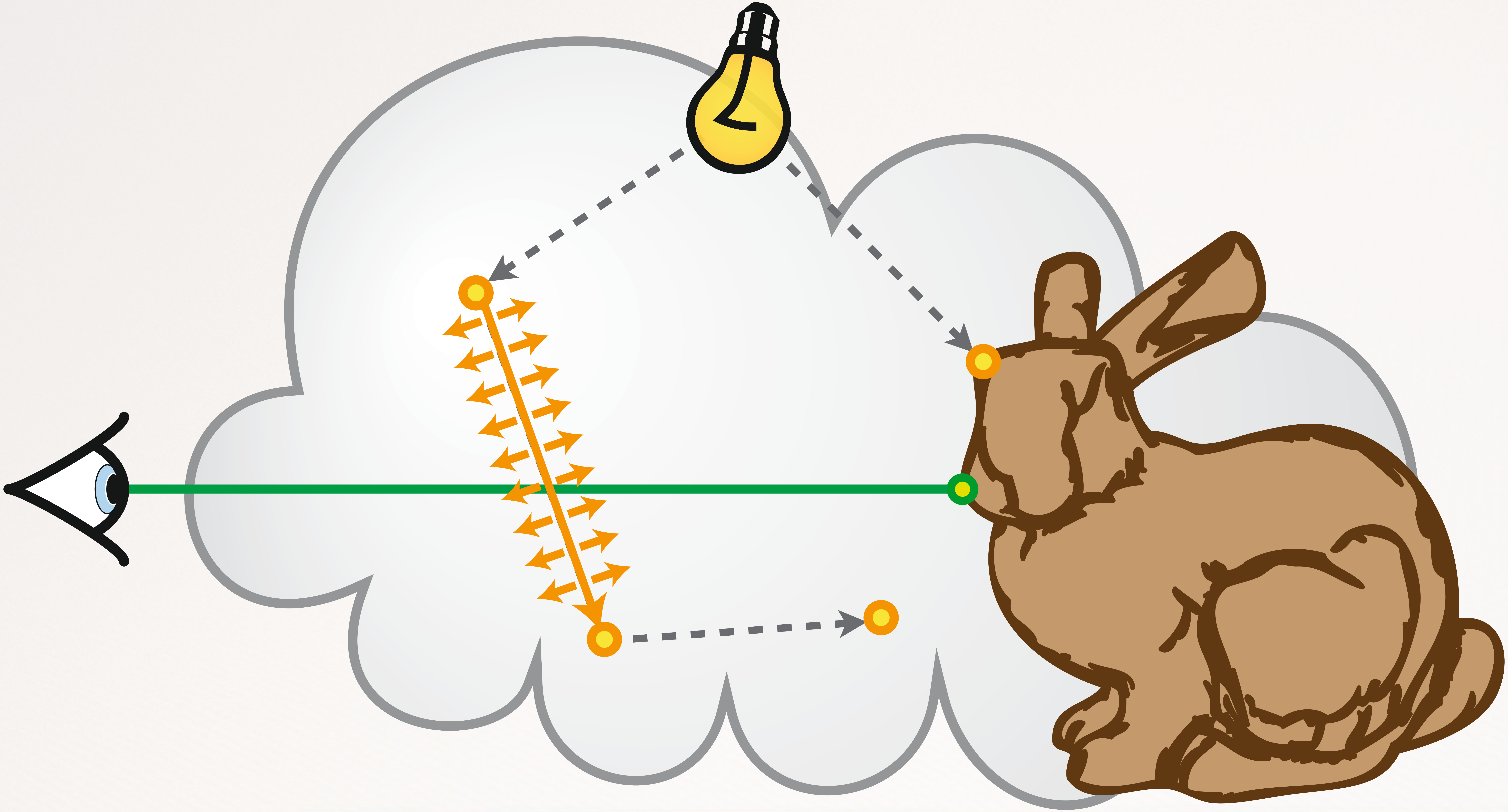

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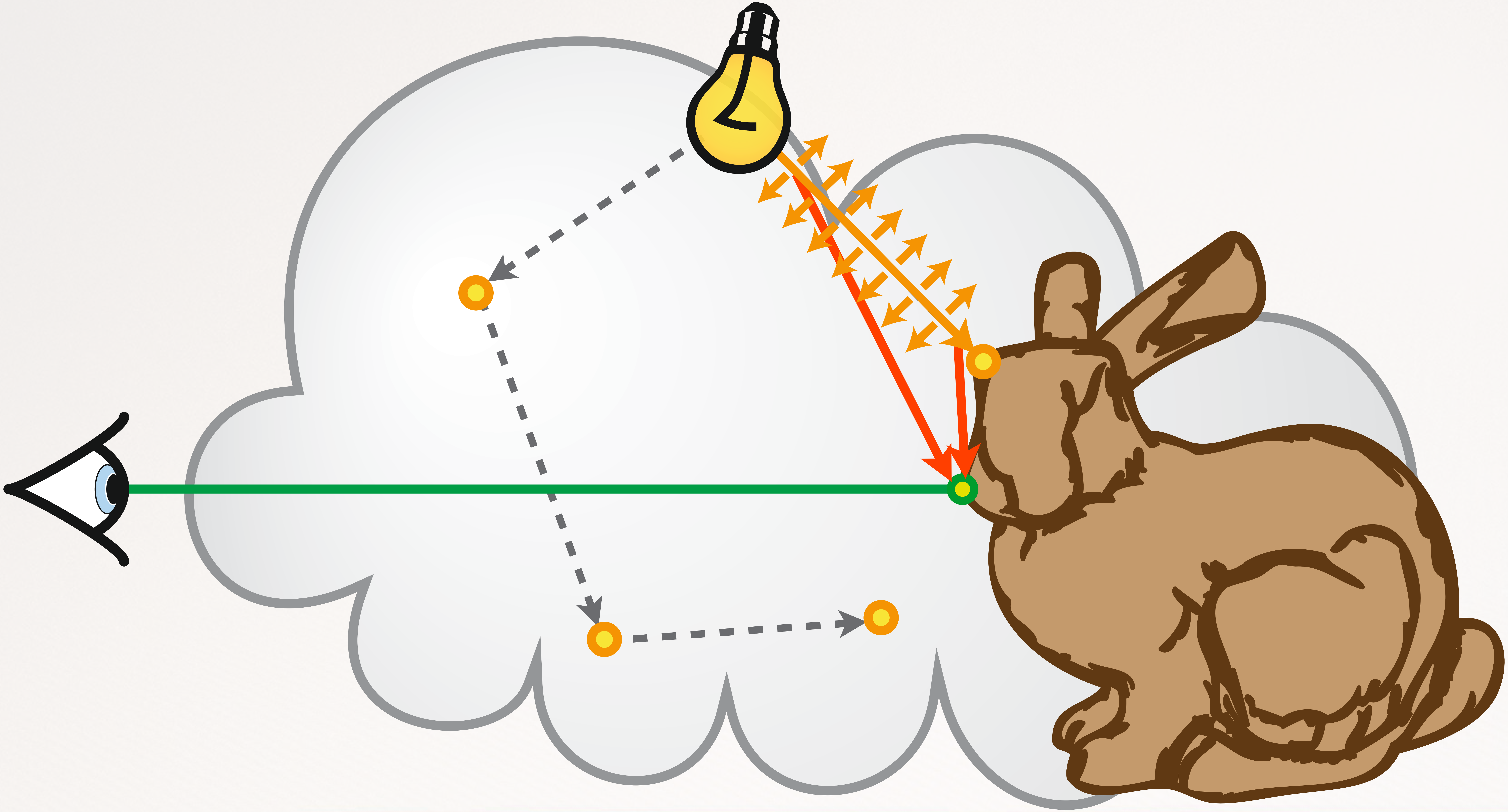

Ray-to-Ray transport

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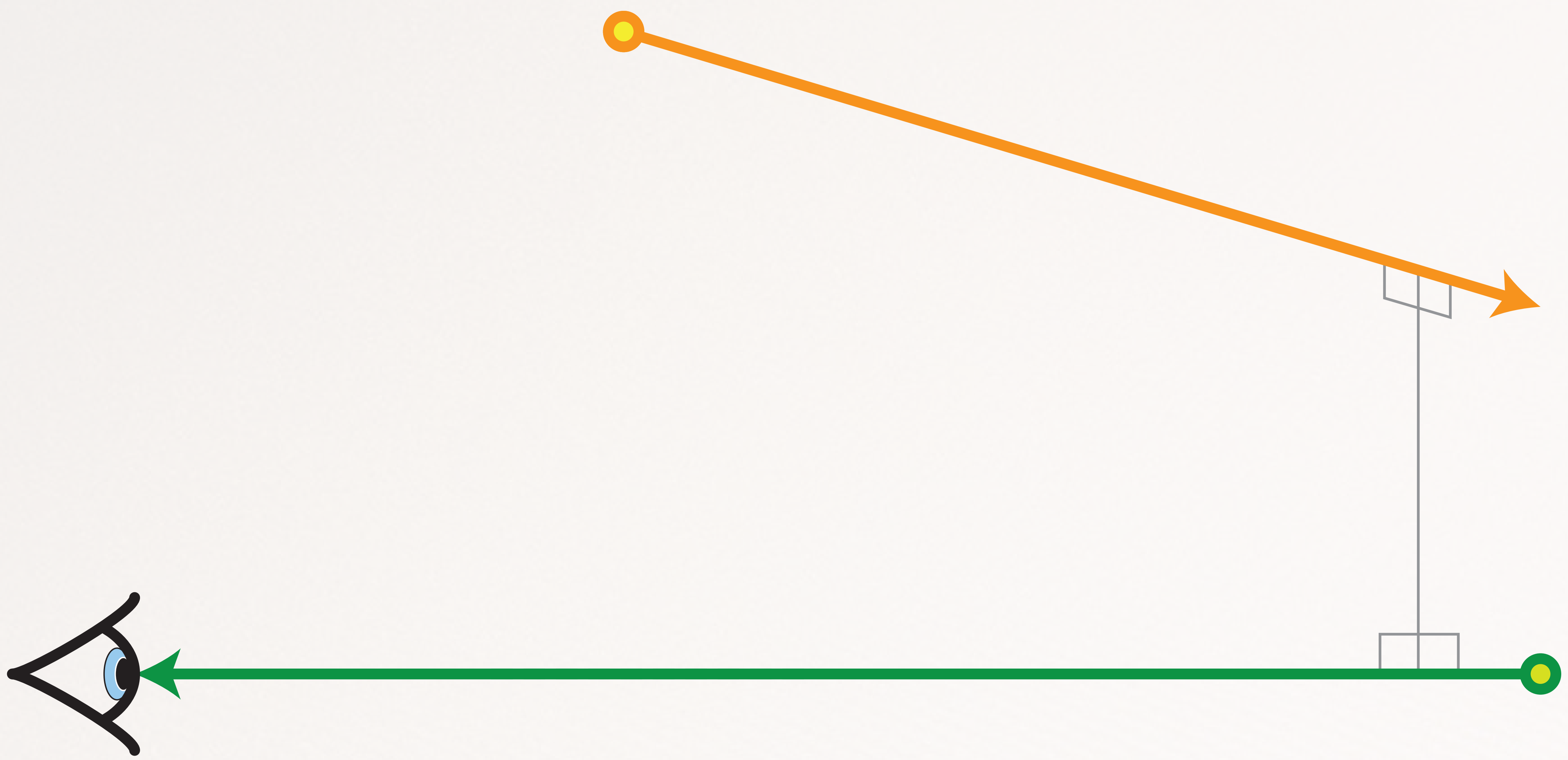

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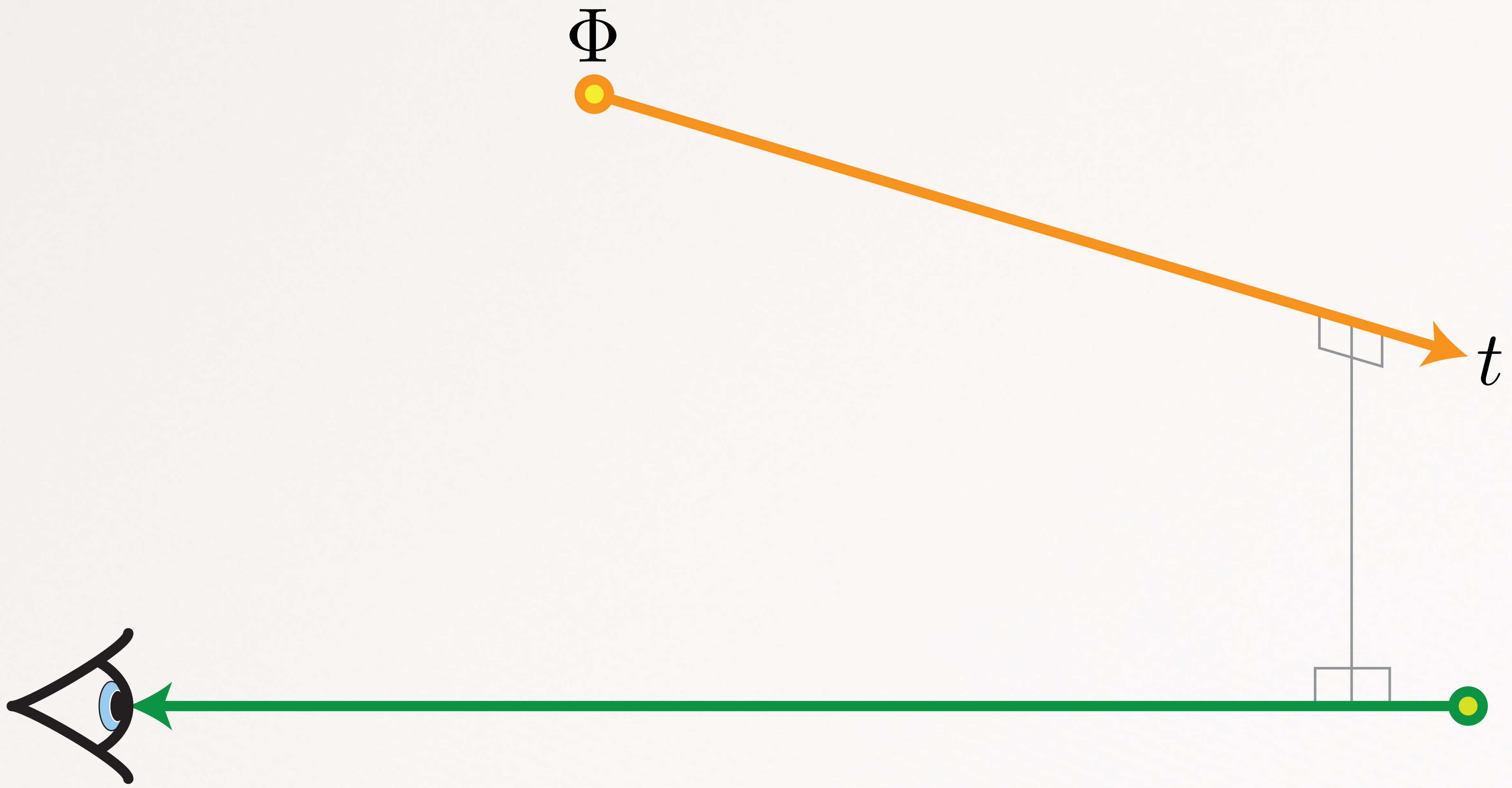

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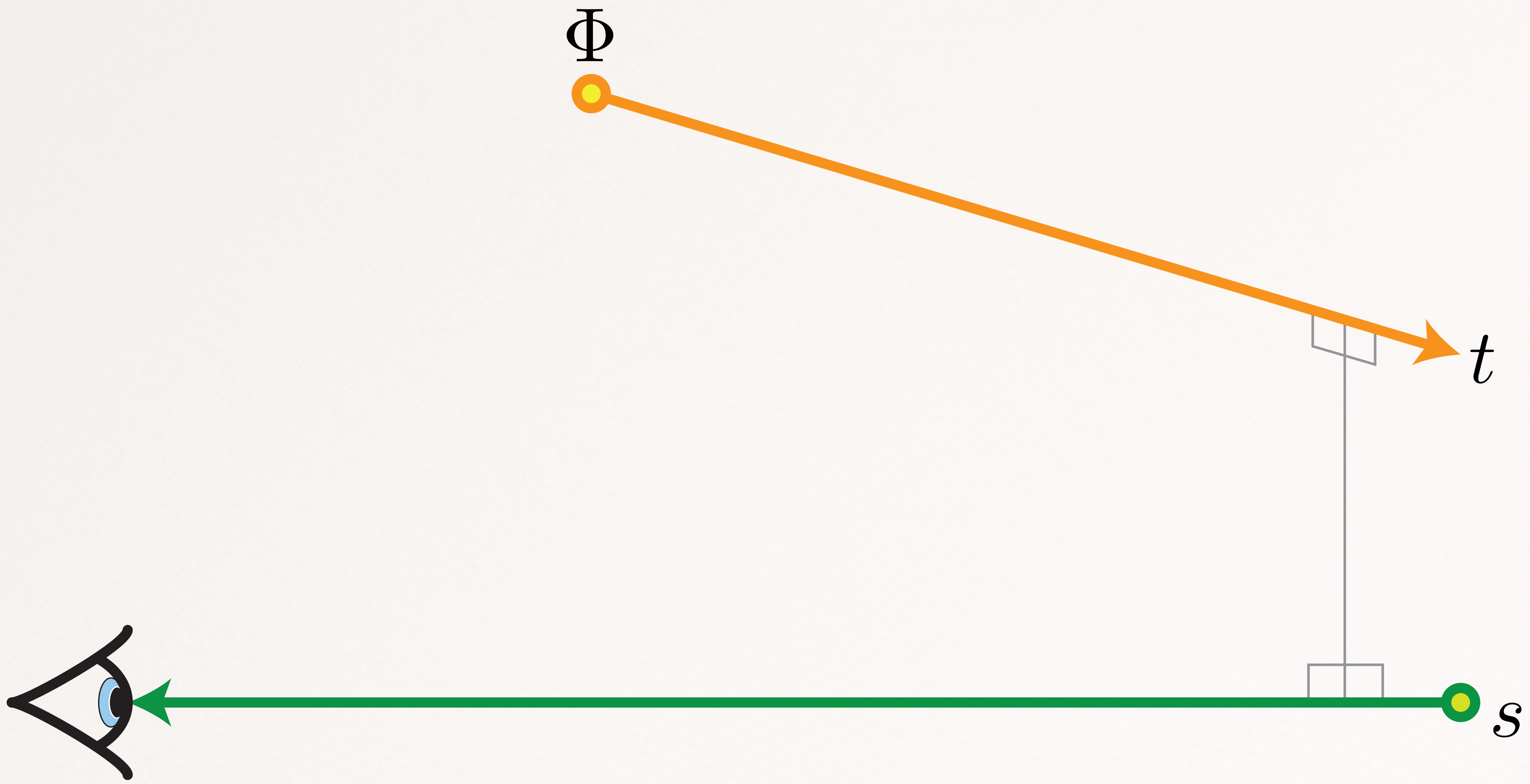

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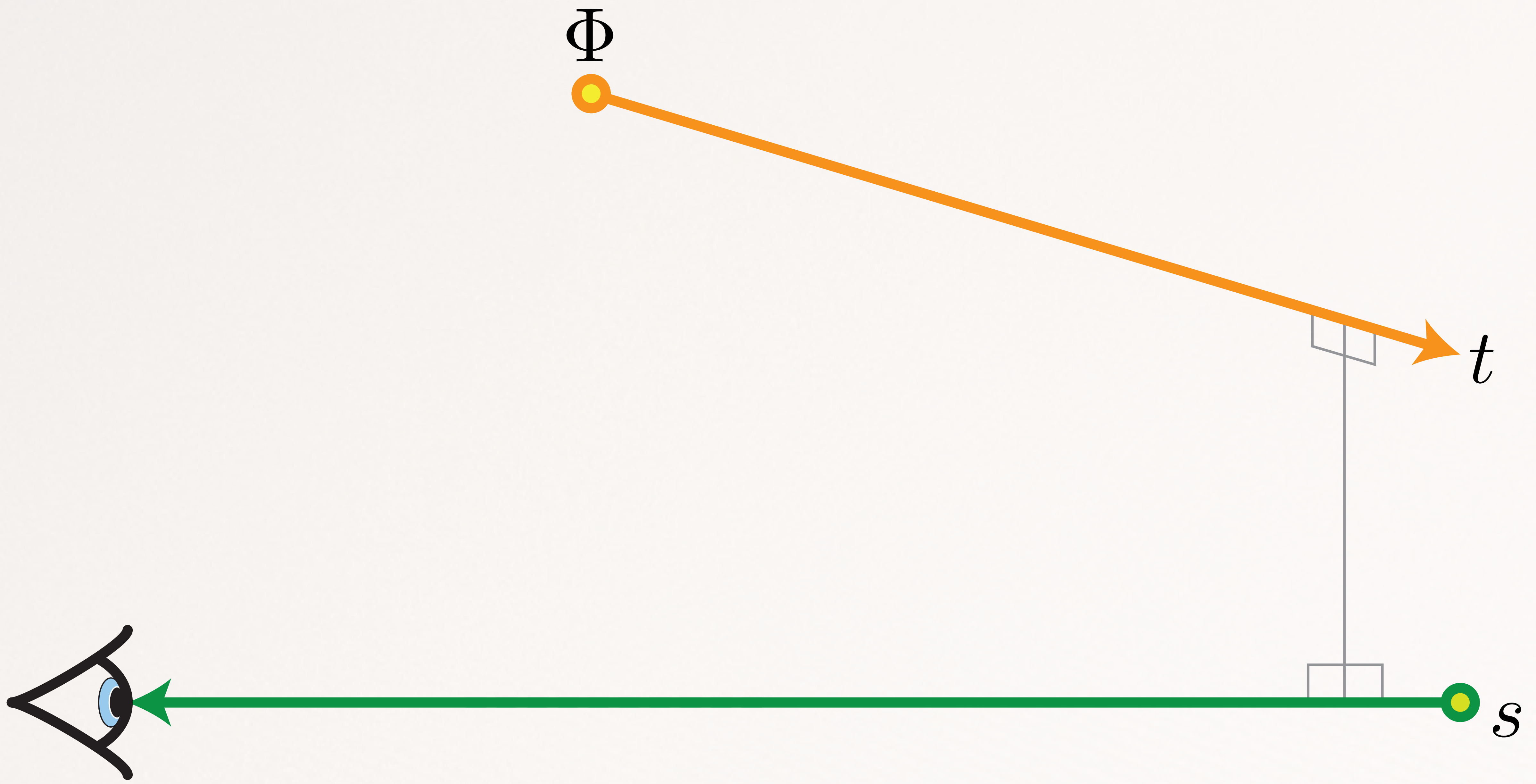
$$L = \Phi \int_0^s \int_0^t \frac{\quad}{\quad} \, \mathrm{d}v \mathrm{d}u$$



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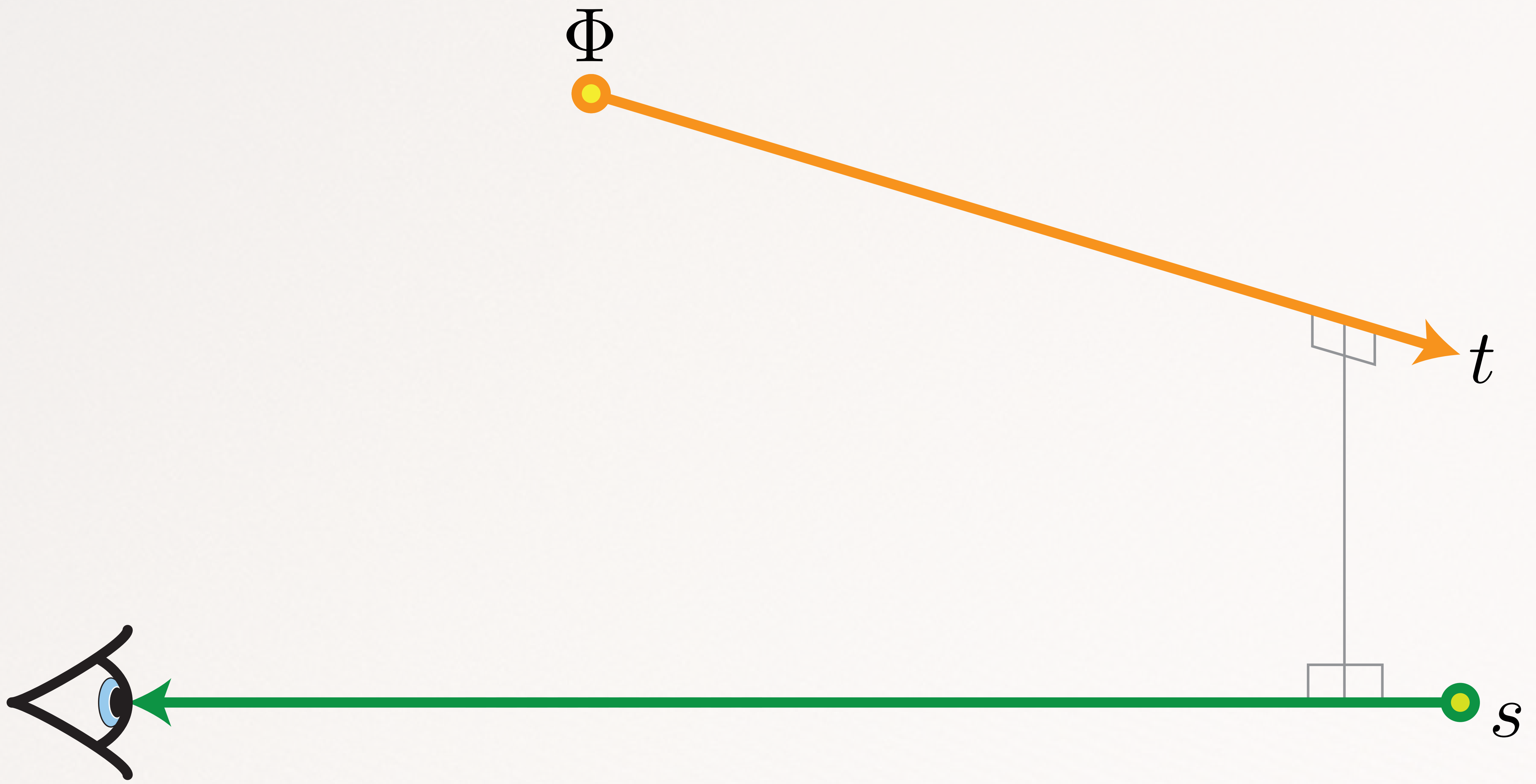

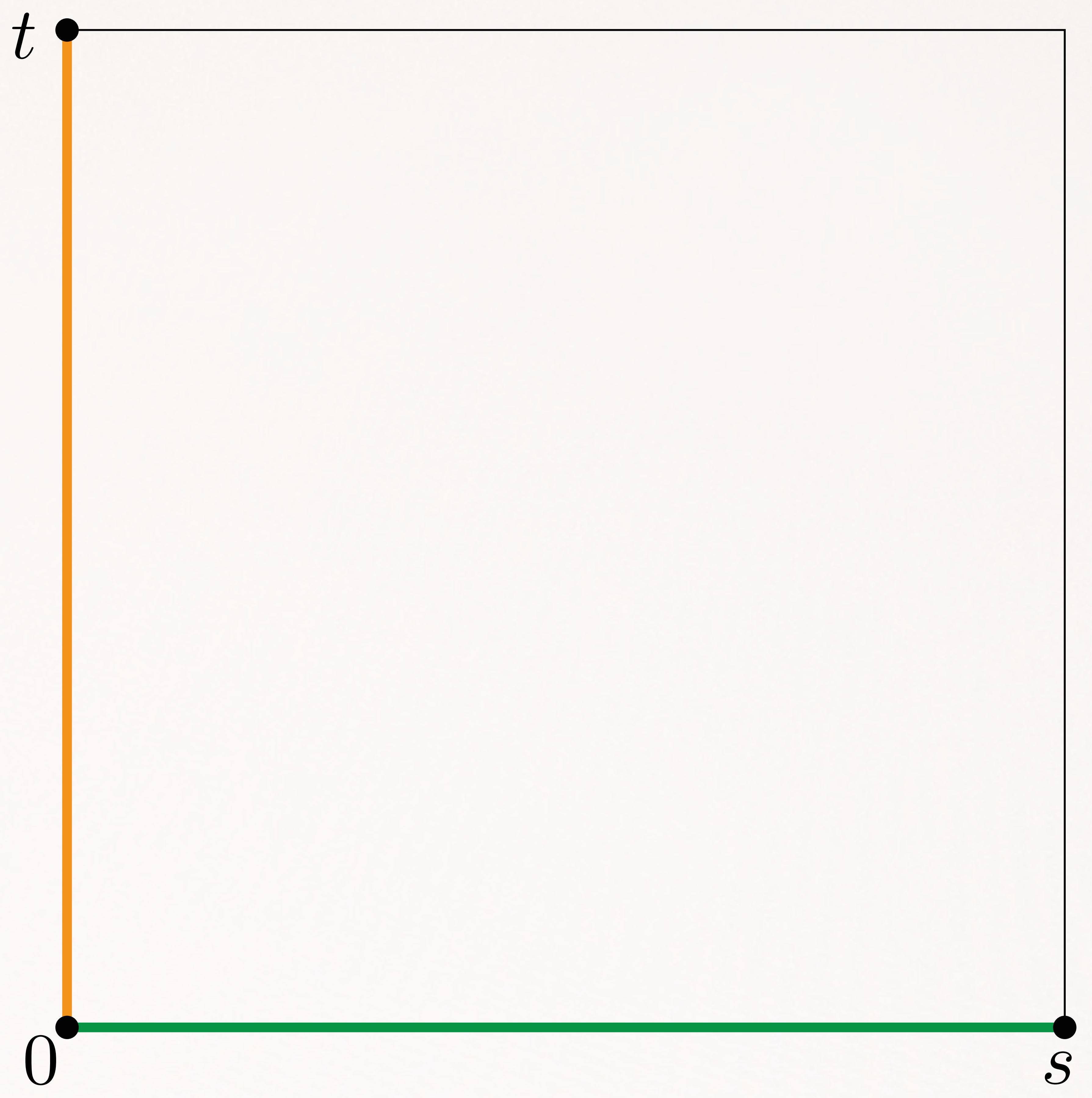

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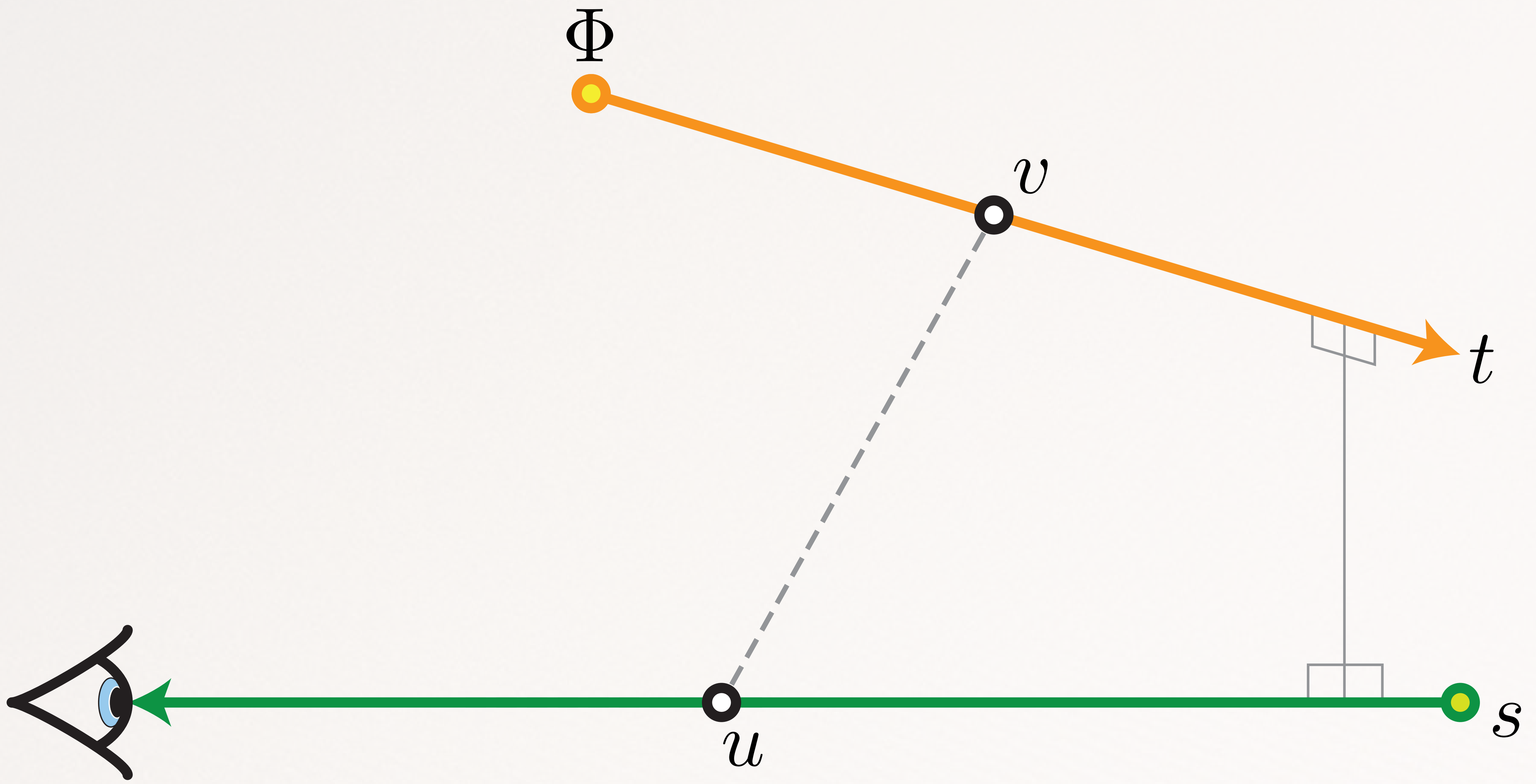
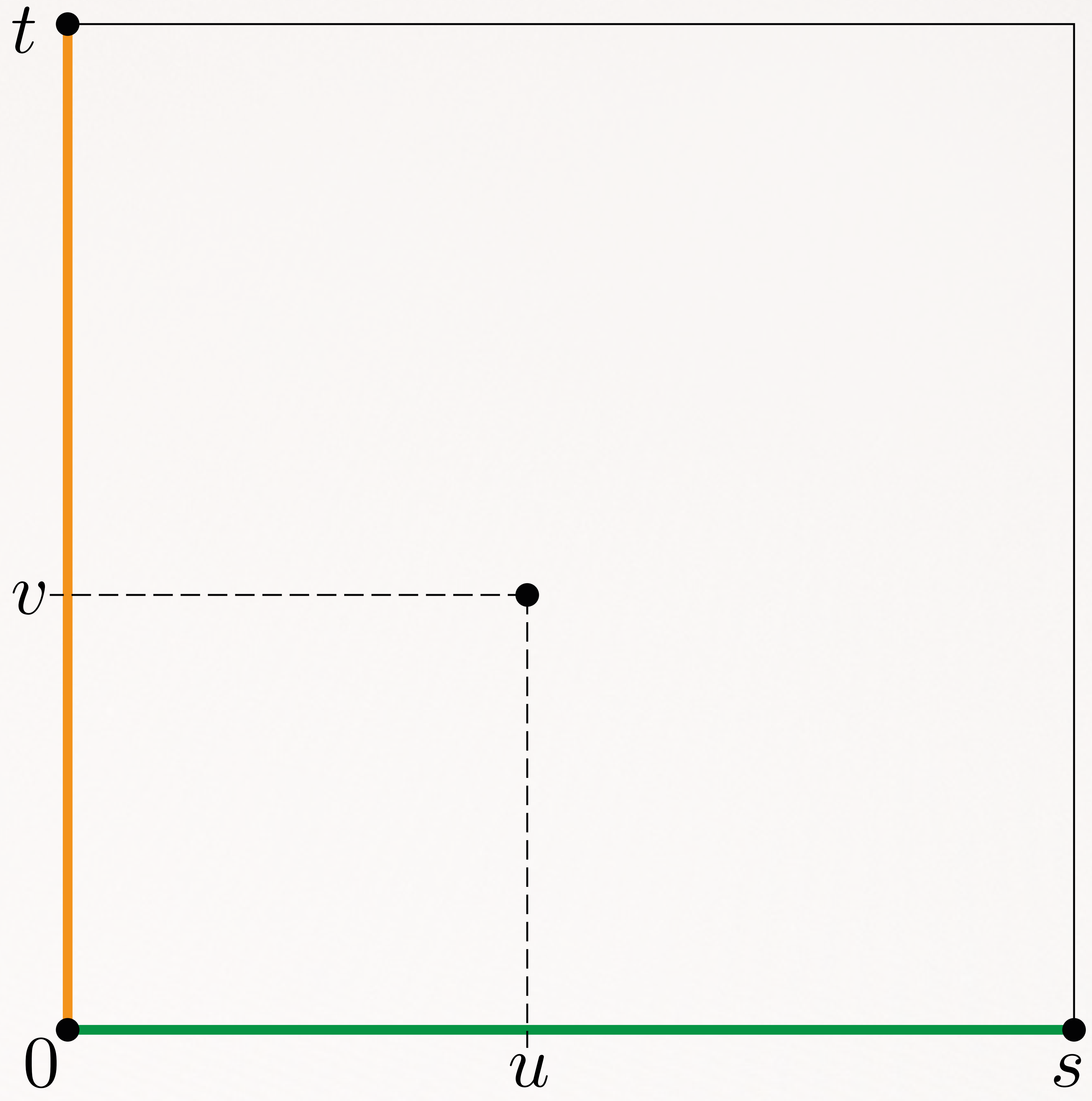
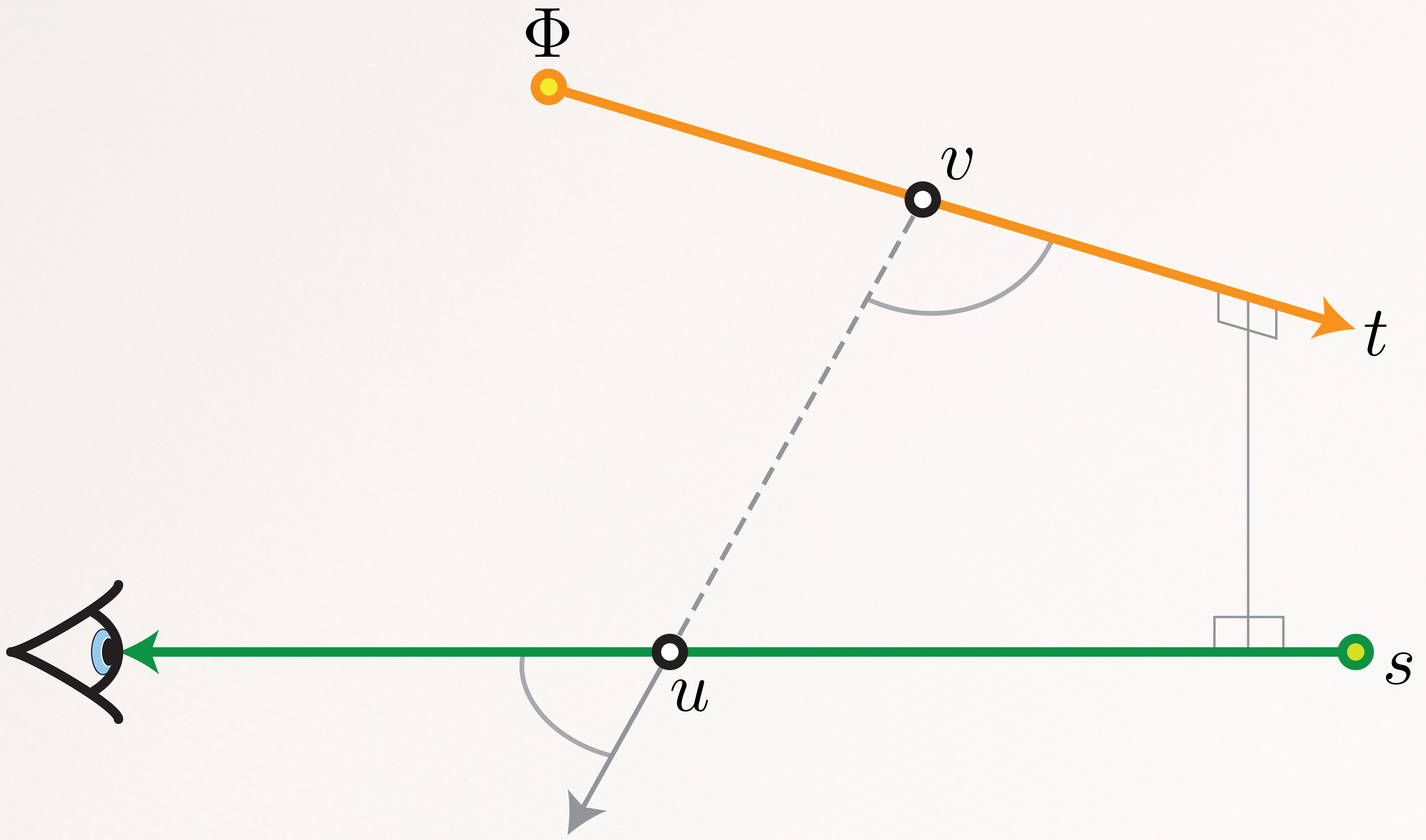


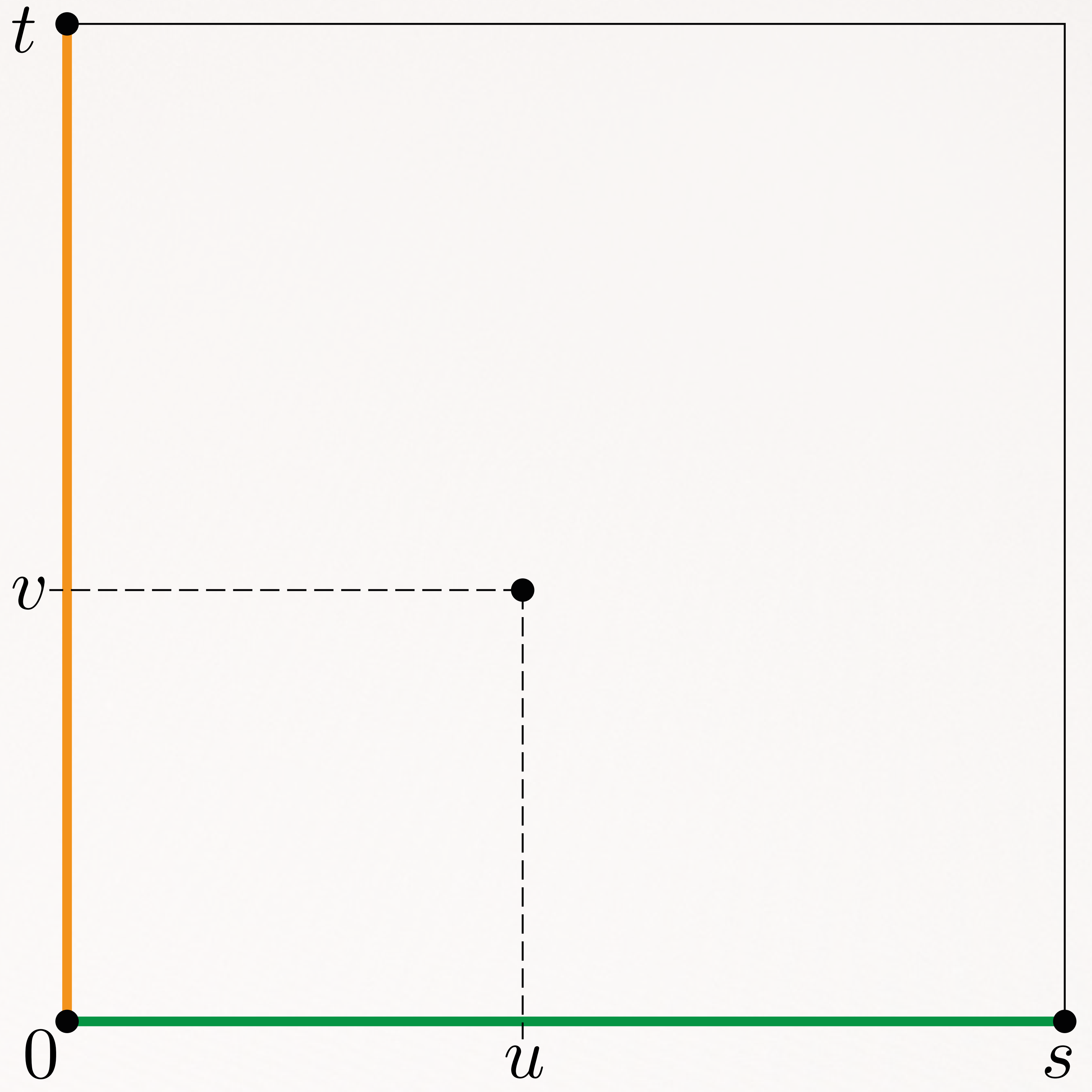


Ray-to-Ray transport

phase functions

$$L = \Phi \int_0^s \int_0^t \frac{f_s(\theta_u) f_s(\theta_v)}{\qquad\qquad} \mathrm{d}v\mathrm{d}u$$





Ray-to-Ray transport

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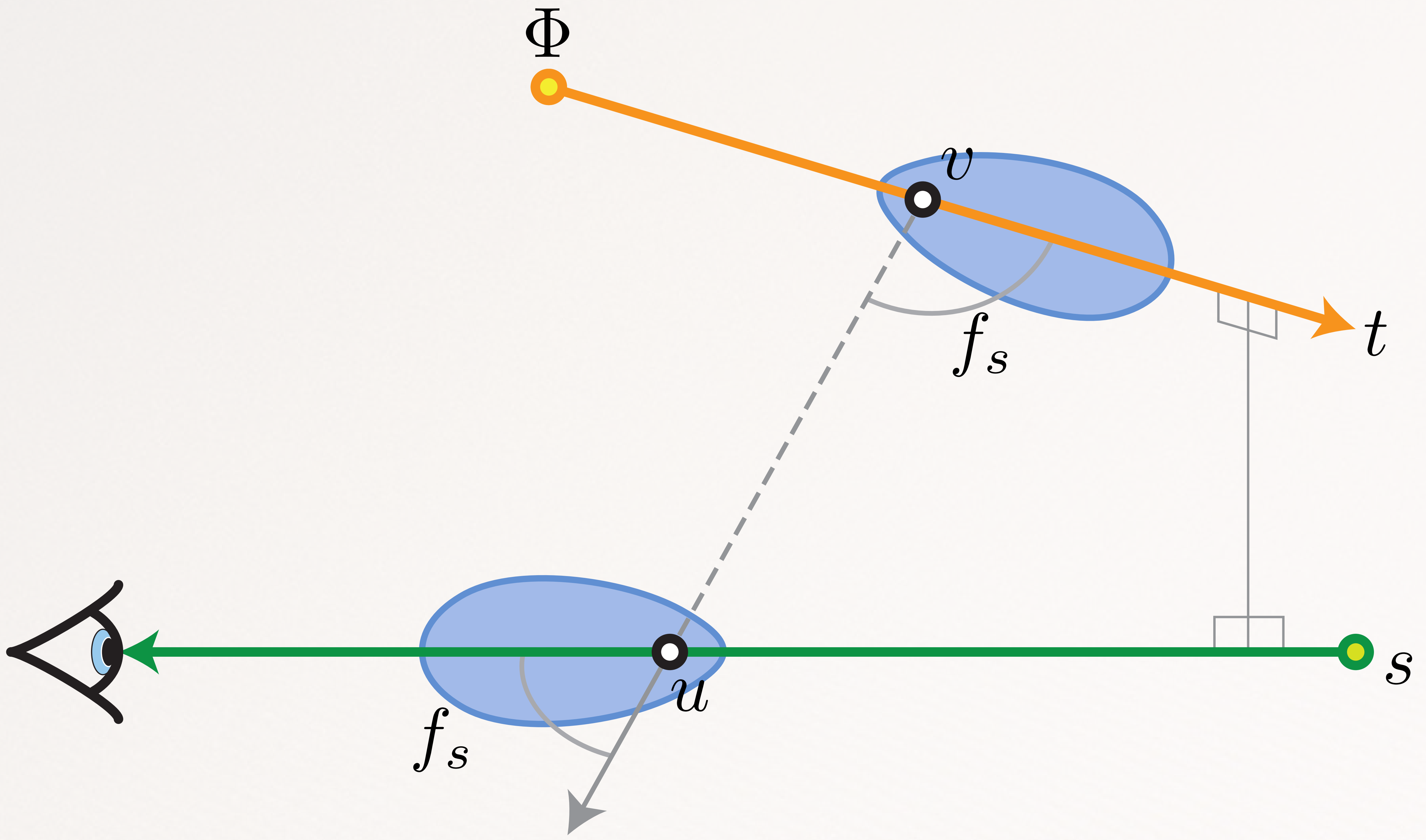

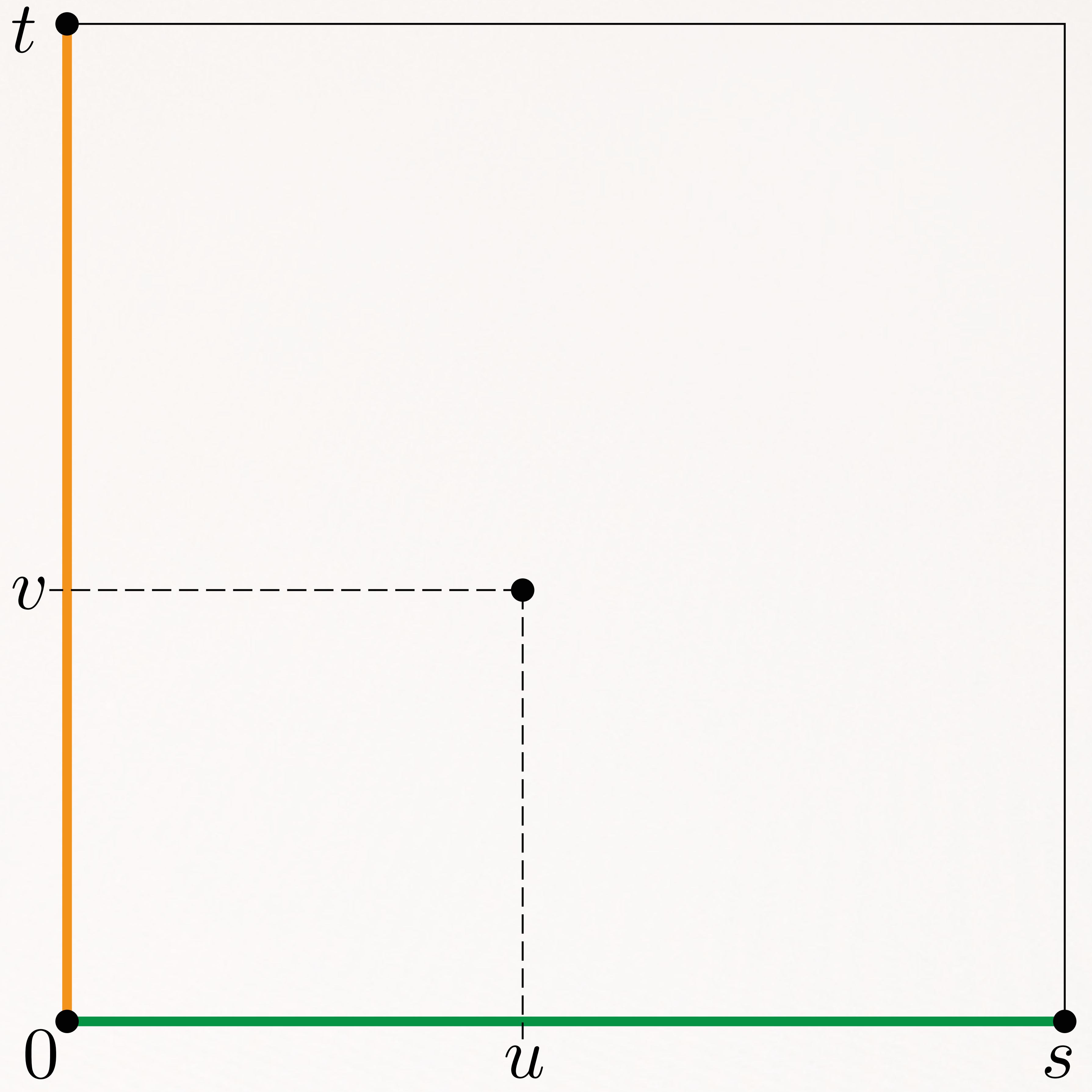

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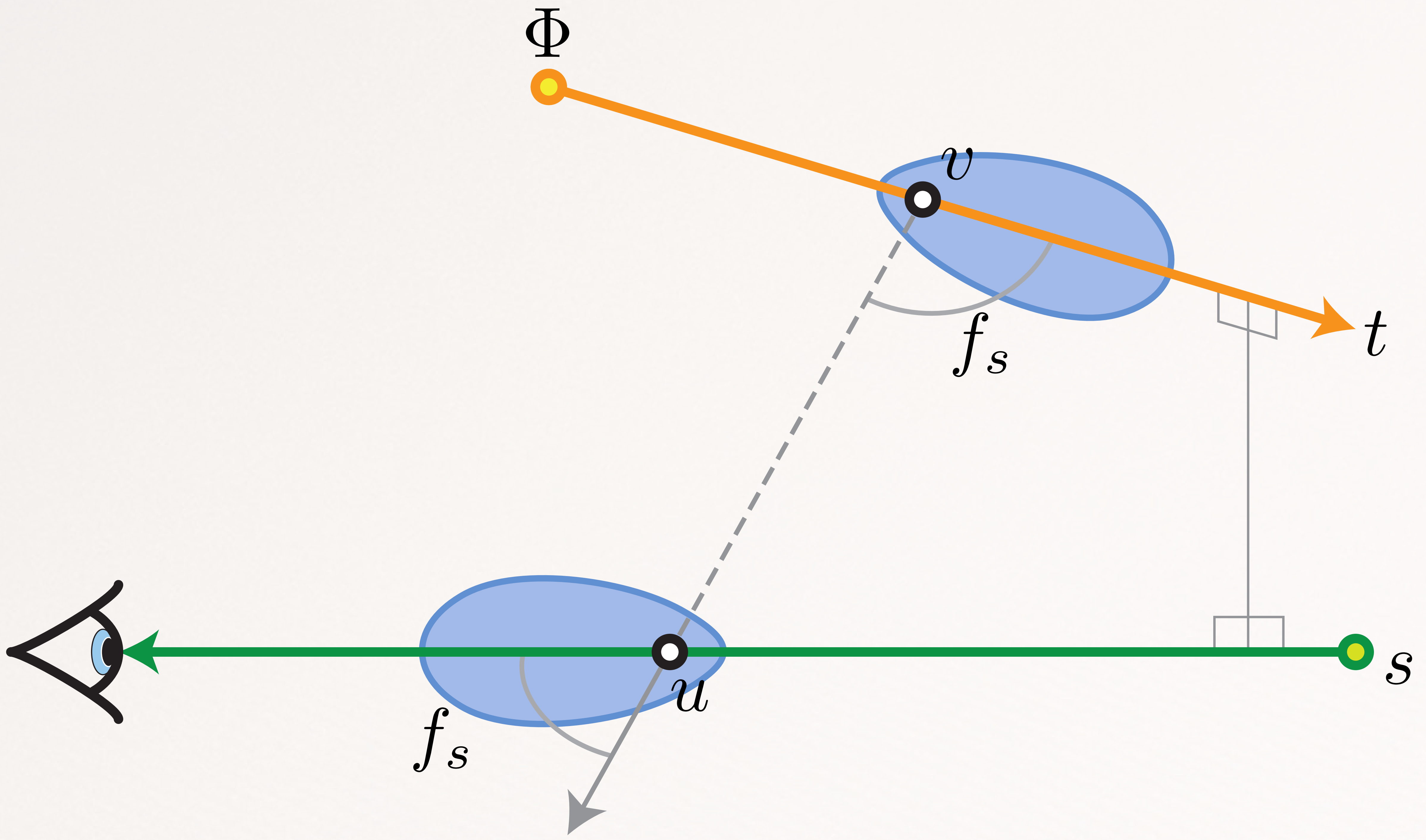
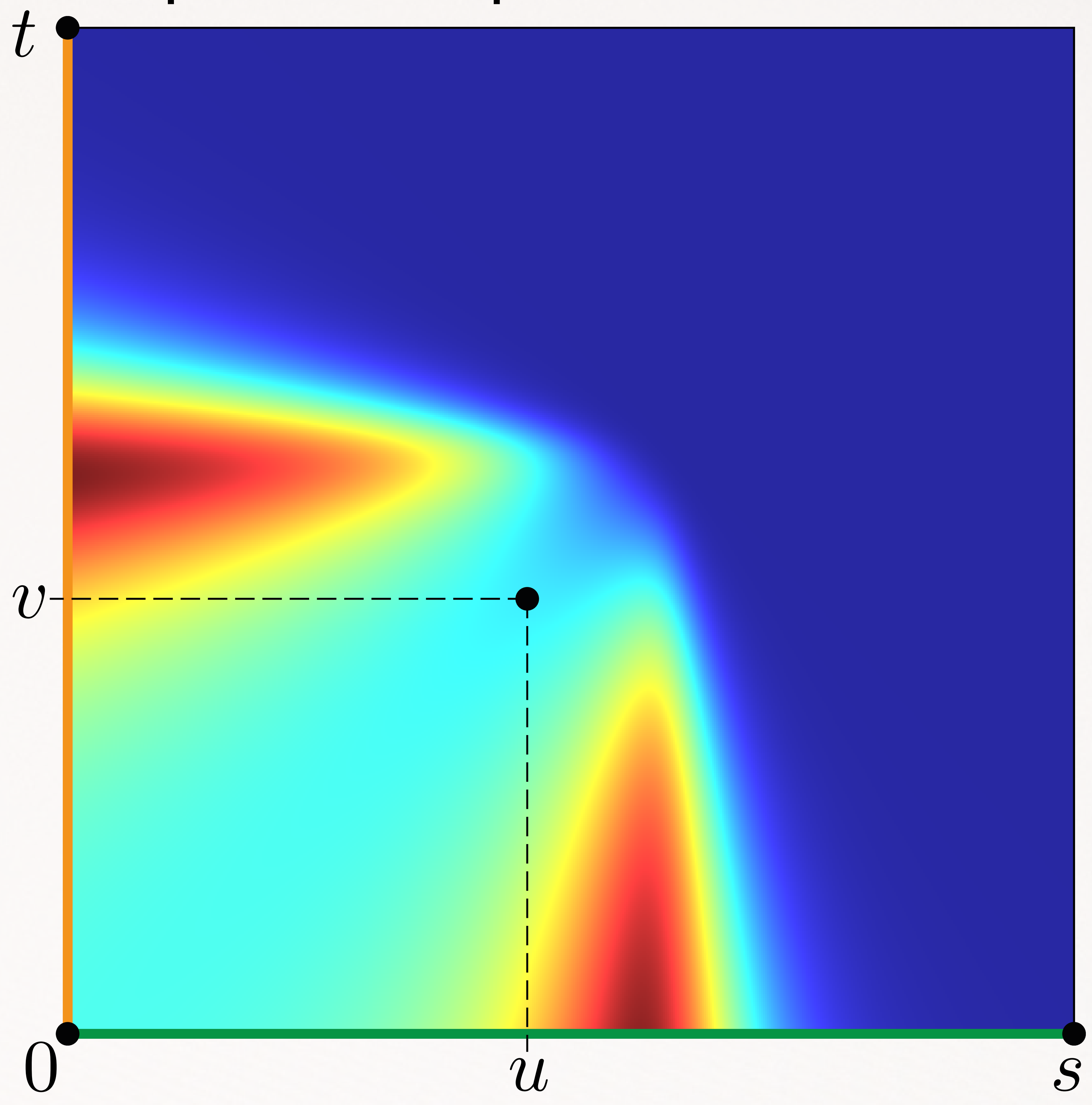


product of phase functions



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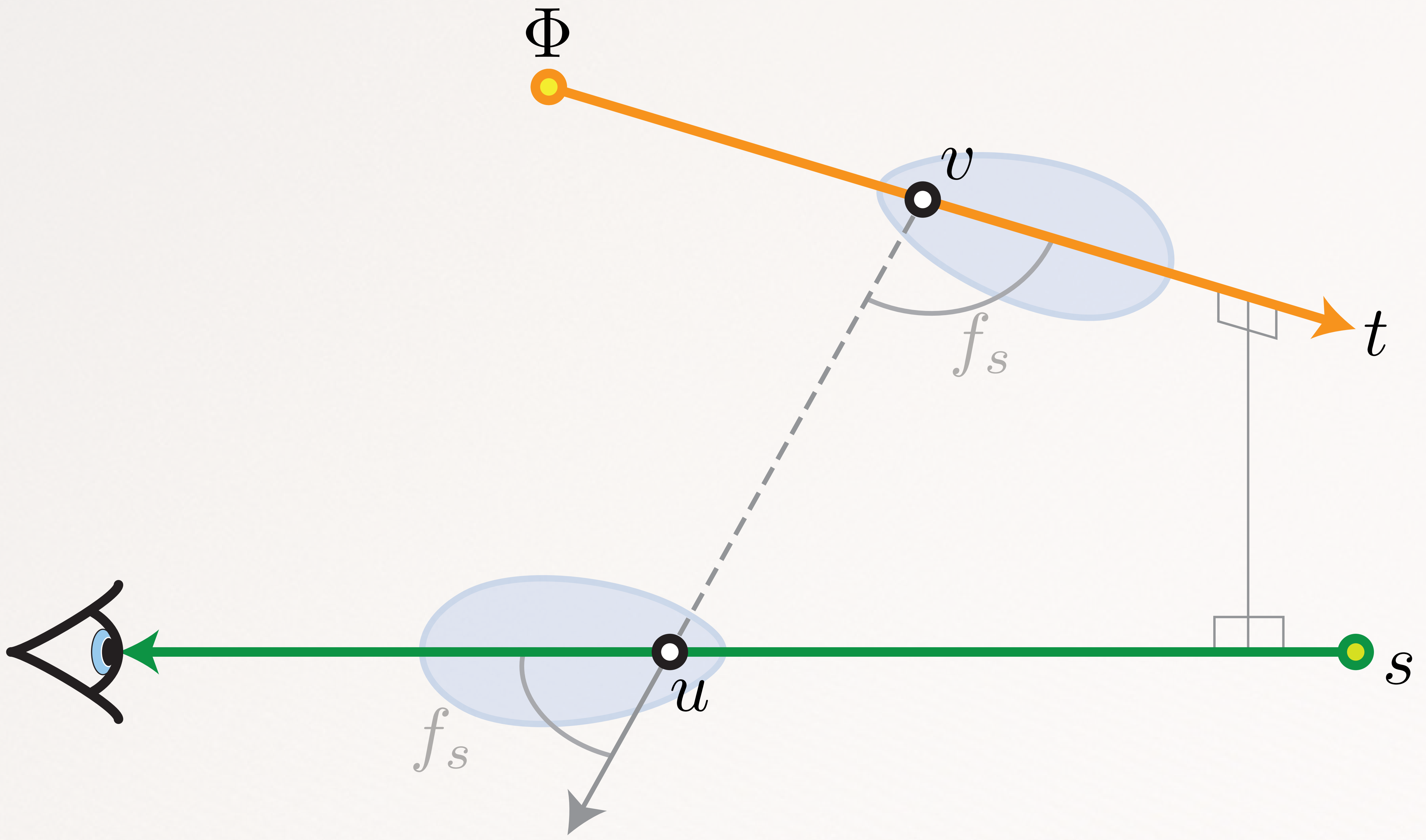
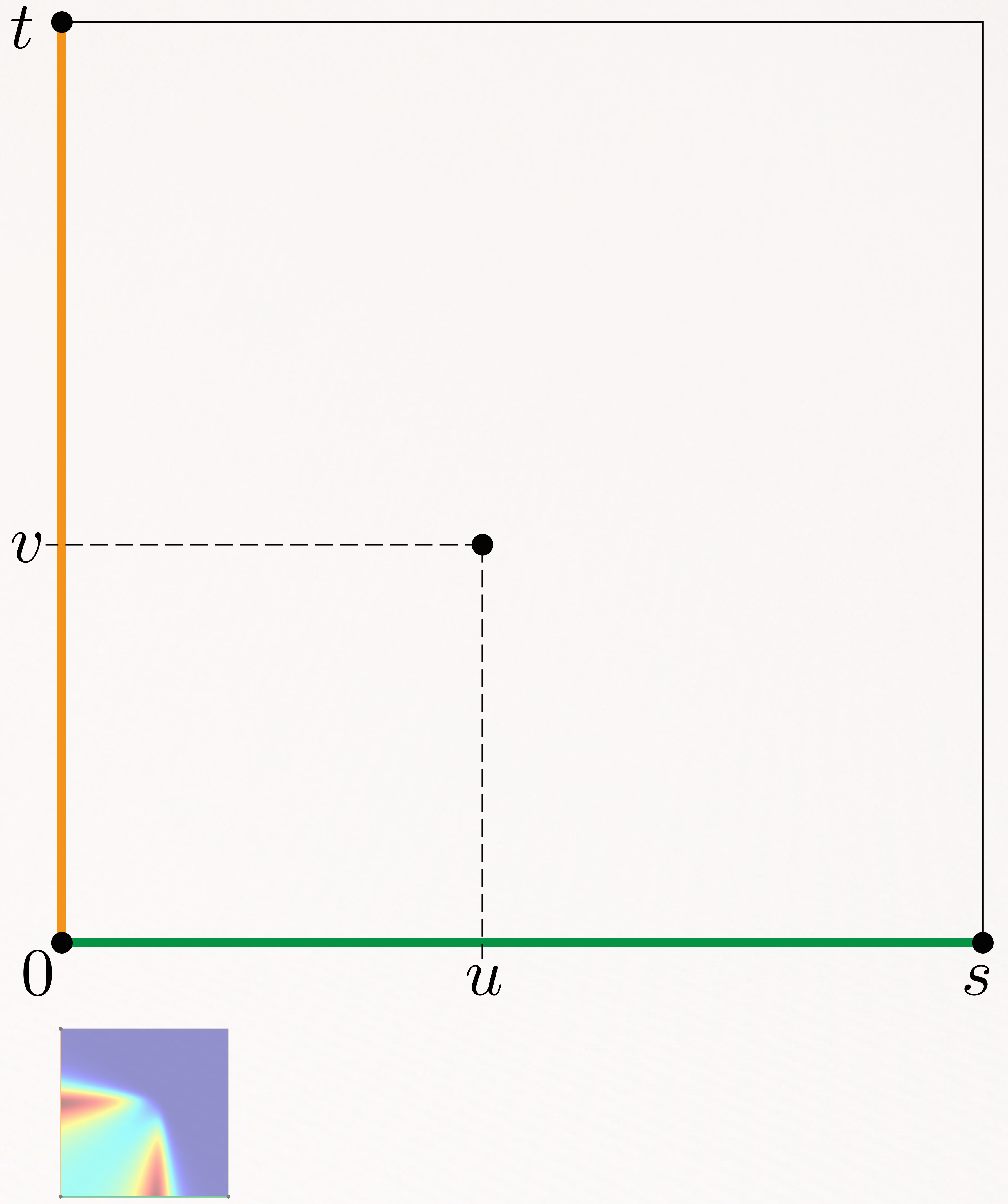
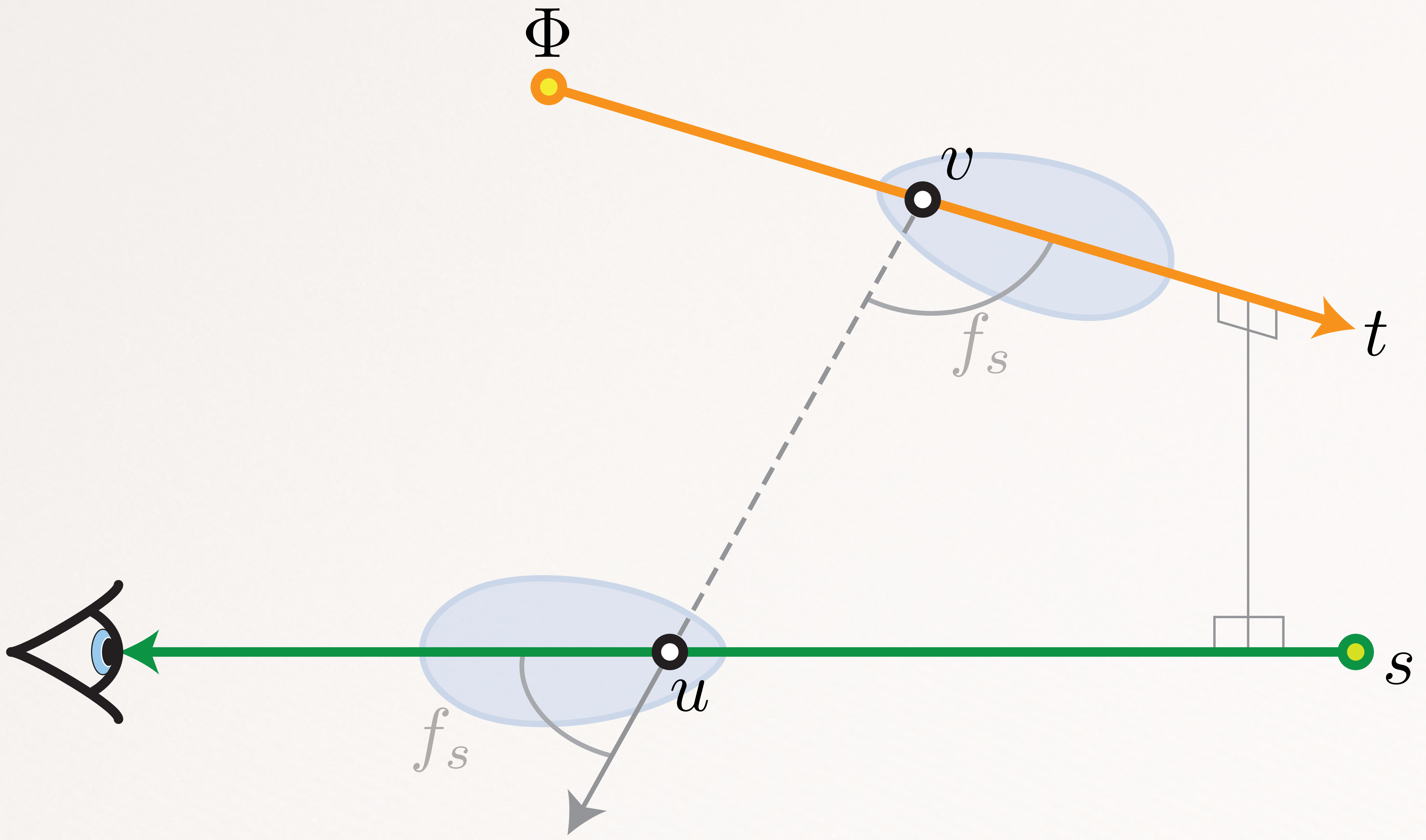


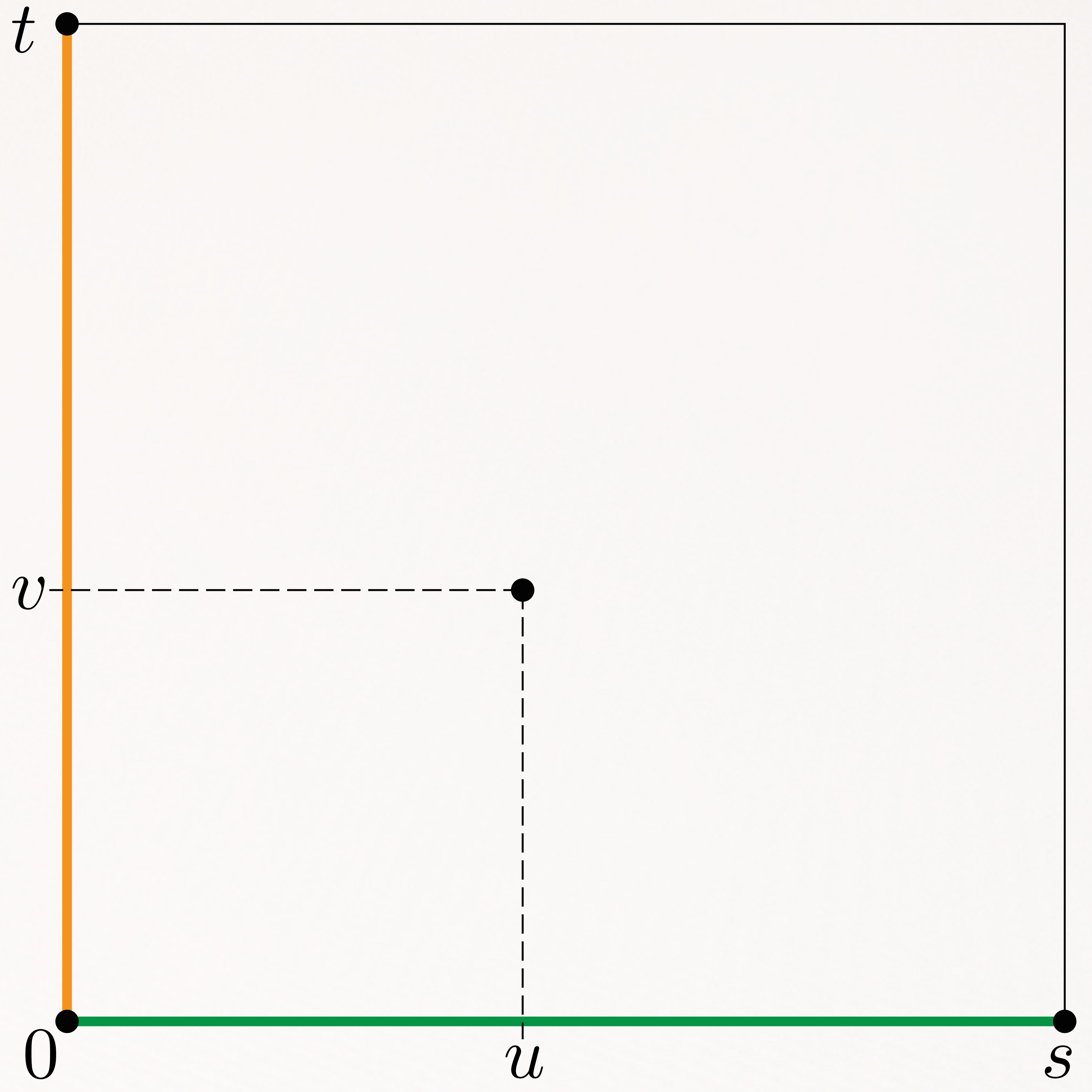


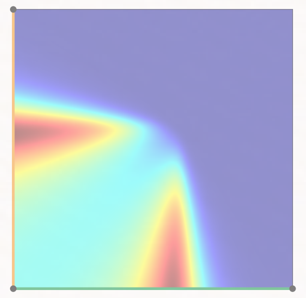
Ray-to-Ray transport

scattering

$$L = \Phi \int_0^s \int_0^t \frac{f_s(\theta_u) f_s(\theta_v)\, \sigma_s(u)\sigma_s(v)}{} \mathrm{d}v\mathrm{d}u$$



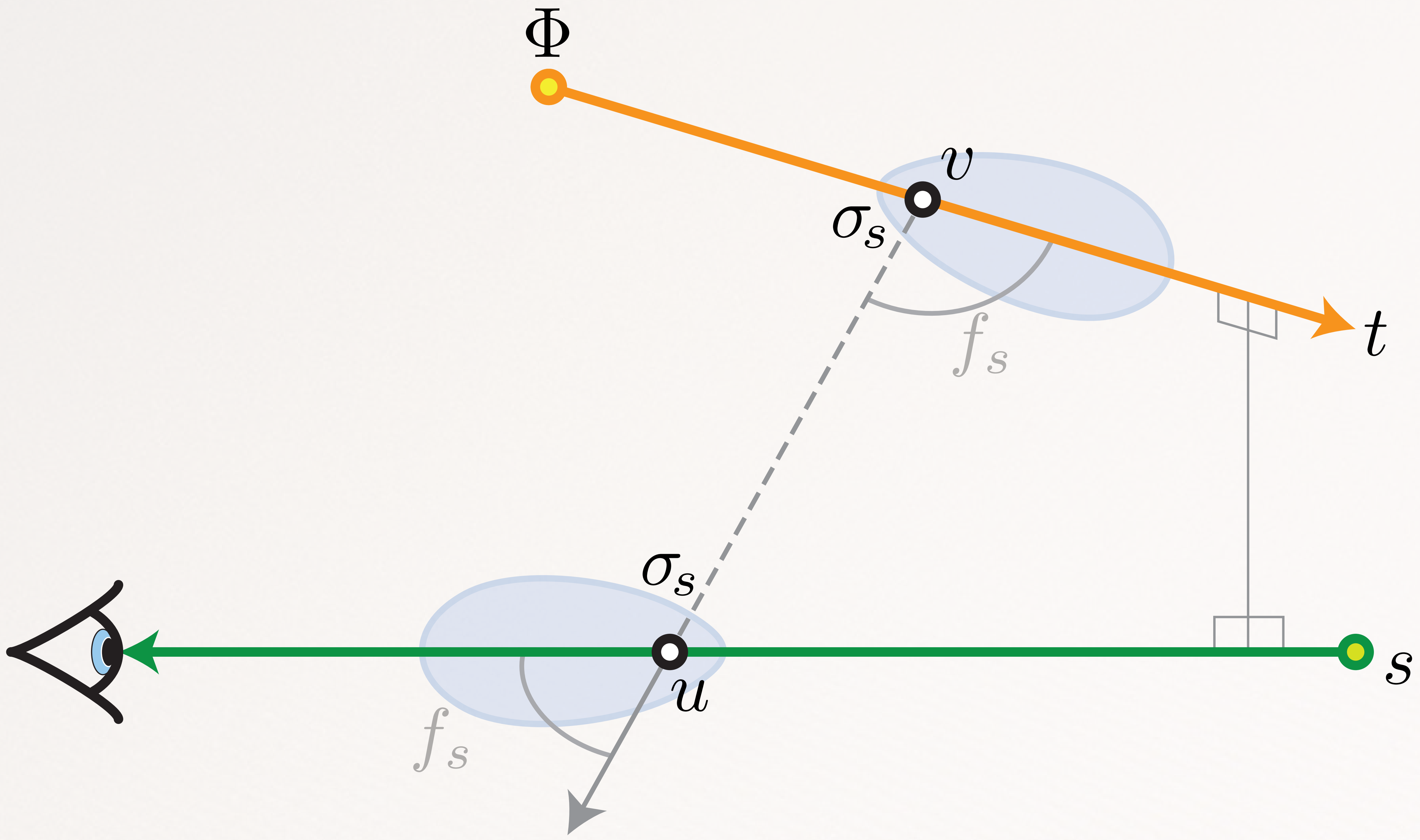


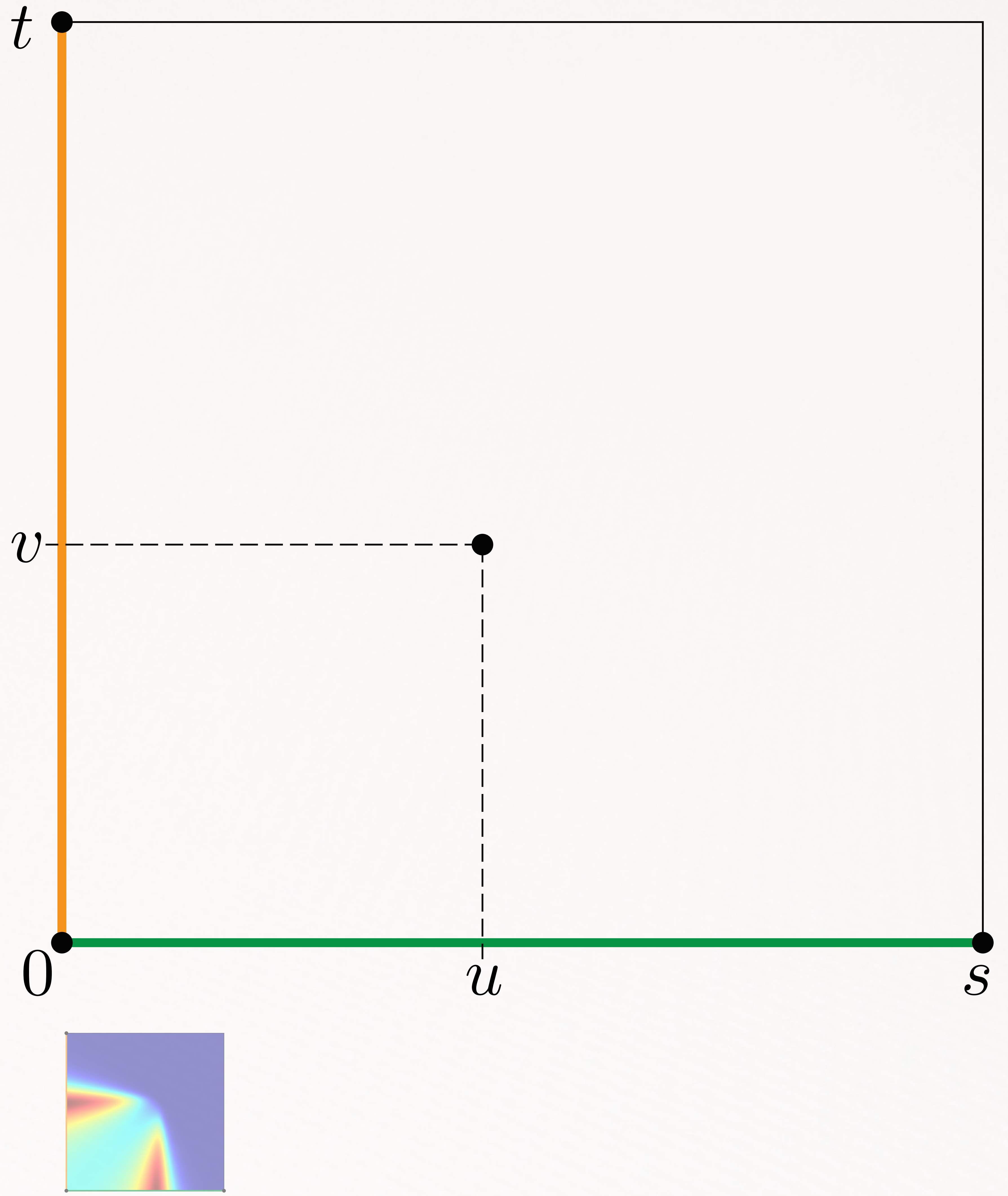


Ray-to-Ray transport

scattering

$$L = \Phi \int_0^s \int_0^t \frac{f_s(\theta_u) f_s(\theta_v)\, \sigma_s(u) \sigma_s(v)}{}\, \mathrm{d}v \mathrm{d}u$$

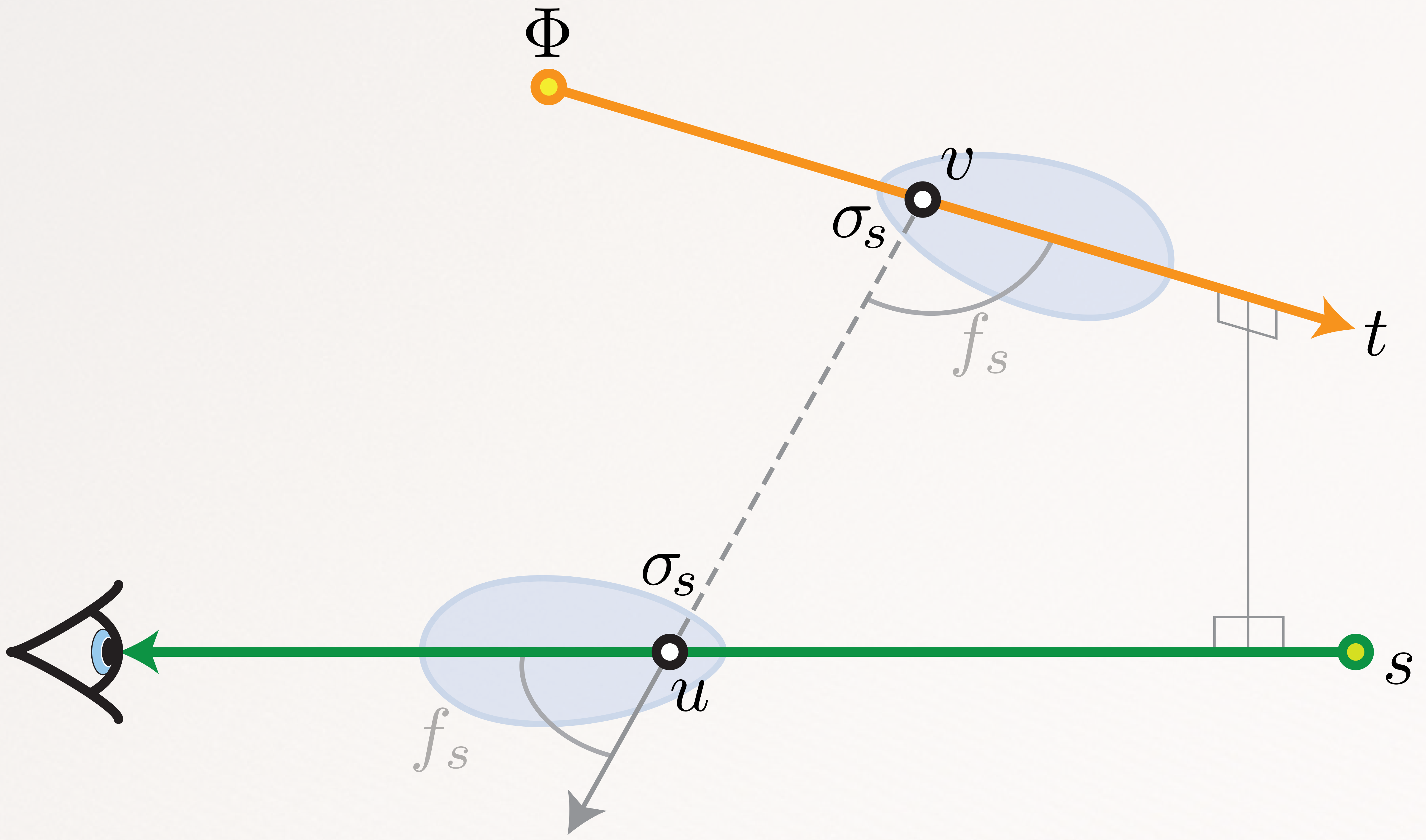




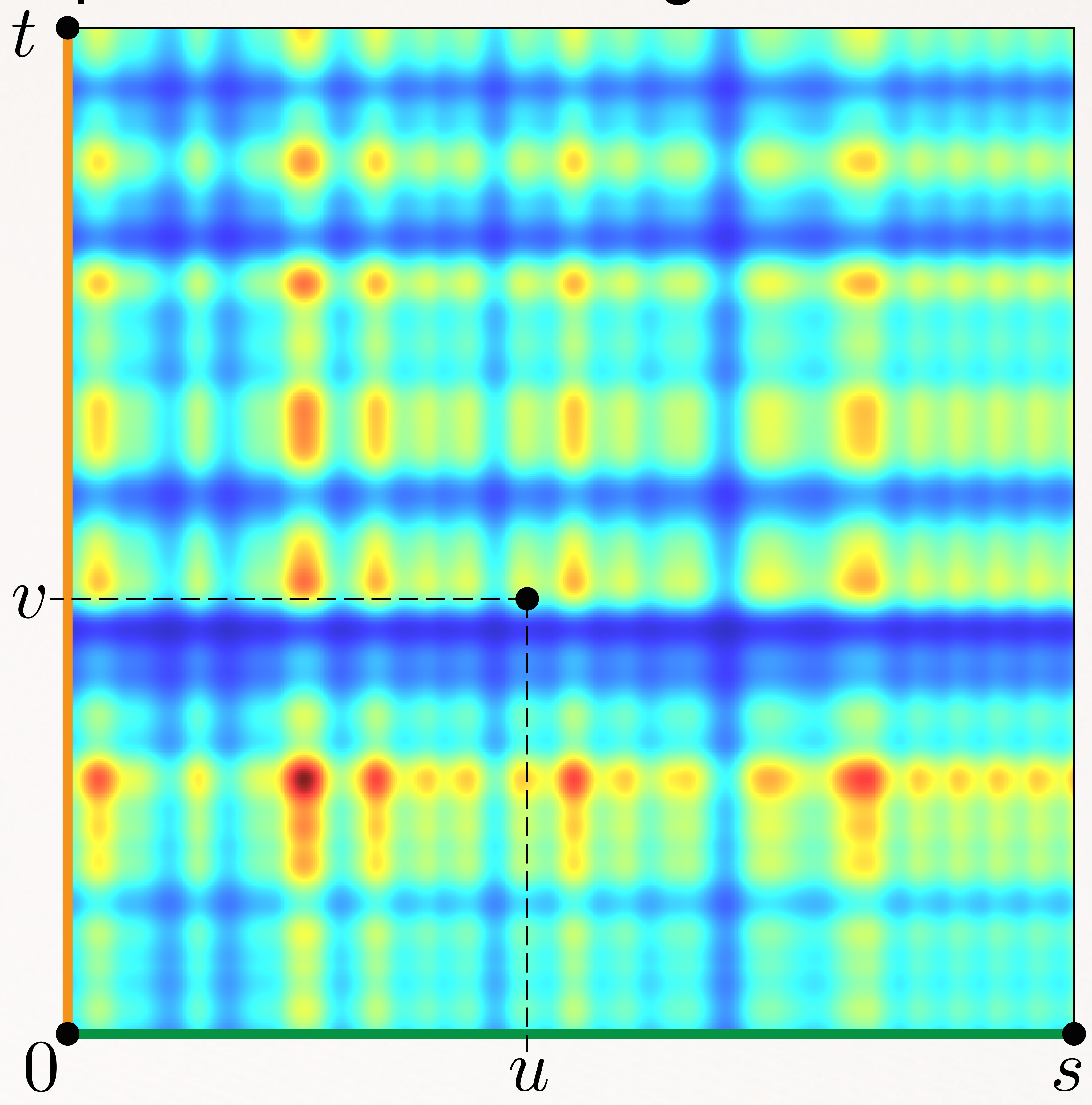
Ray-to-Ray transport

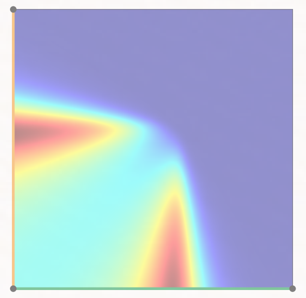
scattering

$$L = \Phi \int_0^s \int_0^t \frac{f_s(\theta_u) f_s(\theta_v)\, \sigma_s(u) \sigma_s(v)}{} \mathrm{d}v\mathrm{d}u$$



product of scattering coefficients

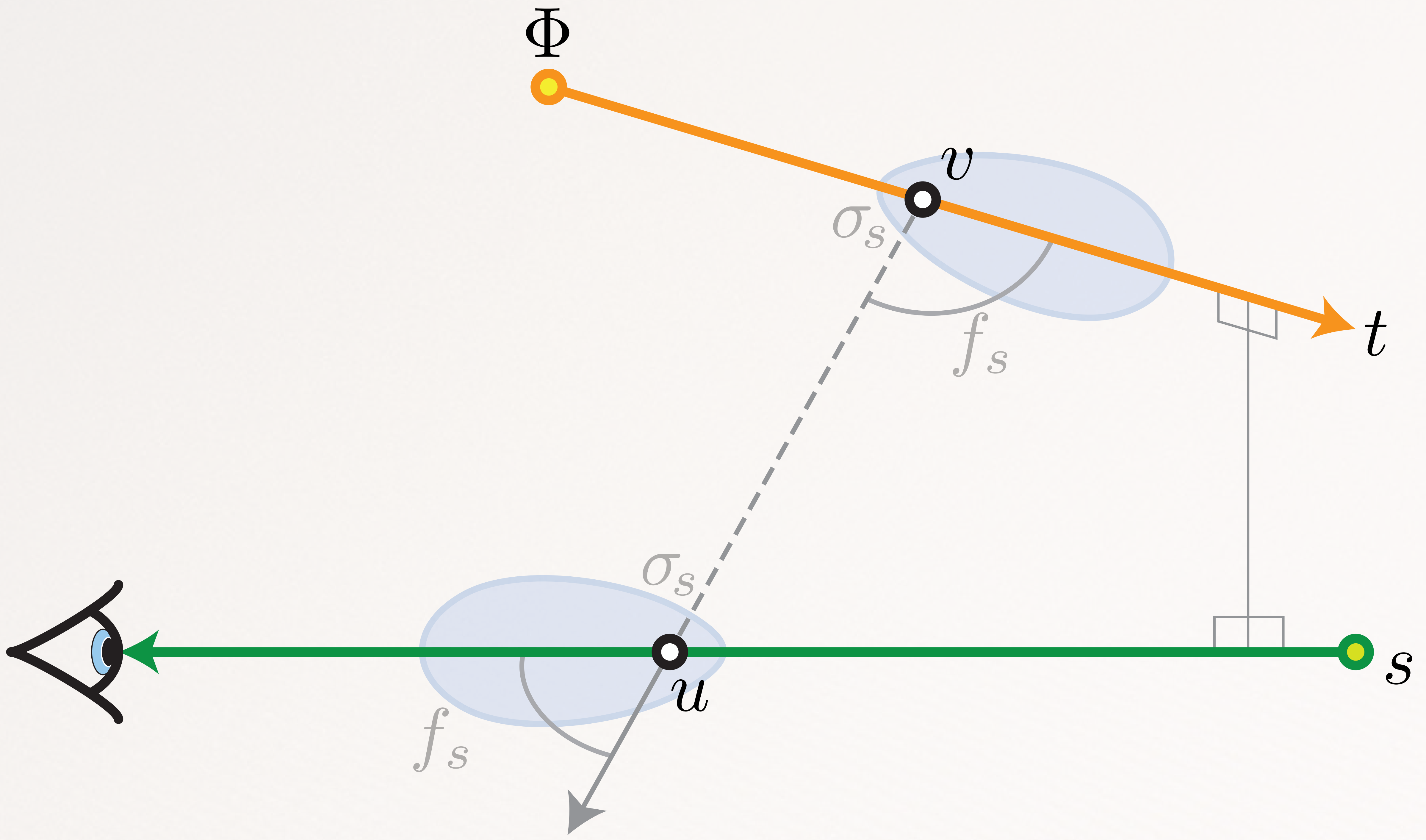


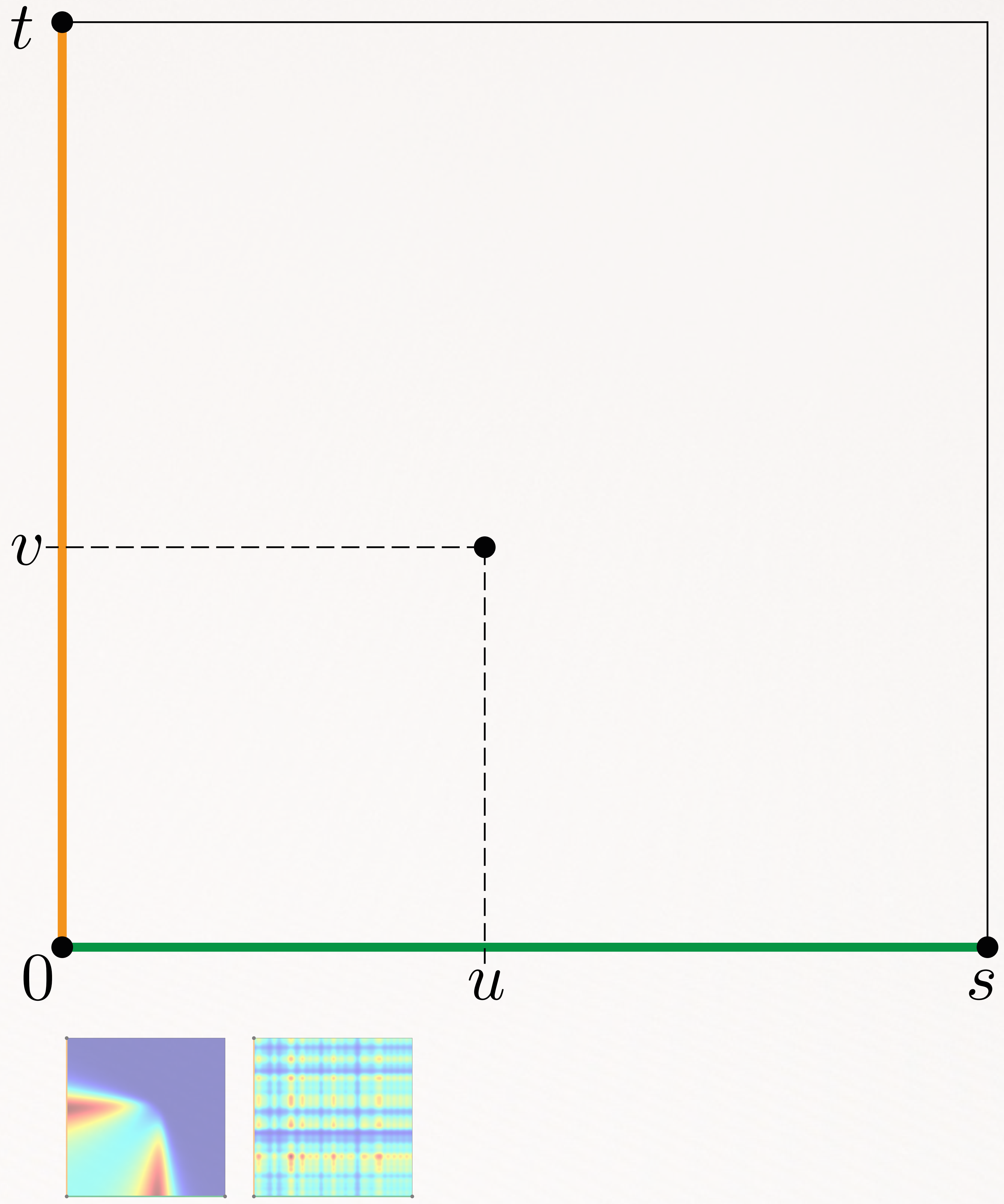


Ray-to-Ray transport

SIGGRAPH2012

$$L = \Phi \int_0^s \int_0^t \frac{f_s(\theta_u) f_s(\theta_v)\, \sigma_s(u) \sigma_s(v)}{} \mathrm{d}v\mathrm{d}u$$

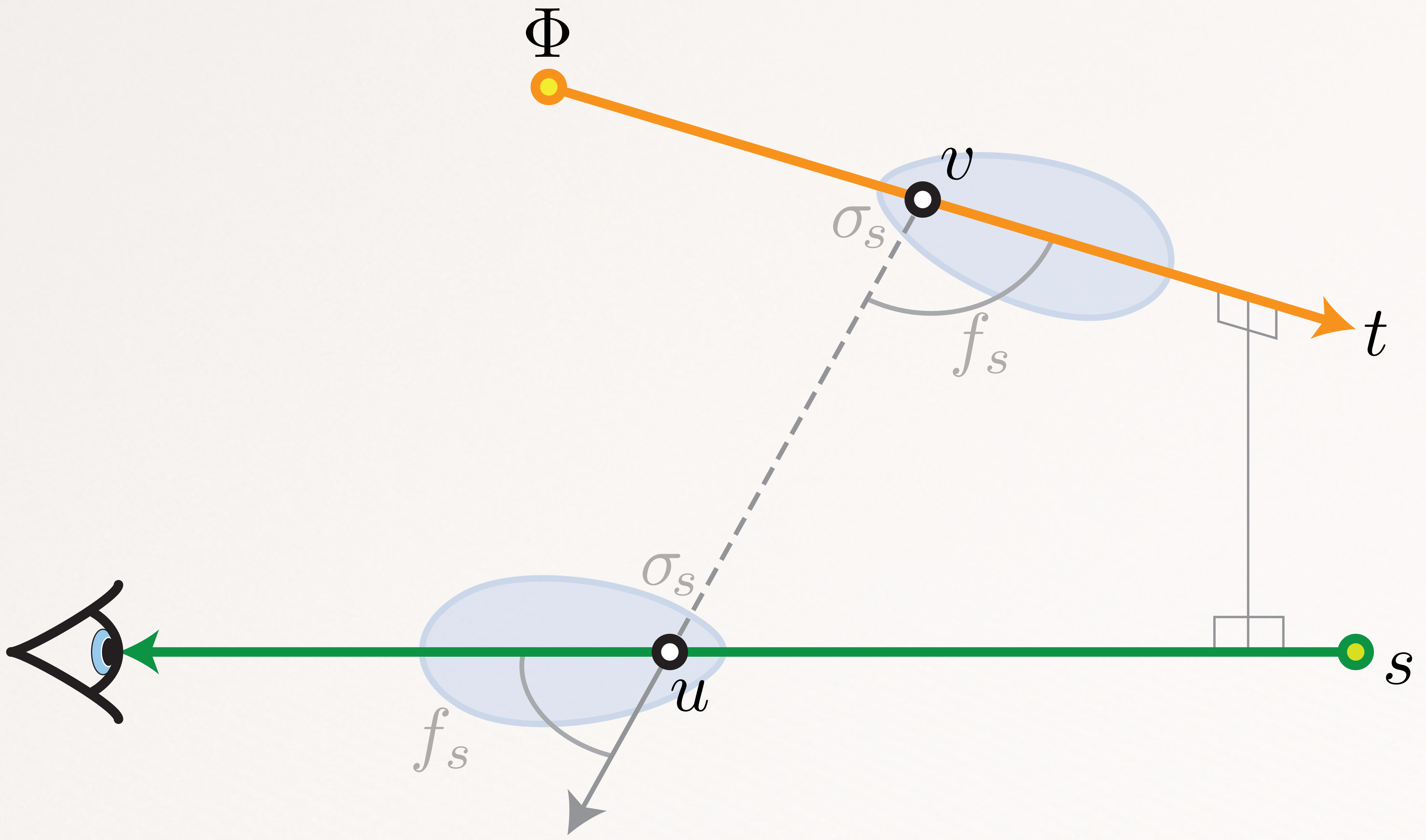


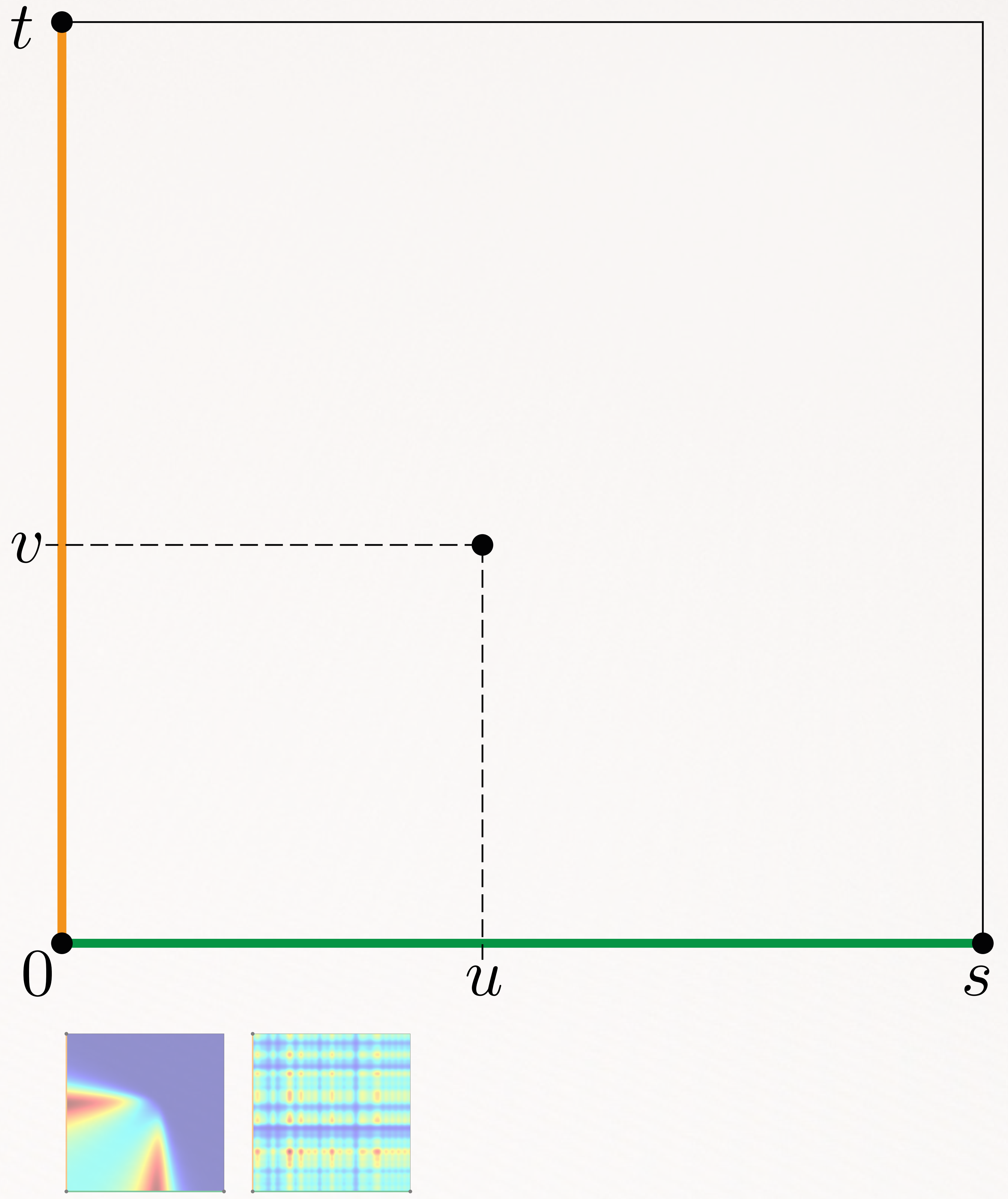


Ray-to-Ray transport

transmittance

$$L = \Phi \int_0^s \int_0^t \frac{f_s(\theta_u) f_s(\theta_v)\, \sigma_s(u)\sigma_s(v)\, T(u)T(v)T(w)}{\quad} \mathrm{d}v\mathrm{d}u$$

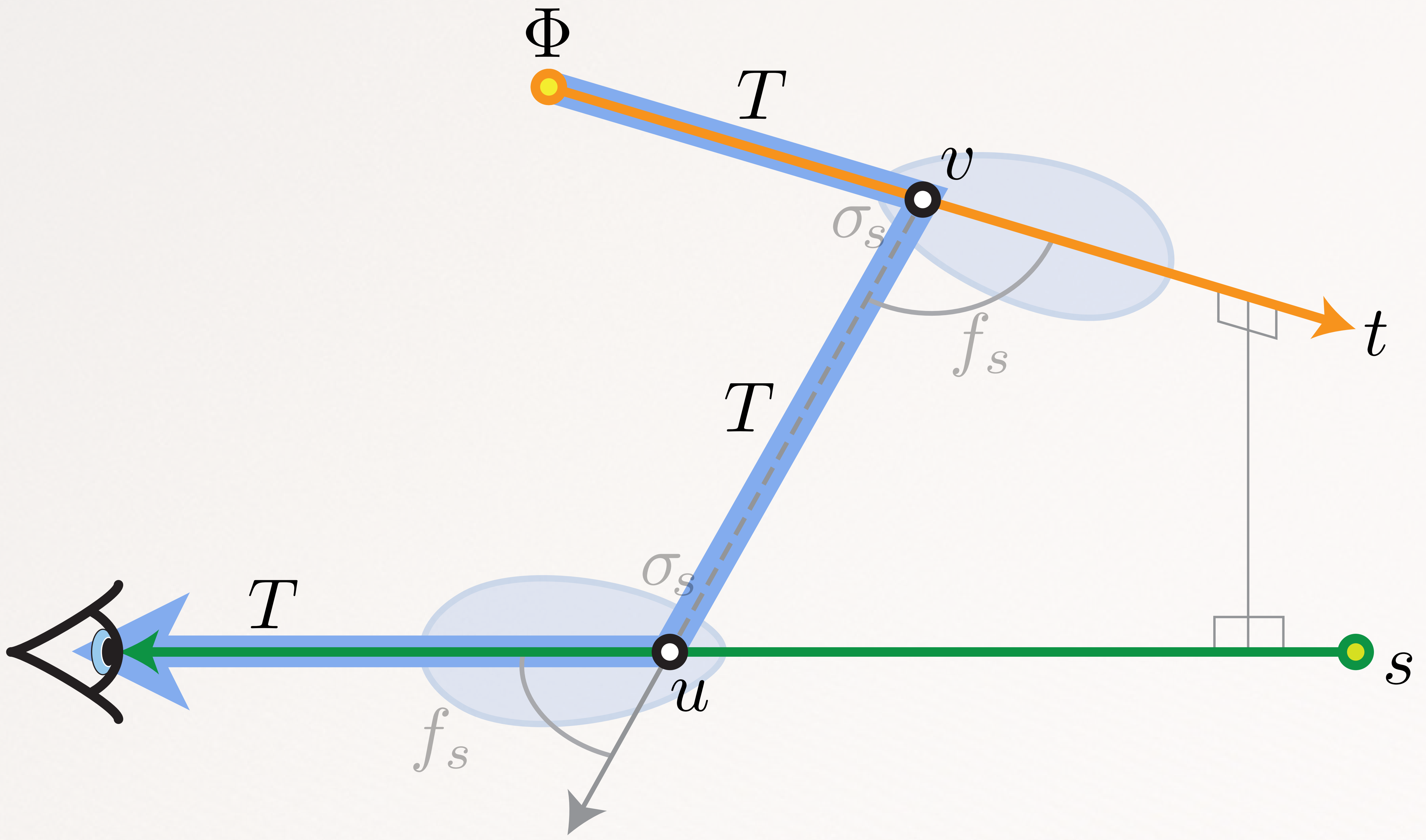


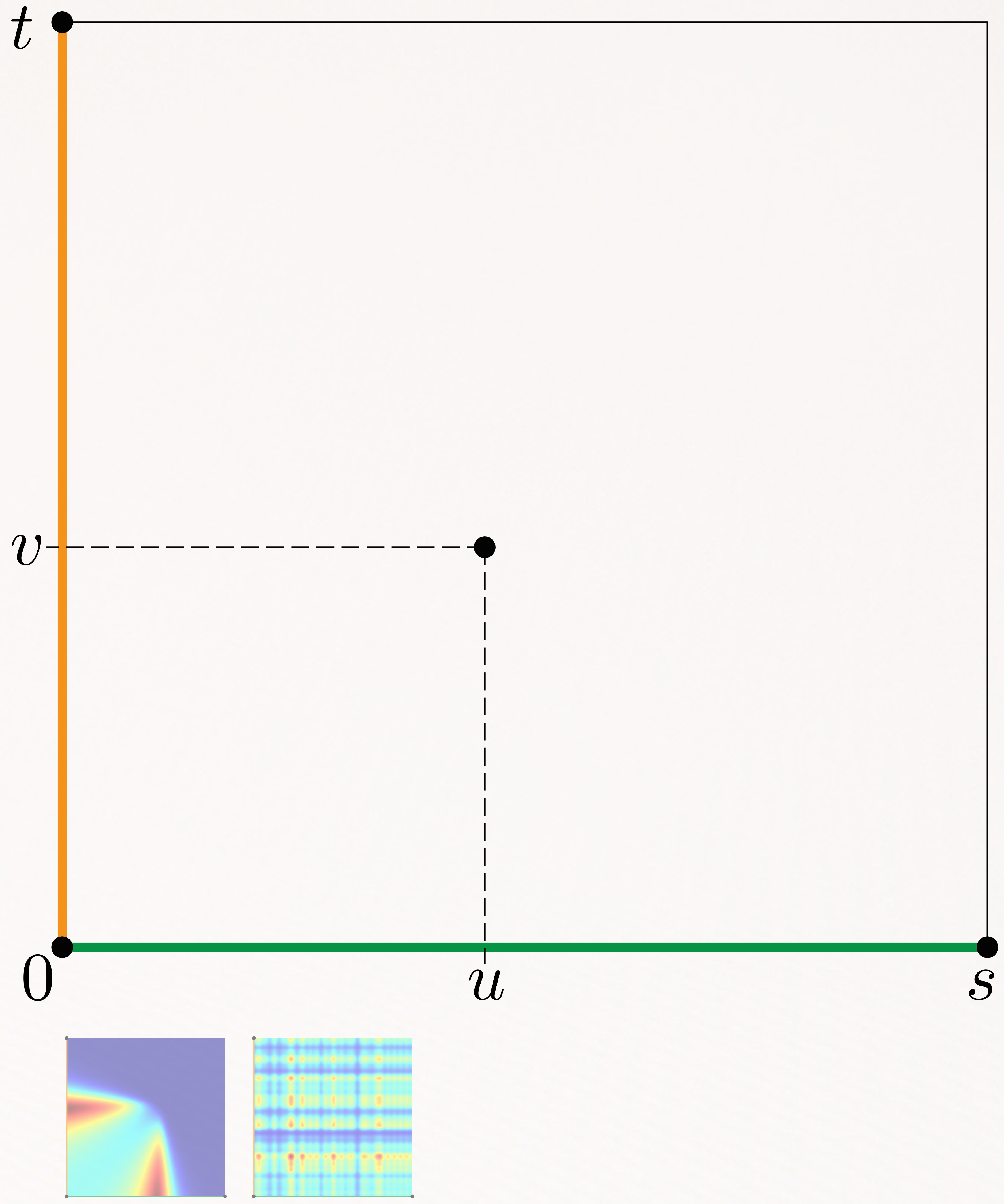


Ray-to-Ray transport

transmittance

$$L = \Phi \int_0^s \int_0^t \frac{f_s(\theta_u) f_s(\theta_v)\, \sigma_s(u)\sigma_s(v)\, T(u)T(v)T(w)}{\quad} \mathrm{d}v\mathrm{d}u$$



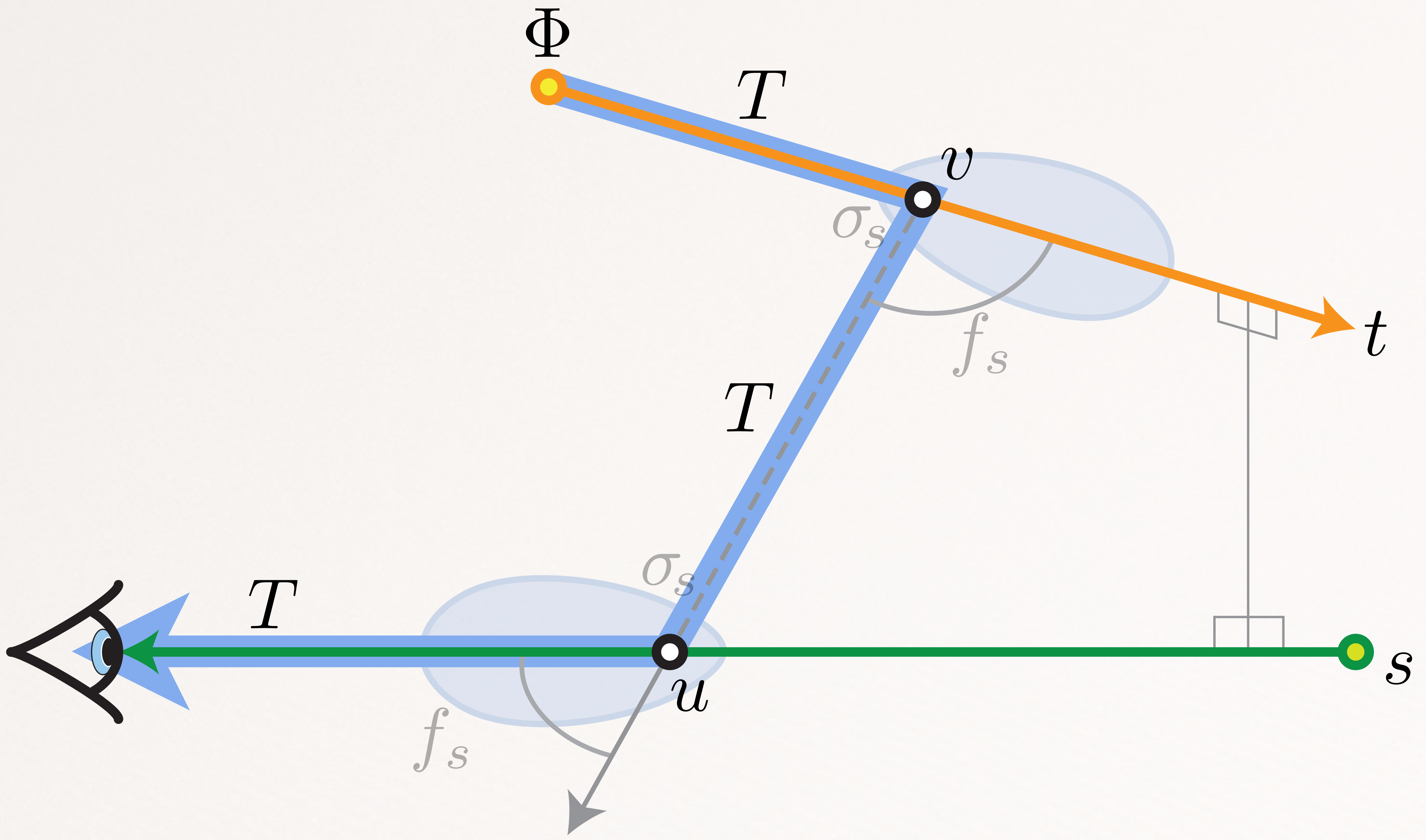


Ray-to-Ray transport

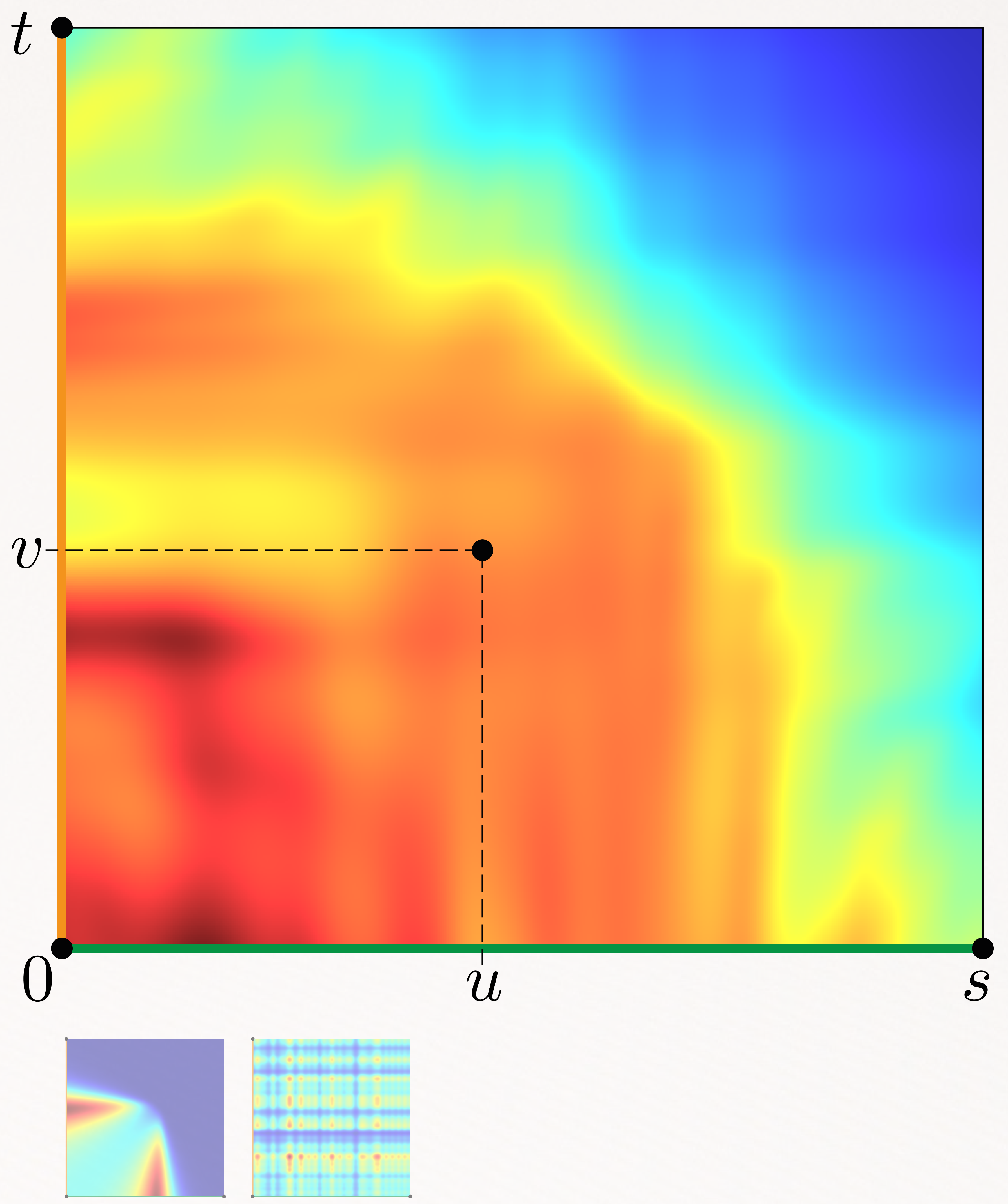
SIGGRAPH2012

transmittance

$$L = \Phi \int_0^s \int_0^t \frac{f_s(\theta_u) f_s(\theta_v)\, \sigma_s(u)\sigma_s(v)\, T(u)T(v)T(w)}{} \, \mathrm{d}v\mathrm{d}u$$

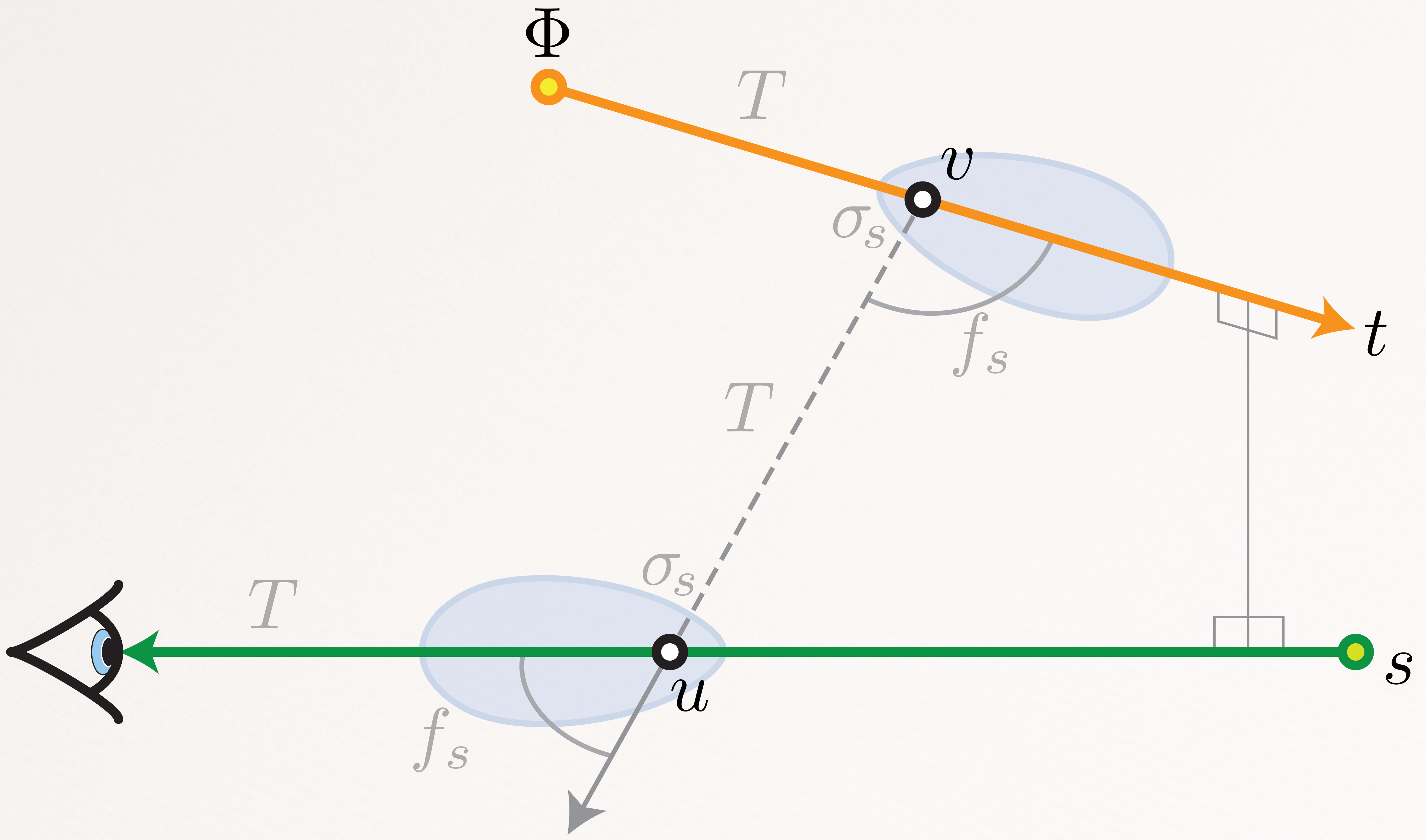


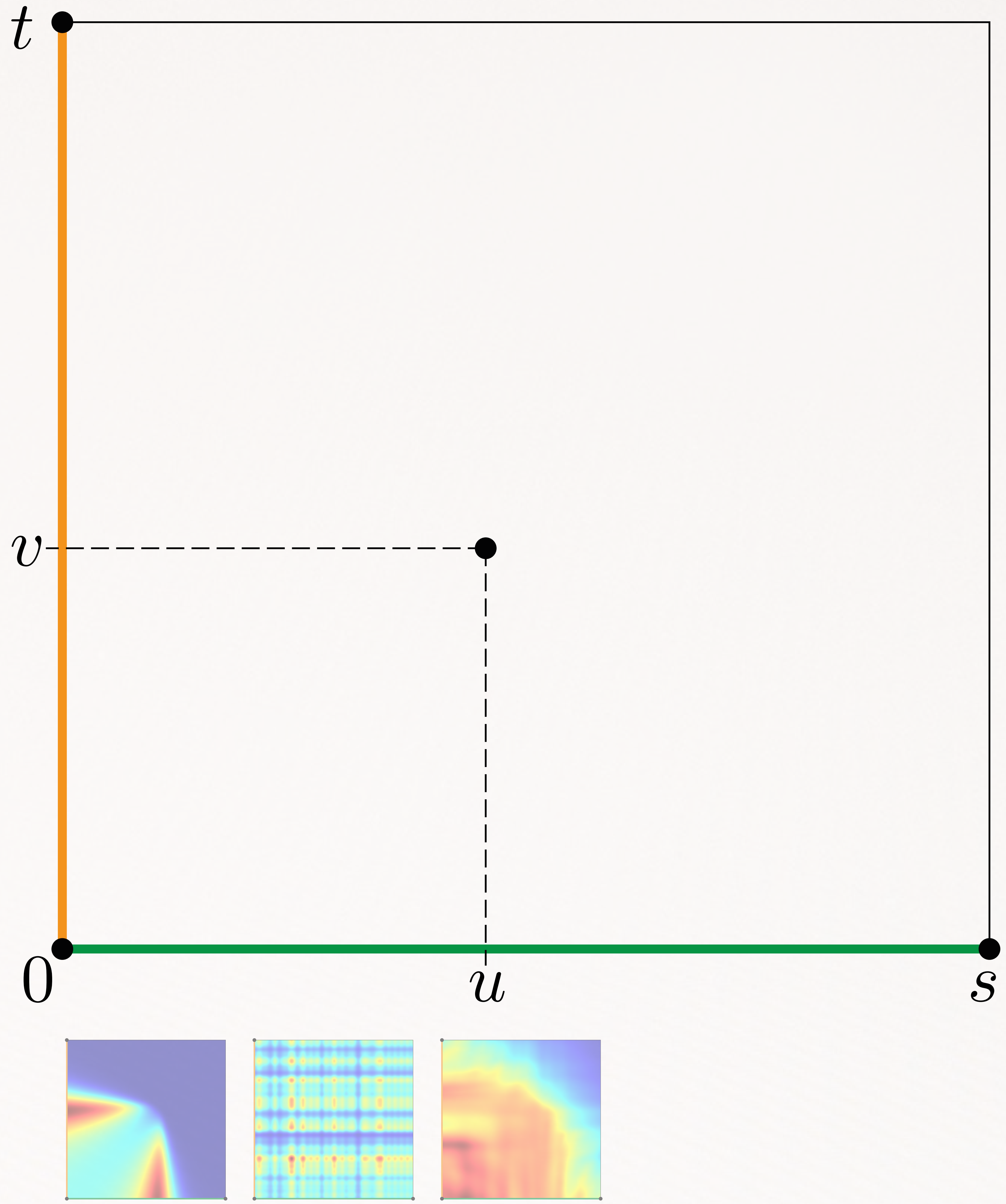
transmittance



Ray-to-Ray transport

$$L = \Phi \int_0^s \int_0^t \frac{f_s(\theta_u) f_s(\theta_v)\, \sigma_s(u) \sigma_s(v)\, T(u) T(v) T(w)}{} \, \mathrm{d}v \mathrm{d}u$$

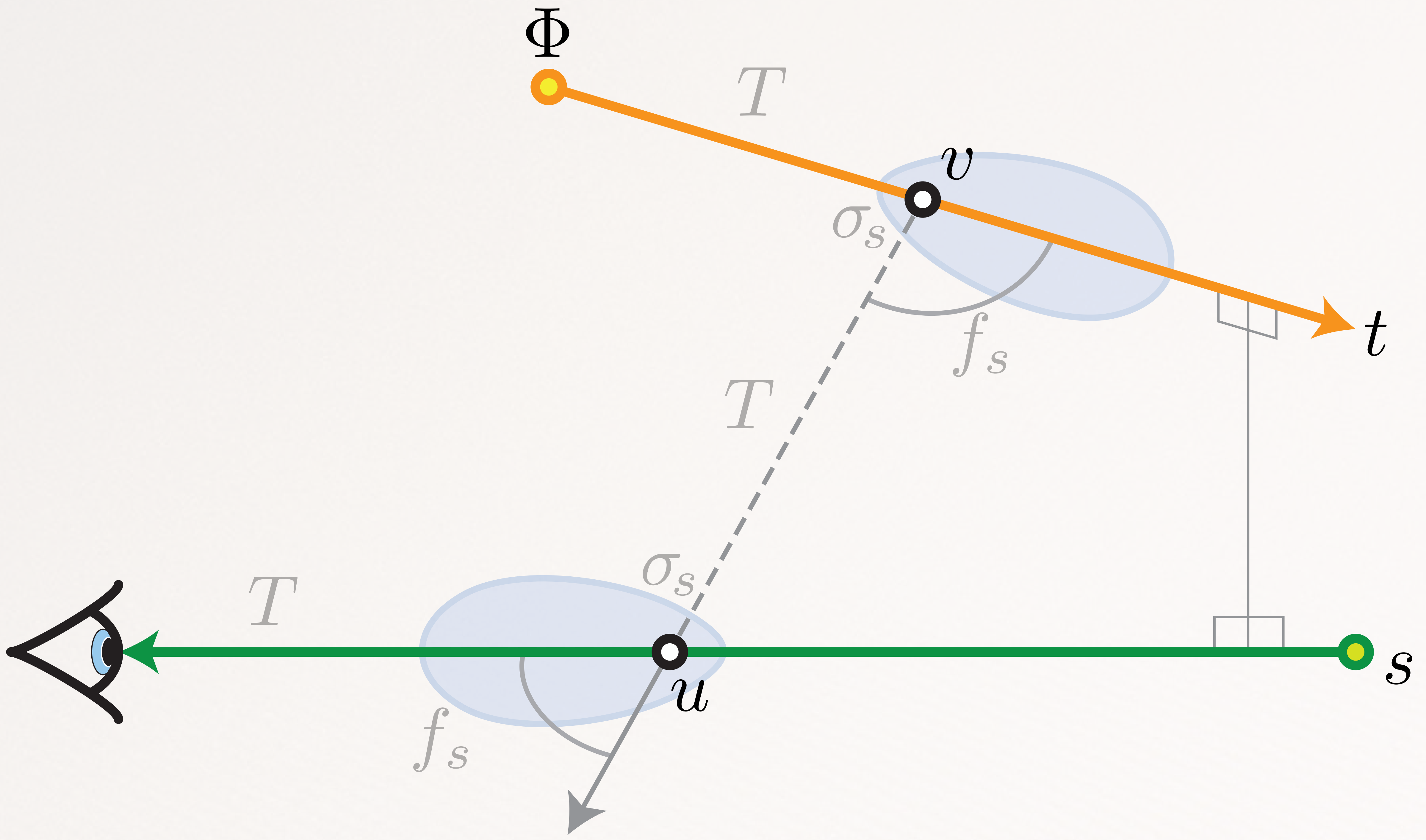


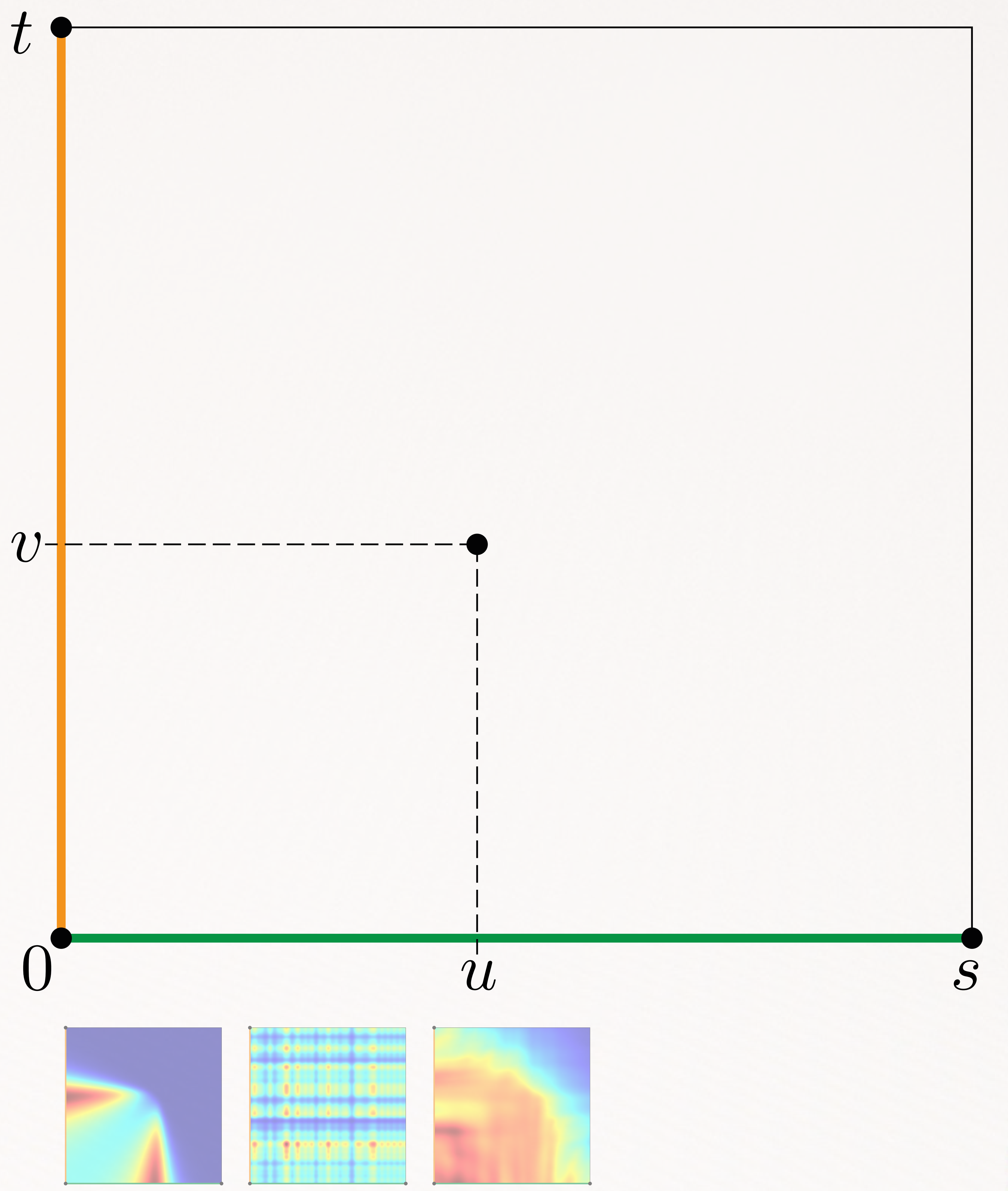


Ray-to-Ray transport

visibility

$$L = \Phi \int_0^s \int_0^t \underline{f_s(\theta_u) f_s(\theta_v)\, \sigma_s(u)\sigma_s(v)\, T(u)T(v)T(w)\, V}\, \mathrm{d}v\mathrm{d}u$$

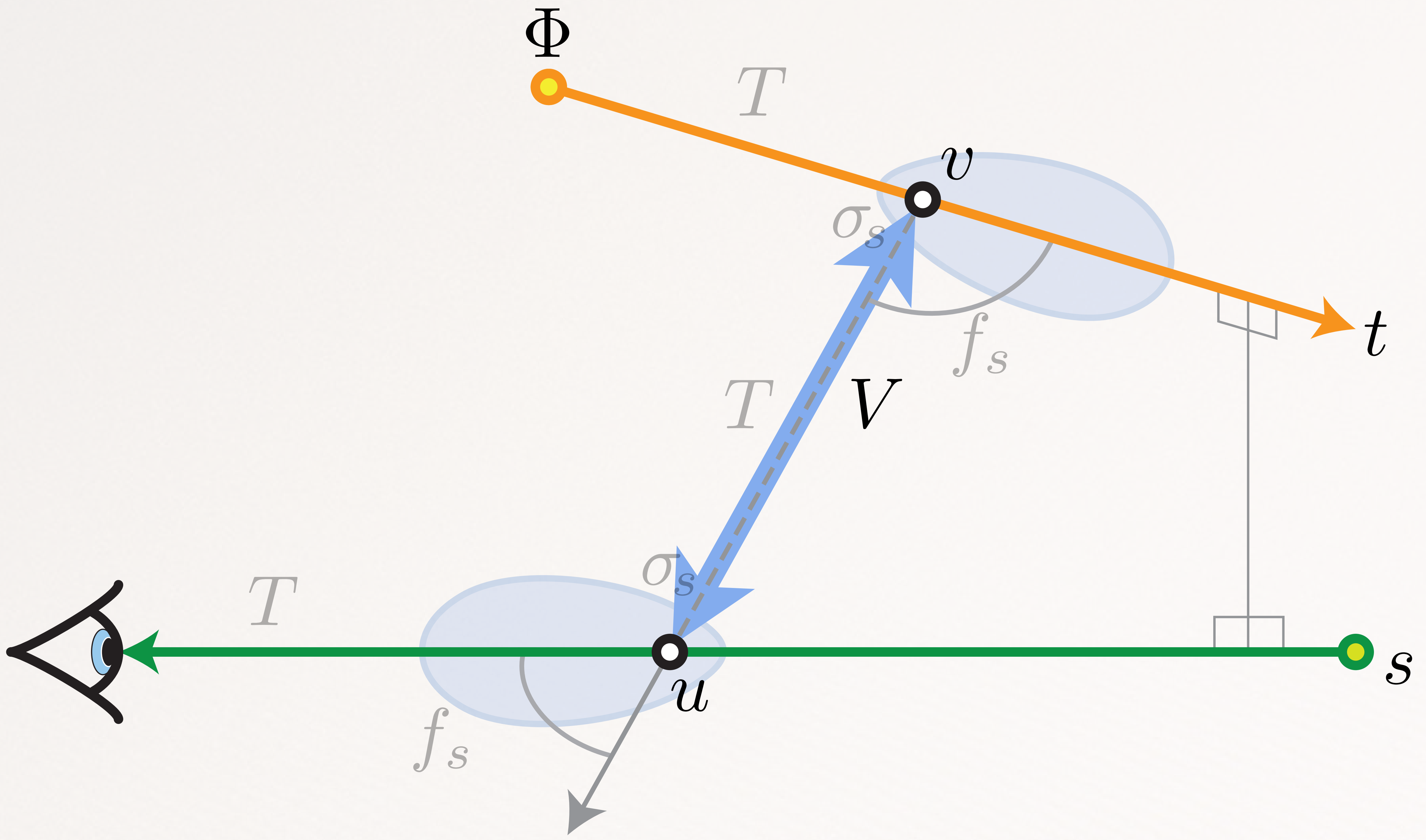


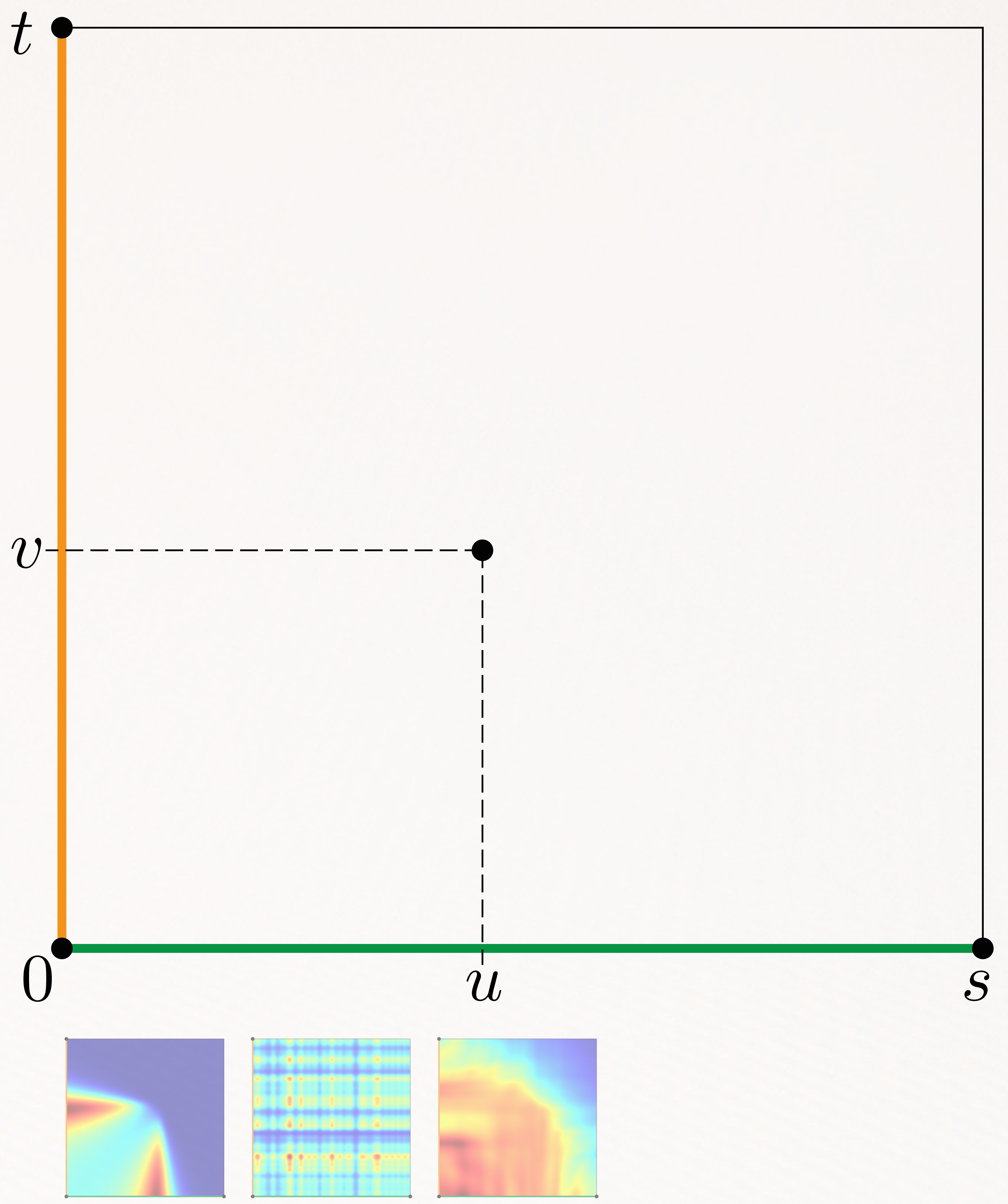


Ray-to-Ray transport

visibility

$$L = \Phi \int_0^s \int_0^t \frac{f_s(\theta_u) f_s(\theta_v)\, \sigma_s(u) \sigma_s(v)\, T(u) T(v) T(w)\, V}{} \, dv du$$

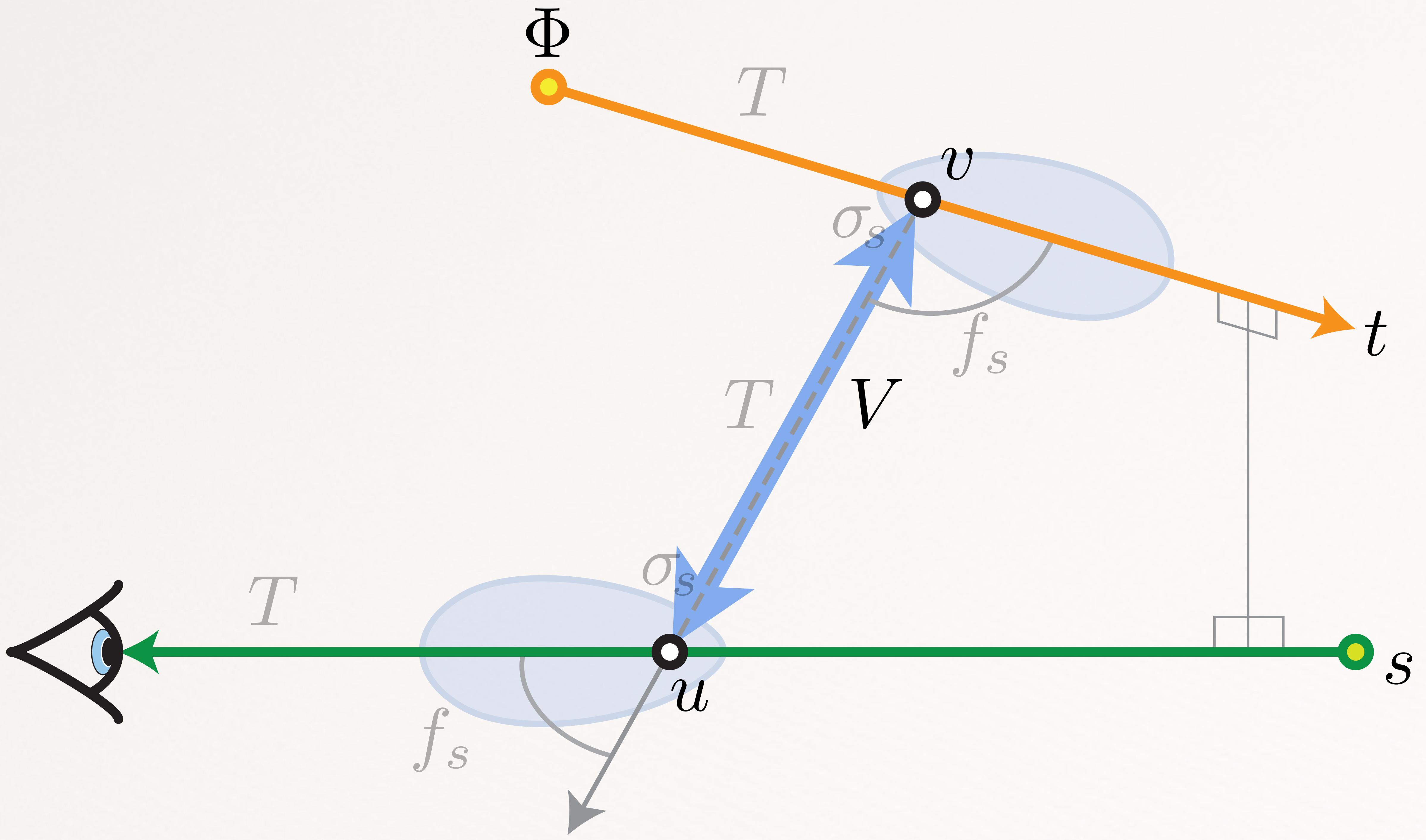


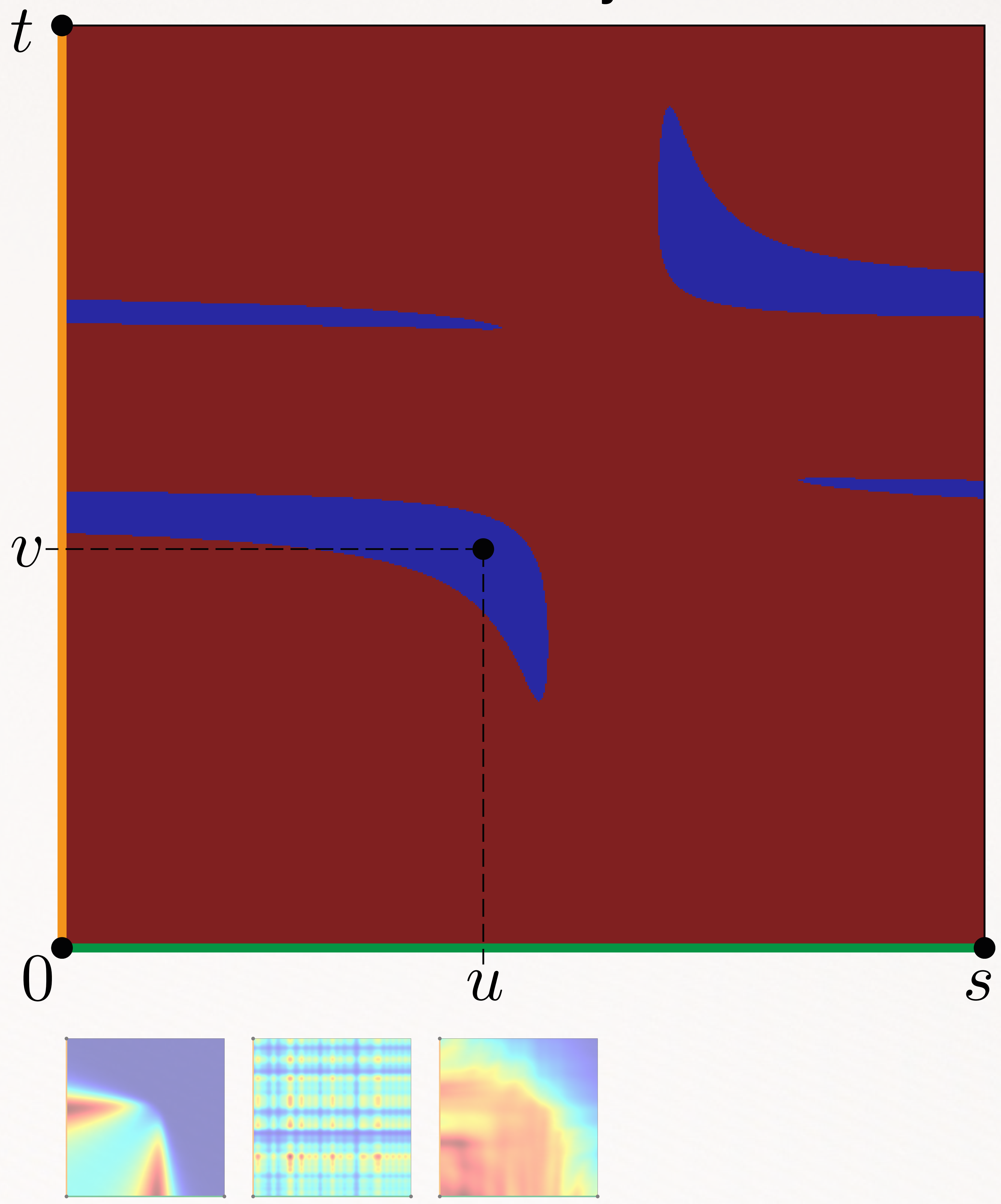


Ray-to-Ray transport

visibility

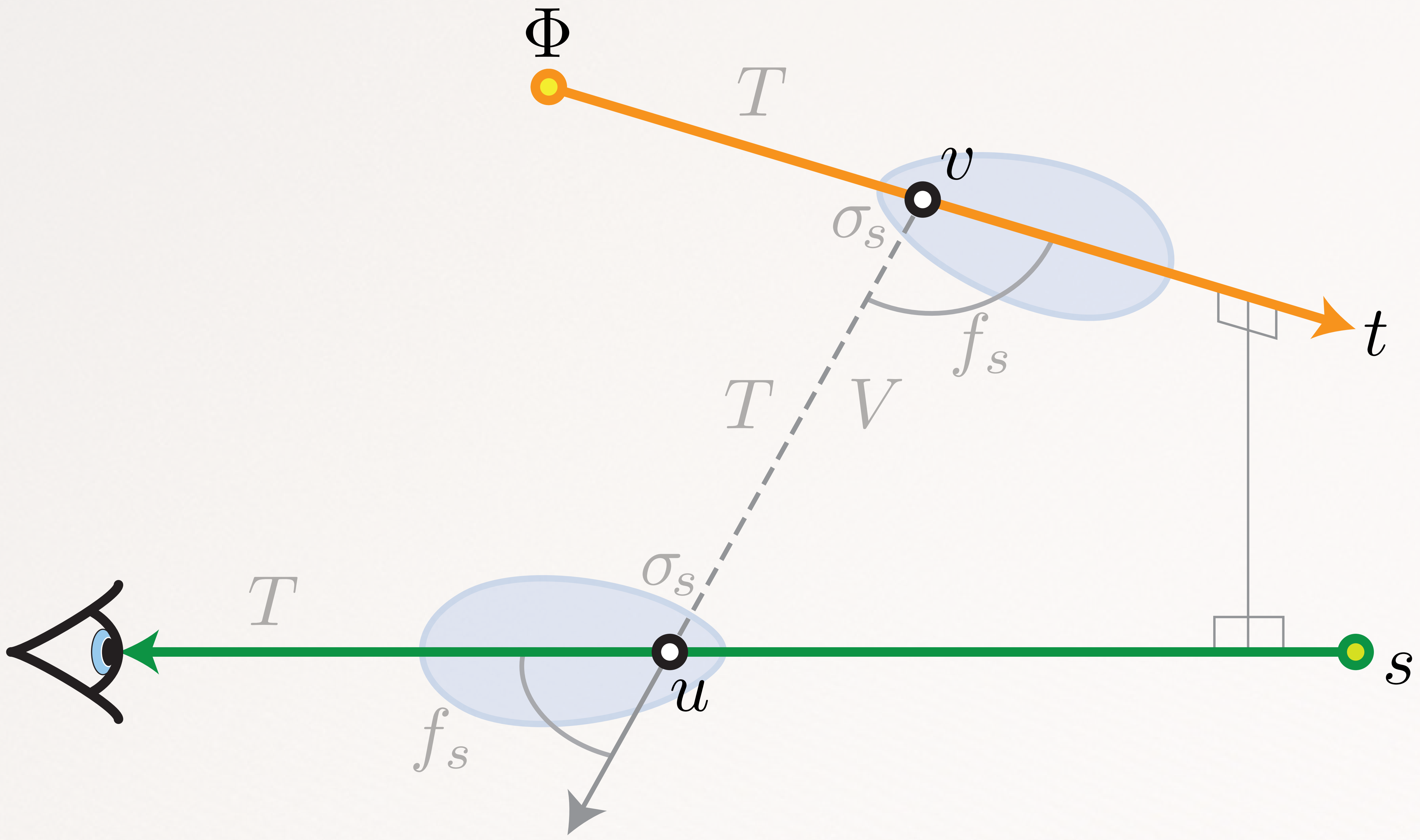
$$L = \Phi \int_0^s \int_0^t \frac{f_s(\theta_u) f_s(\theta_v)\, \sigma_s(u) \sigma_s(v)\, T(u) T(v) T(w)\, V}{} \mathrm{d}v \mathrm{d}u$$

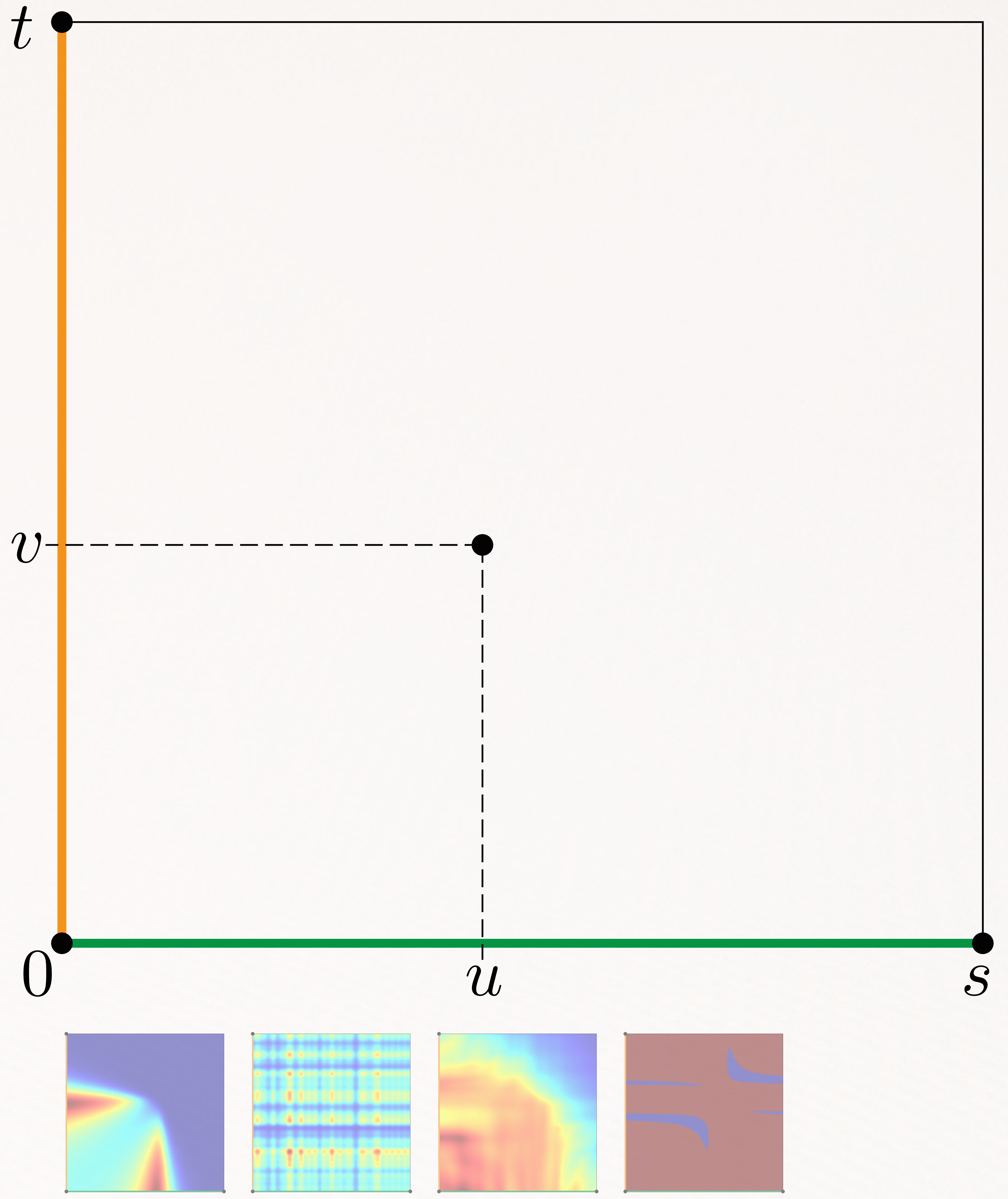




Ray-to-Ray transport

$$L = \Phi \int_0^s \int_0^t \frac{f_s(\theta_u) f_s(\theta_v)\, \sigma_s(u) \sigma_s(v)\, T(u) T(v) T(w)\, V}{} \mathrm{d}v \mathrm{d}u$$

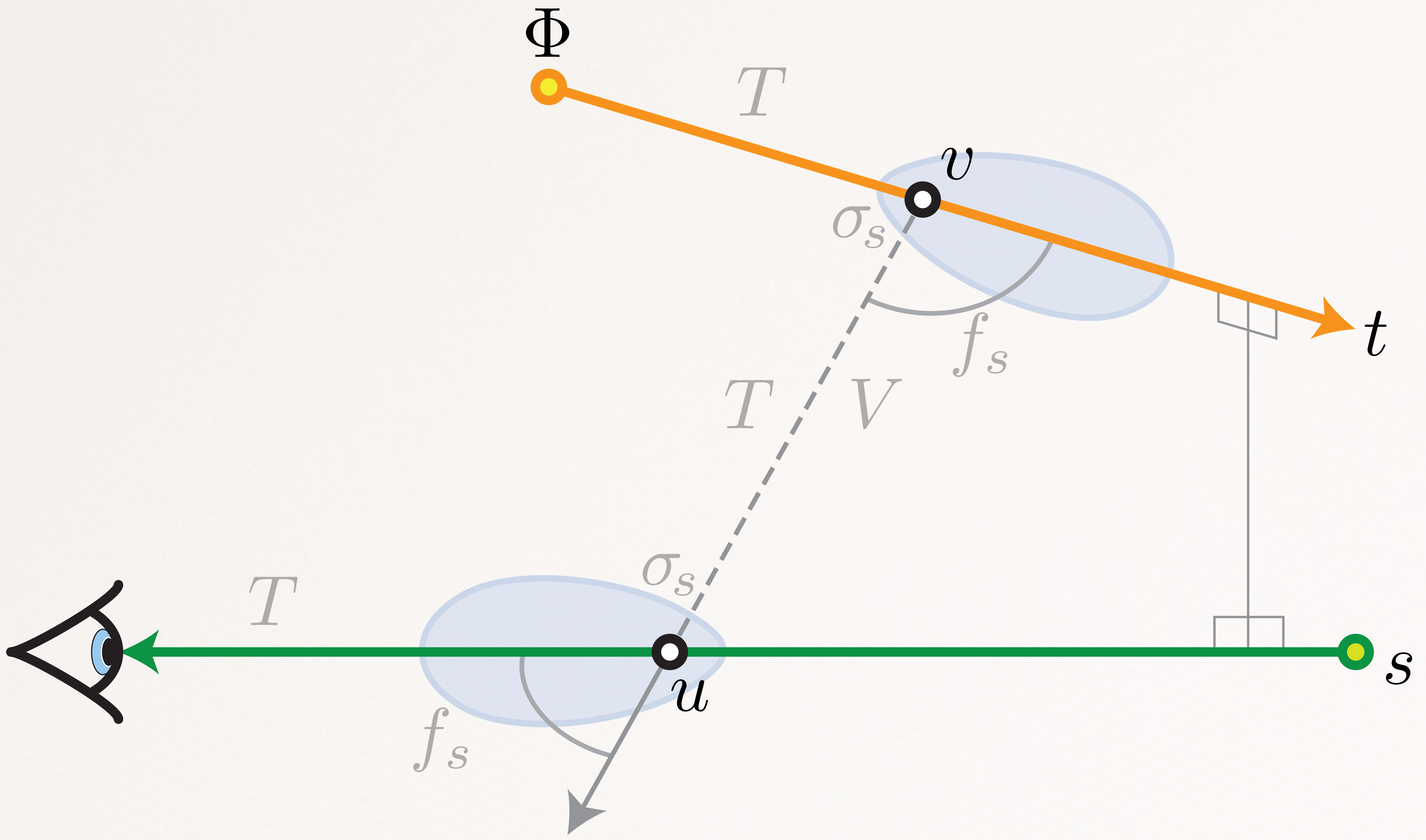


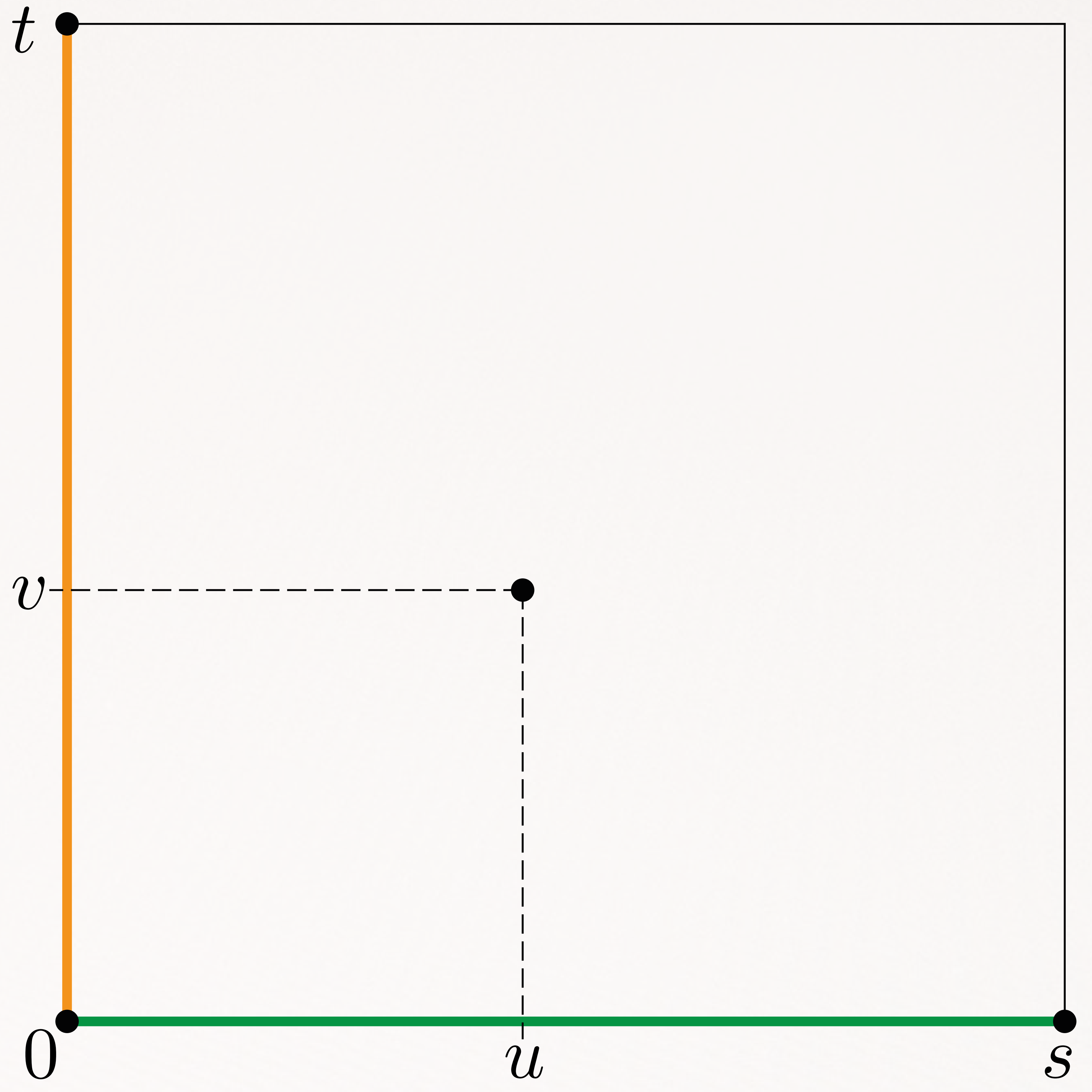


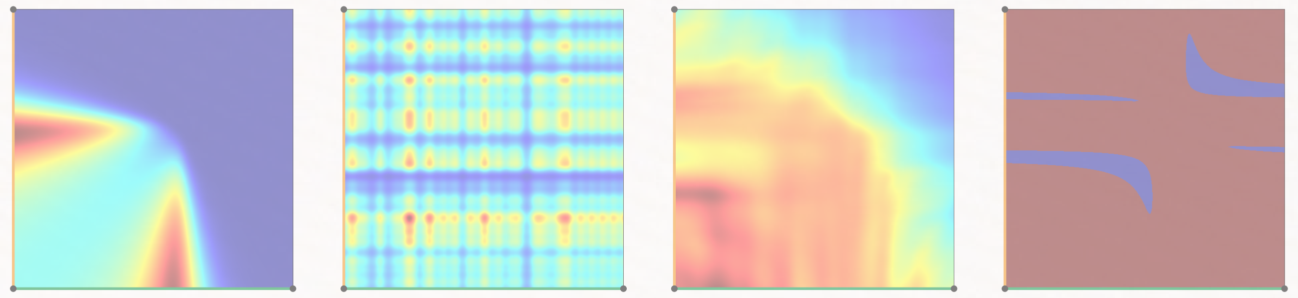
Ray-to-Ray transport

$$L = \Phi \int_0^s \int_0^t \frac{f_s(\theta_u) f_s(\theta_v)\, \sigma_s(u) \sigma_s(v)\, T(u) T(v) T(w)\, V}{w(u,v)^2} \mathrm{d}v \mathrm{d}u$$

squared distance





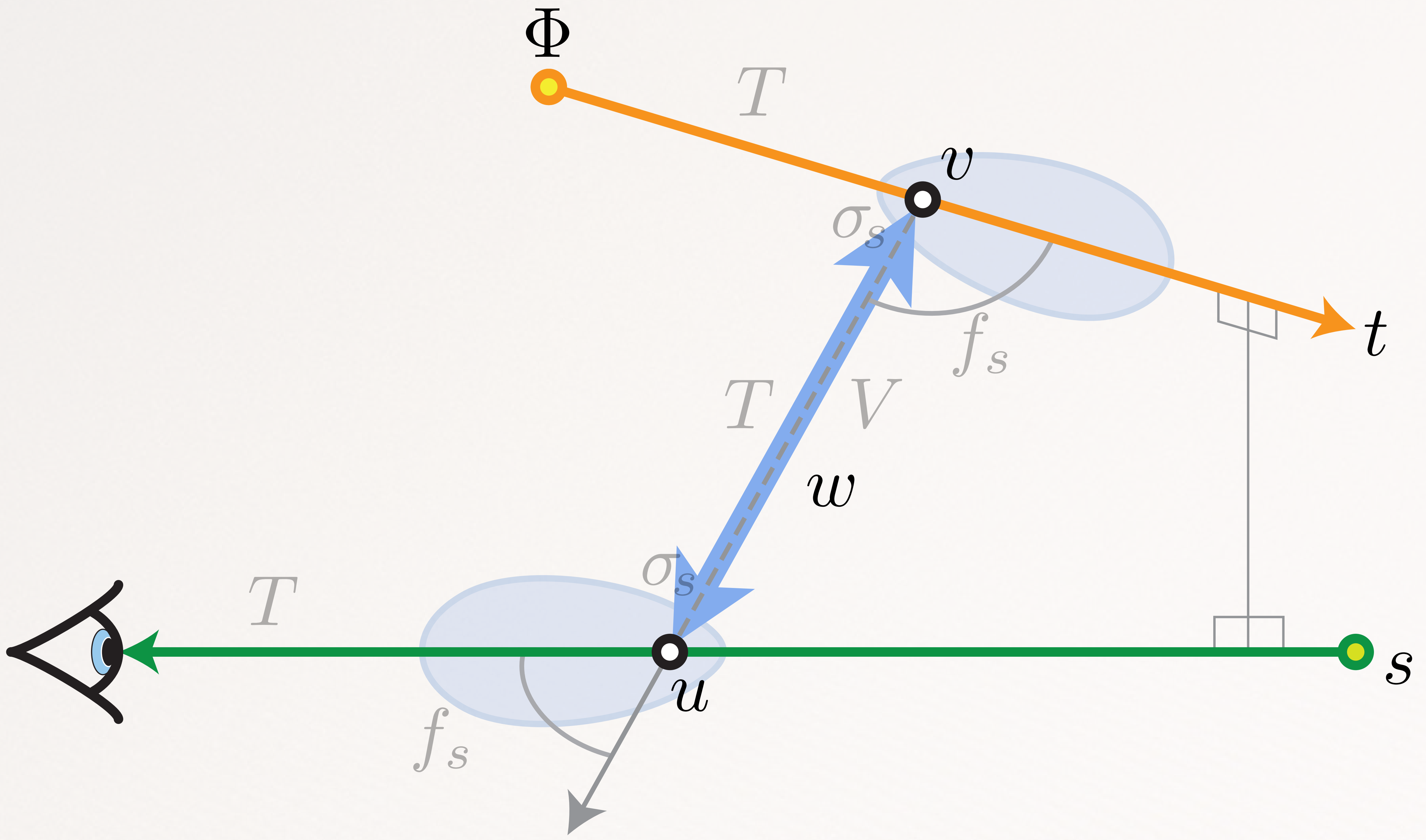


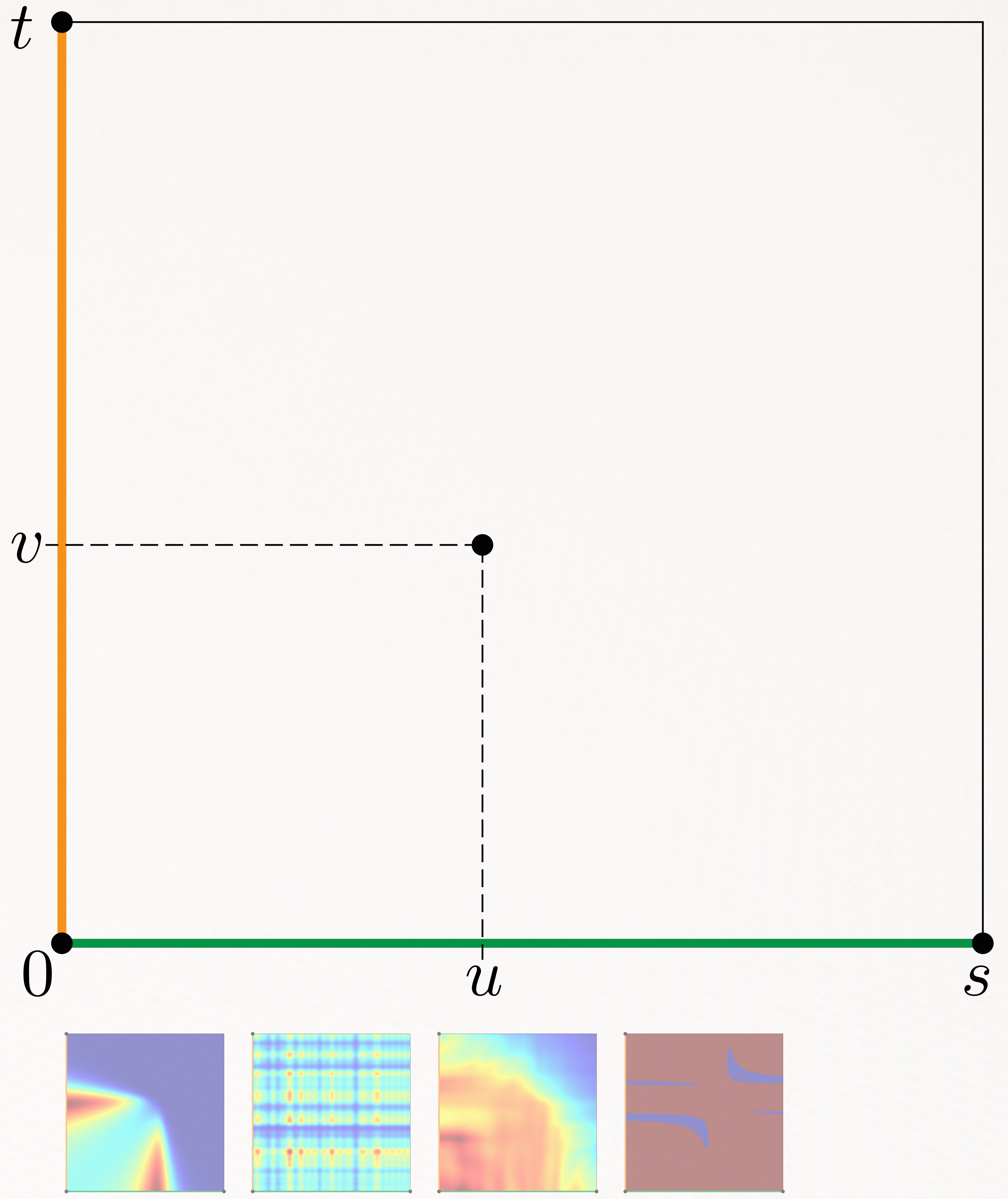
Ray-to-Ray transport

SIGGRAPH2012

$$L = \Phi \int_0^s \int_0^t \frac{f_s(\theta_u) f_s(\theta_v)\, \sigma_s(u)\sigma_s(v)\, T(u)T(v)T(w)\, V}{w(u,v)^2} \mathrm{d}v\mathrm{d}u$$

squared distance



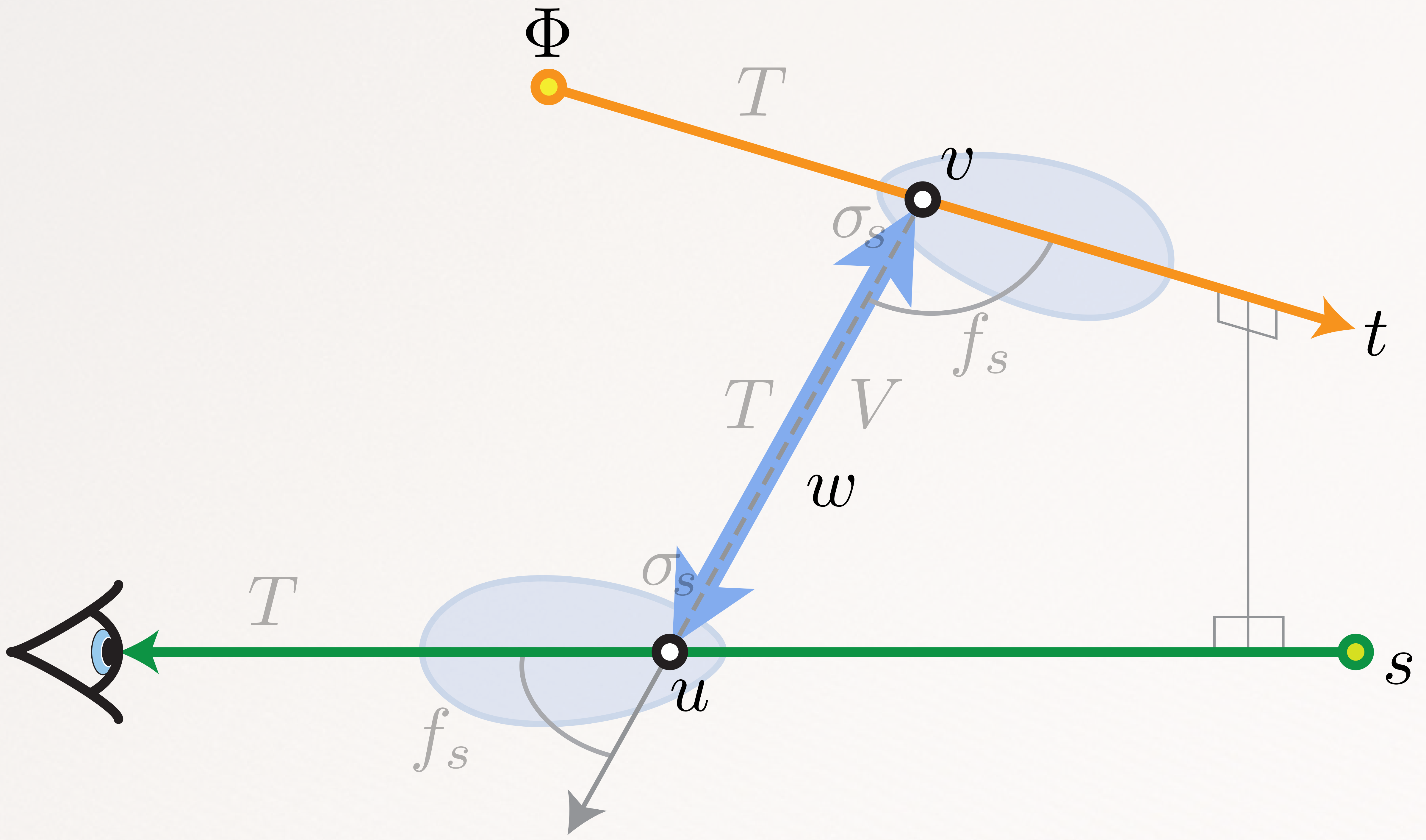


Ray-to-Ray transport

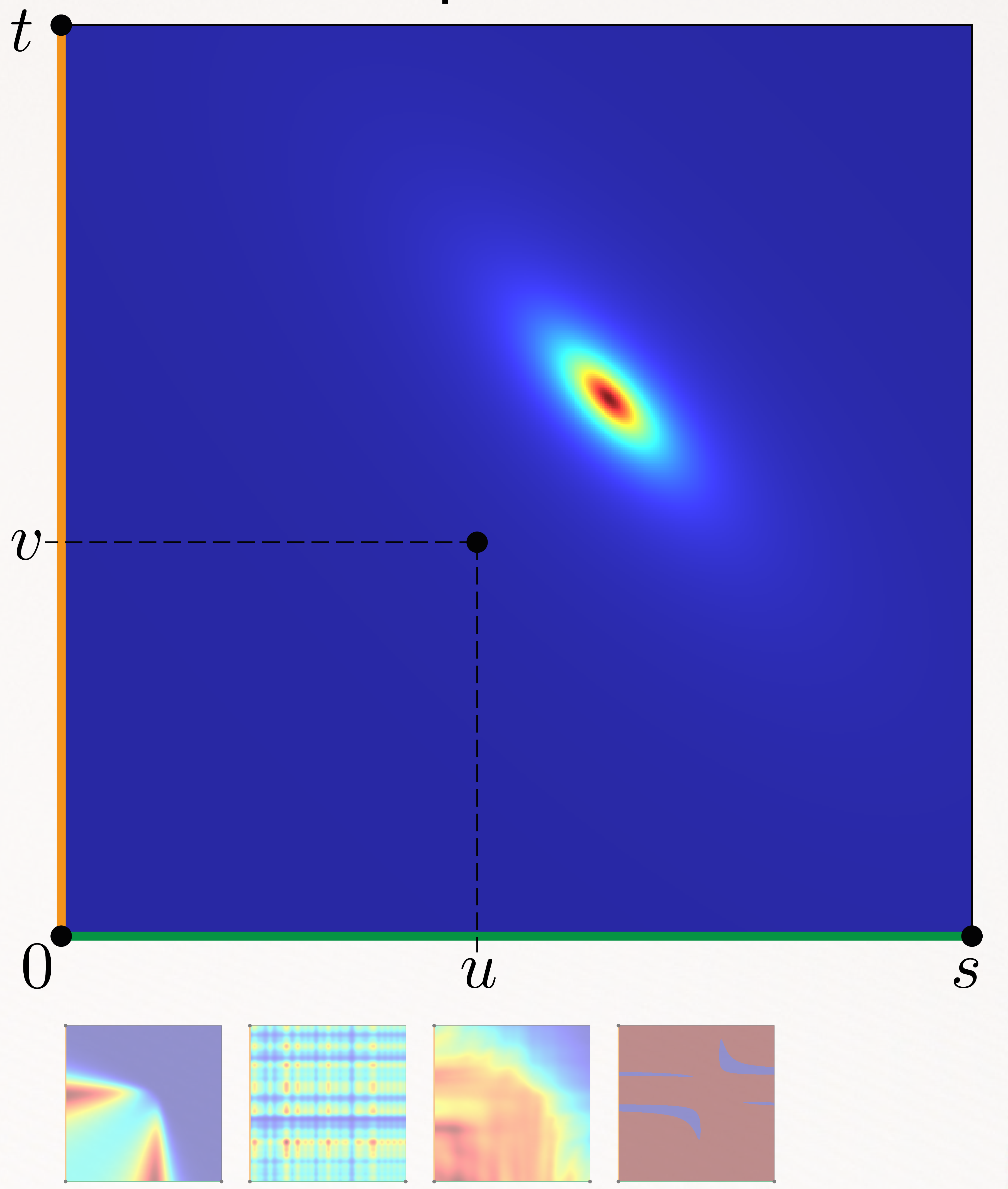
SIGGRAPH2012

$$L = \Phi \int_0^s \int_0^t \frac{f_s(\theta_u) f_s(\theta_v)\, \sigma_s(u)\sigma_s(v)\, T(u)T(v)T(w)\, V}{w(u,v)^2} \mathrm{d}v\mathrm{d}u$$

squared distance

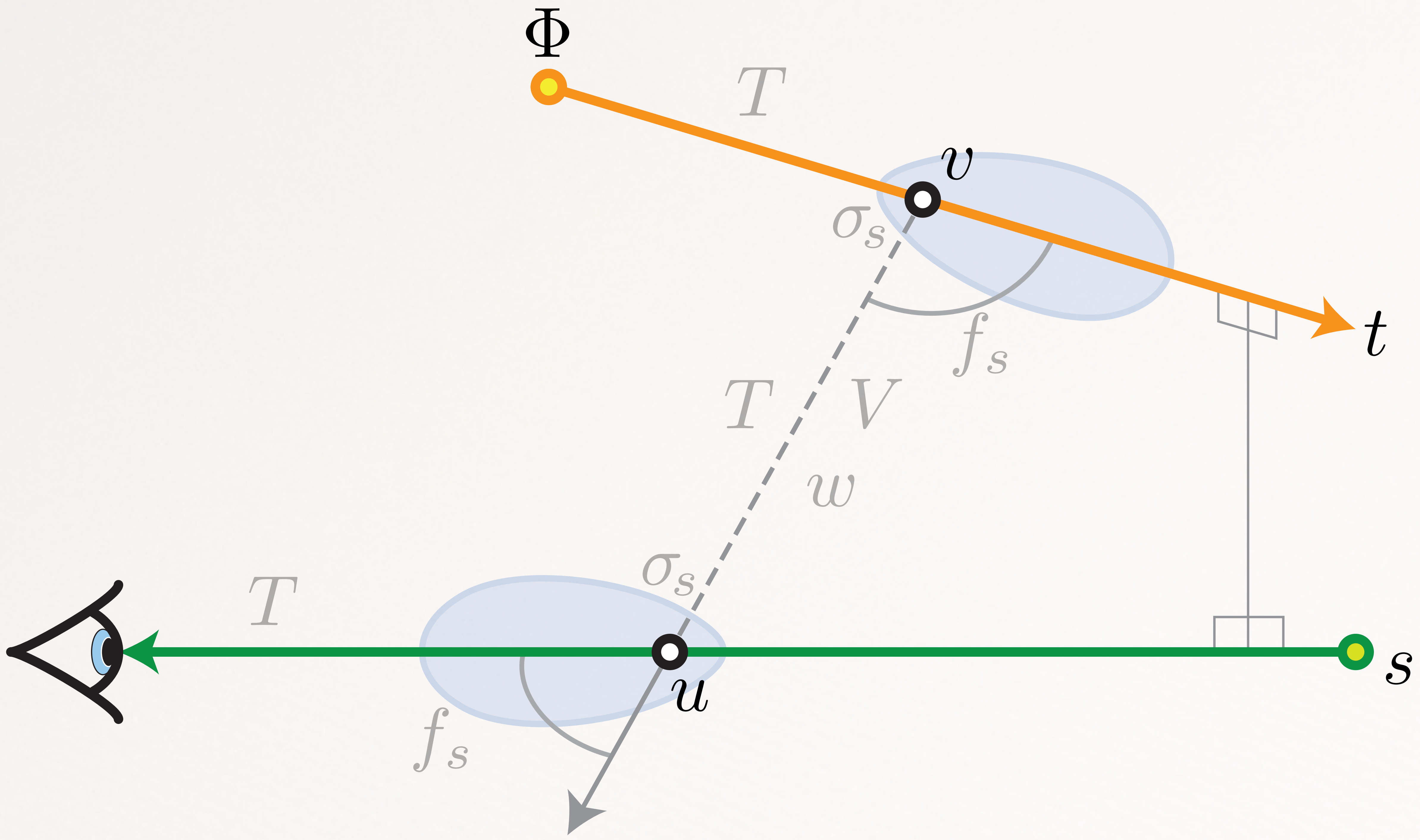


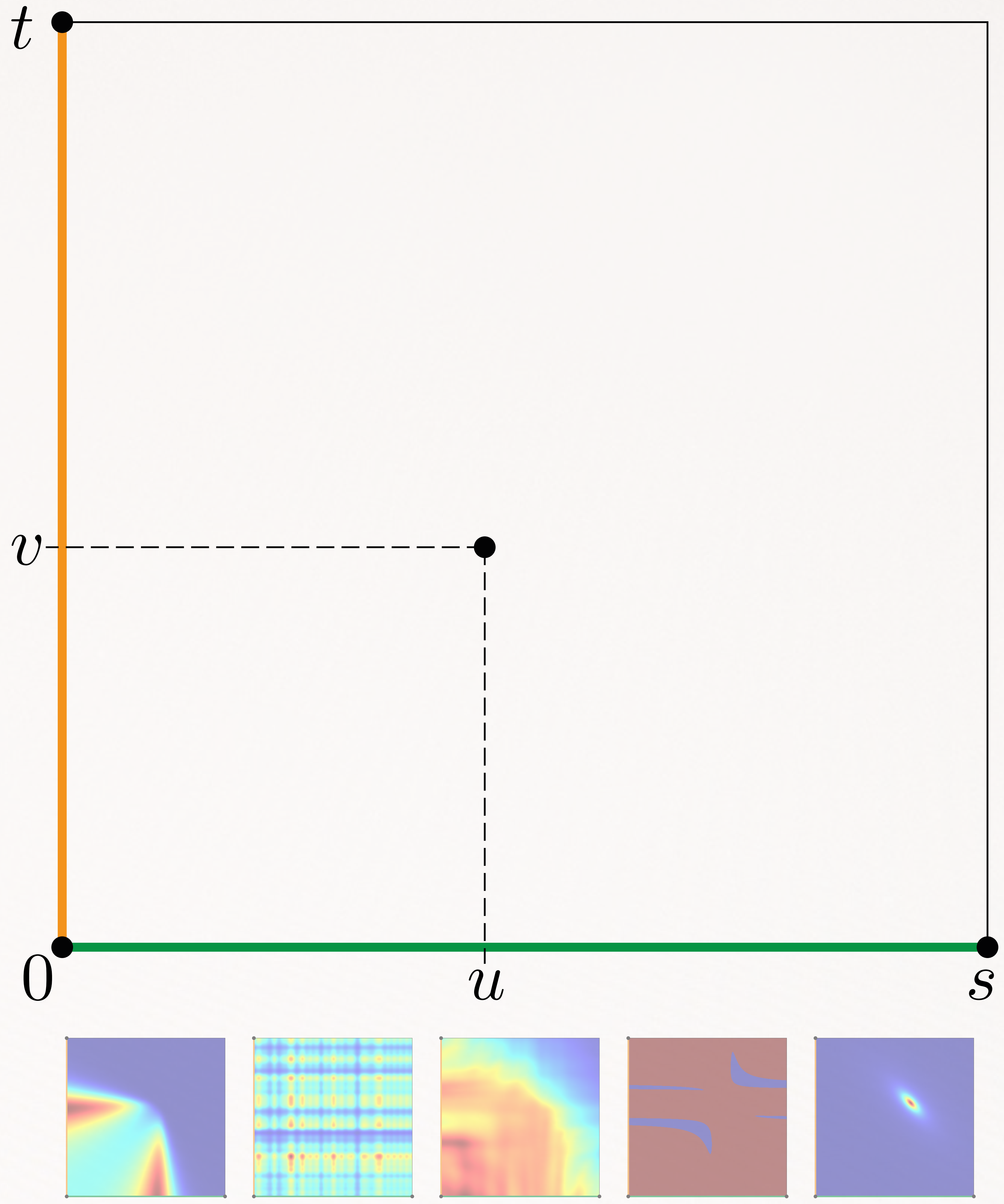
inverse squared distance



Ray-to-Ray transport

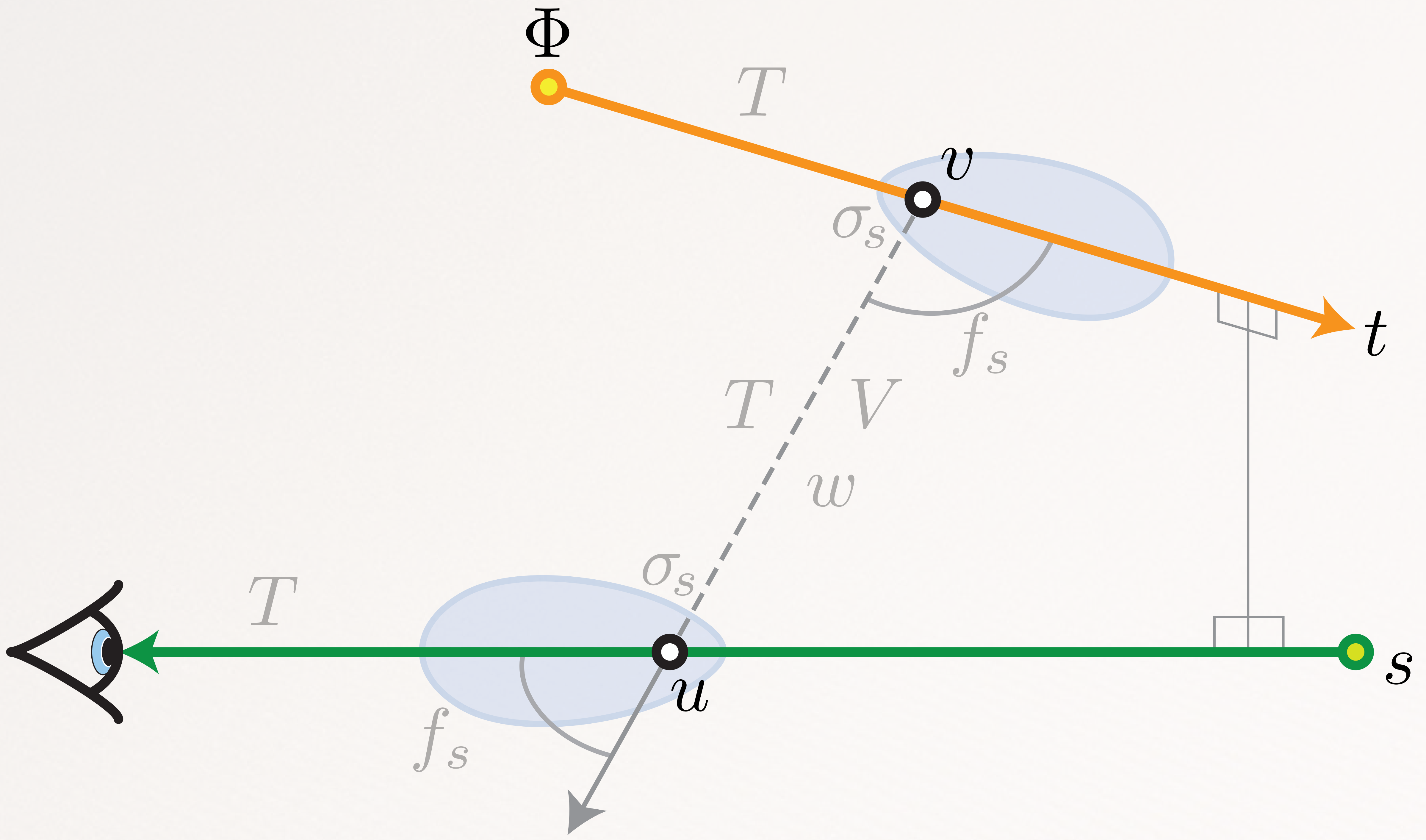
$$L = \Phi \int_0^s \int_0^t \frac{f_s(\theta_u) f_s(\theta_v)\, \sigma_s(u) \sigma_s(v)\, T(u) T(v) T(w)\, V}{w(u,v)^2} \mathrm{d}v\mathrm{d}u$$



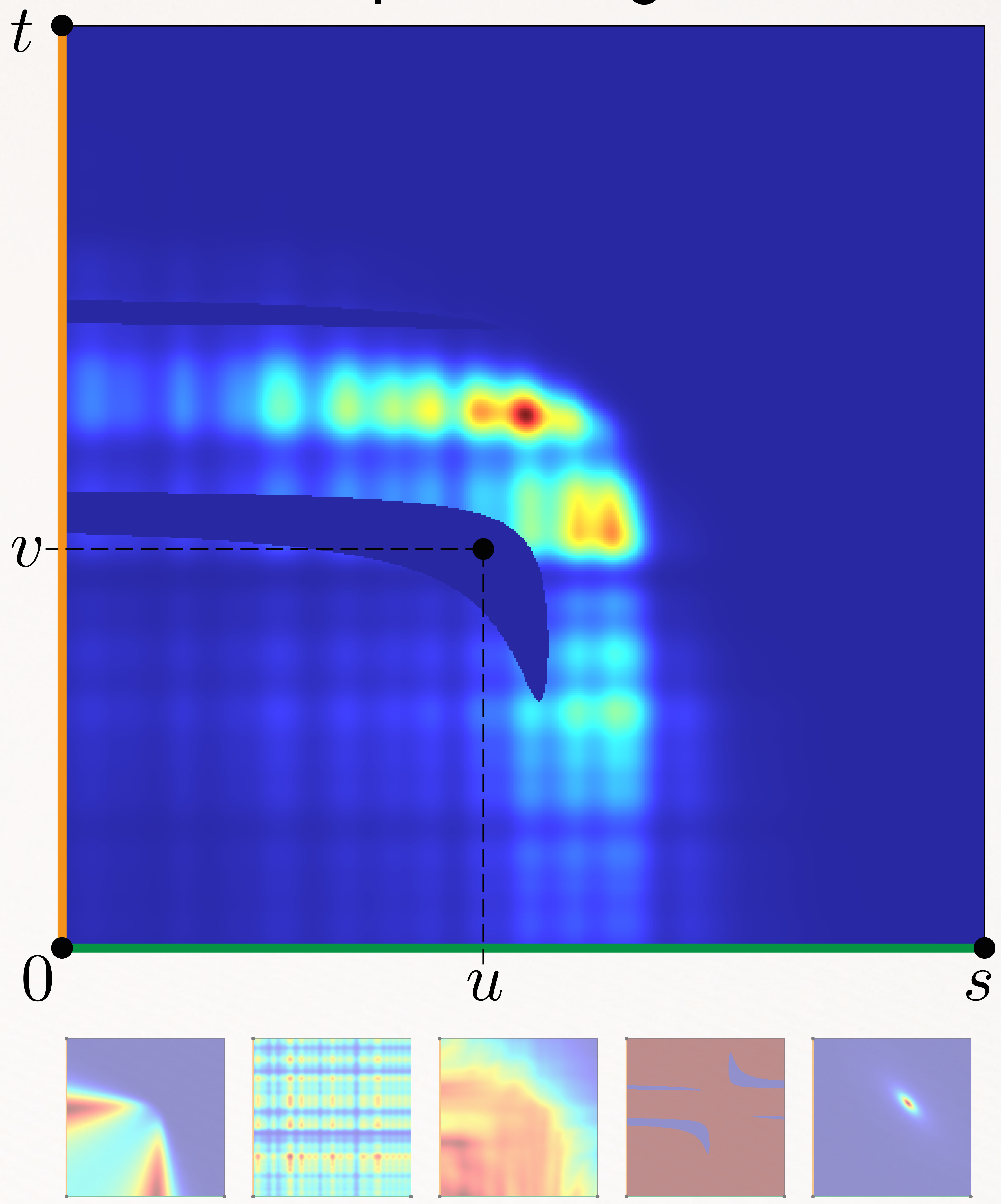


Ray-to-Ray transport

$$L = \Phi \int_0^s \int_0^t \frac{f_s(\theta_u) f_s(\theta_v)\, \sigma_s(u)\sigma_s(v)\, T(u)T(v)T(w)\, V}{w(u,v)^2} \mathrm{d}v\mathrm{d}u$$



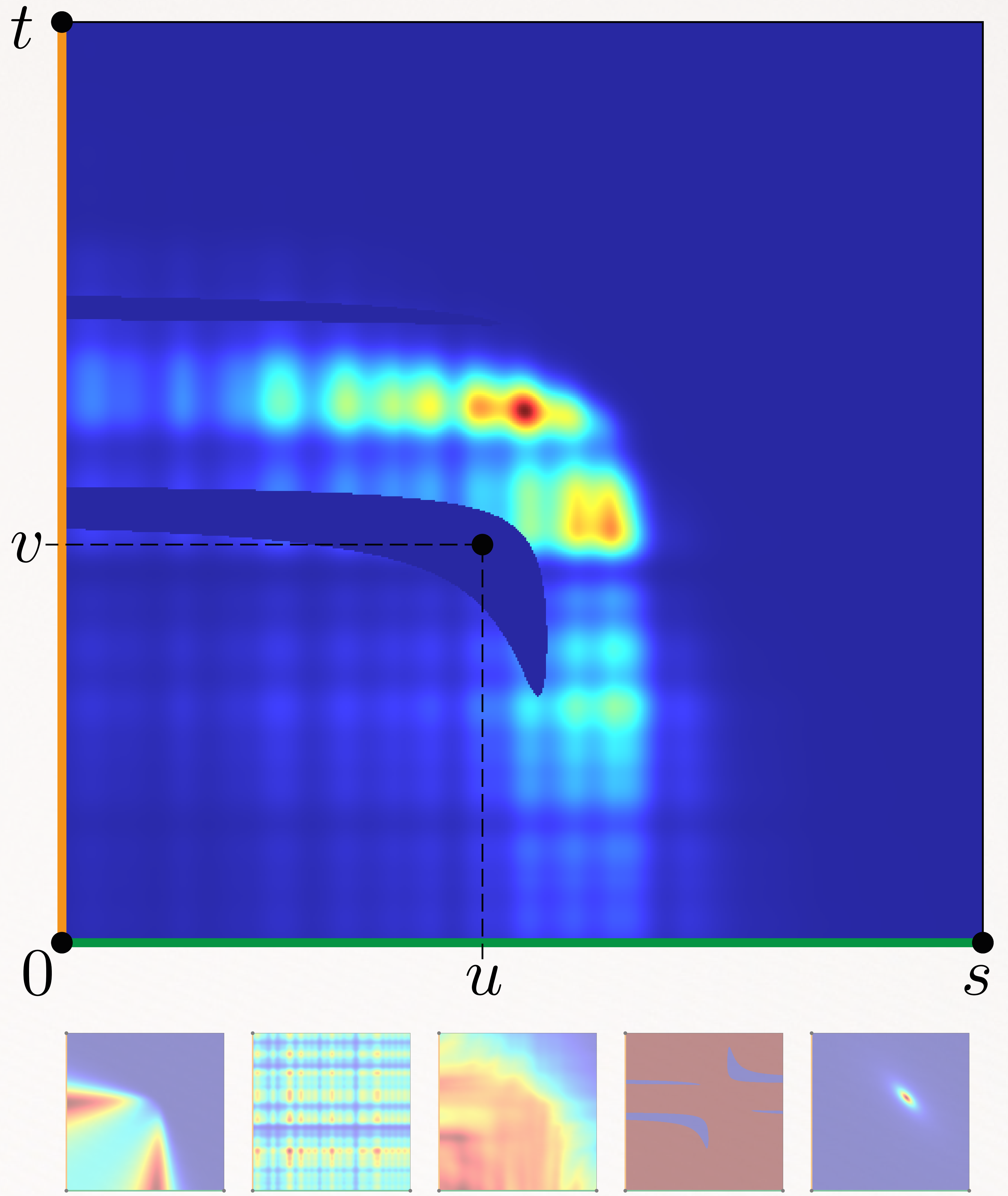
complete integrand



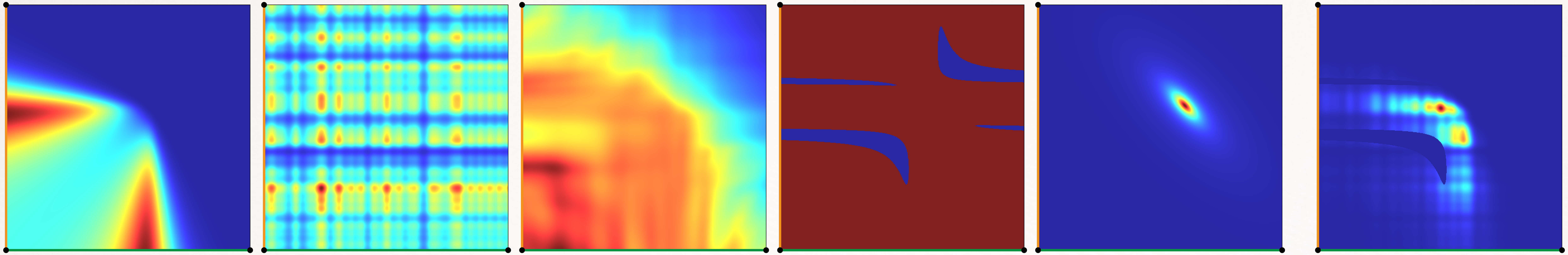
Ray-to-Ray transport

$$L = \Phi \int_0^s \int_0^t \frac{f_s(\theta_u) f_s(\theta_v)\, \sigma_s(u) \sigma_s(v)\, T(u) T(v) T(w)\, V}{w(u,v)^2} \mathrm{d}v \mathrm{d}u$$

approximate using Monte Carlo with importance sampling



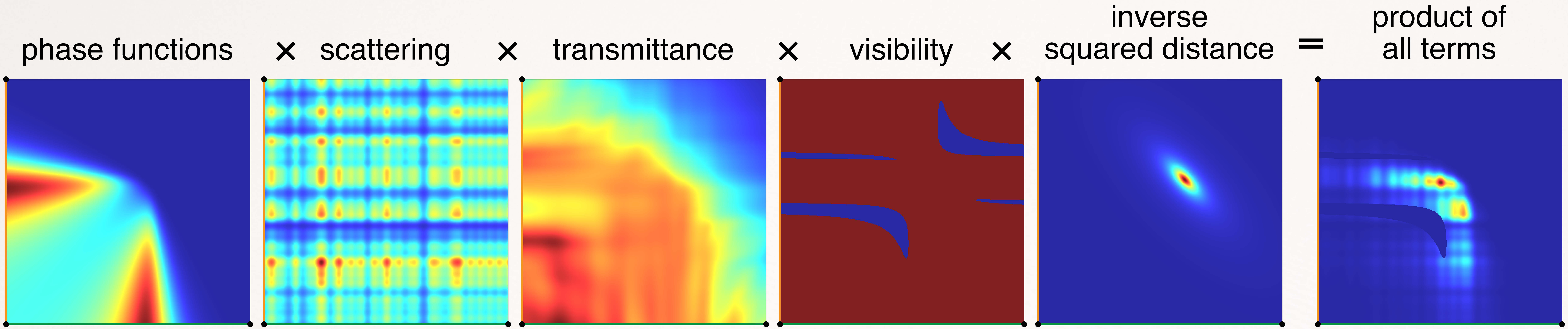
Importance sampling



Importance sampling

SIGGRAPH2012

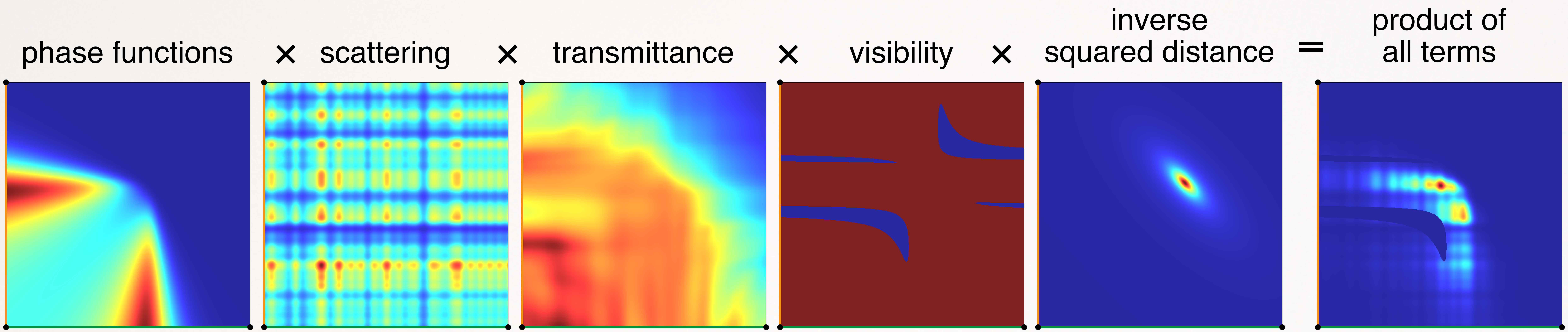
How to (importance) sample?



Importance sampling

How to (importance) sample?

Simple cases first!

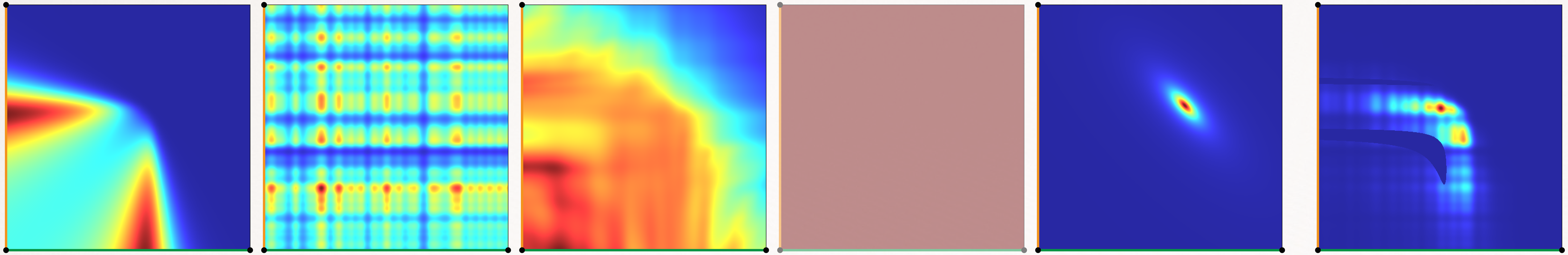


Importance sampling

SIGGRAPH2012

How to (importance) sample?

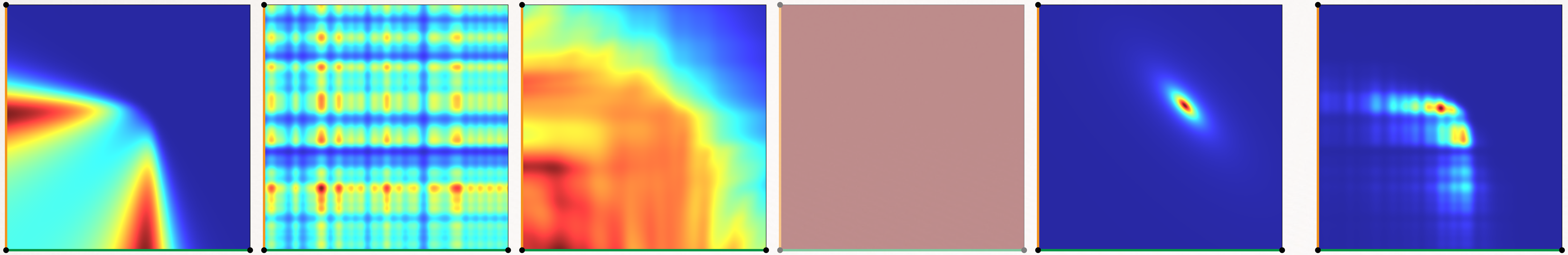
Simple cases first!



Importance sampling

How to (importance) sample?

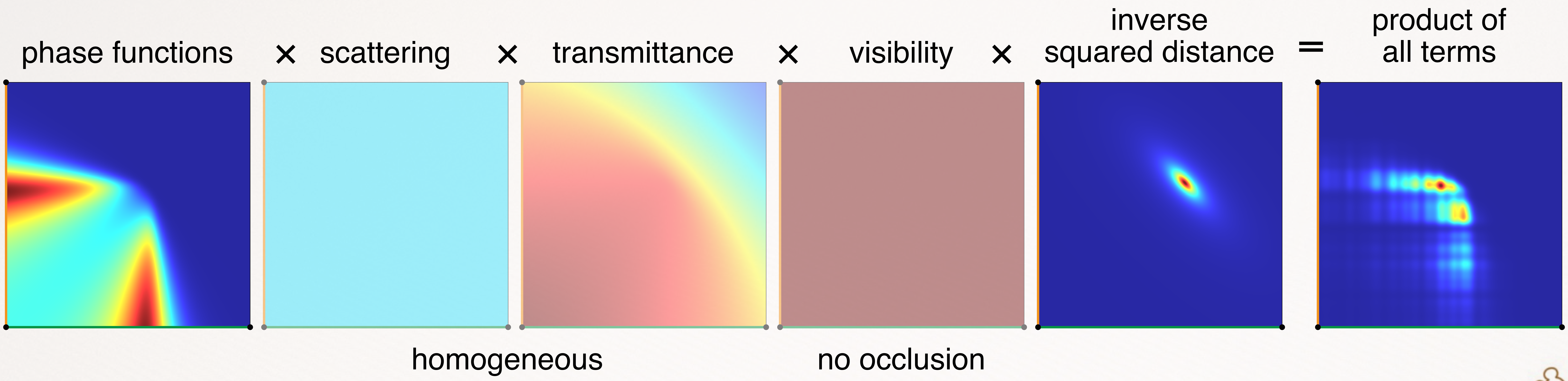
Simple cases first!



Importance sampling

How to (importance) sample?

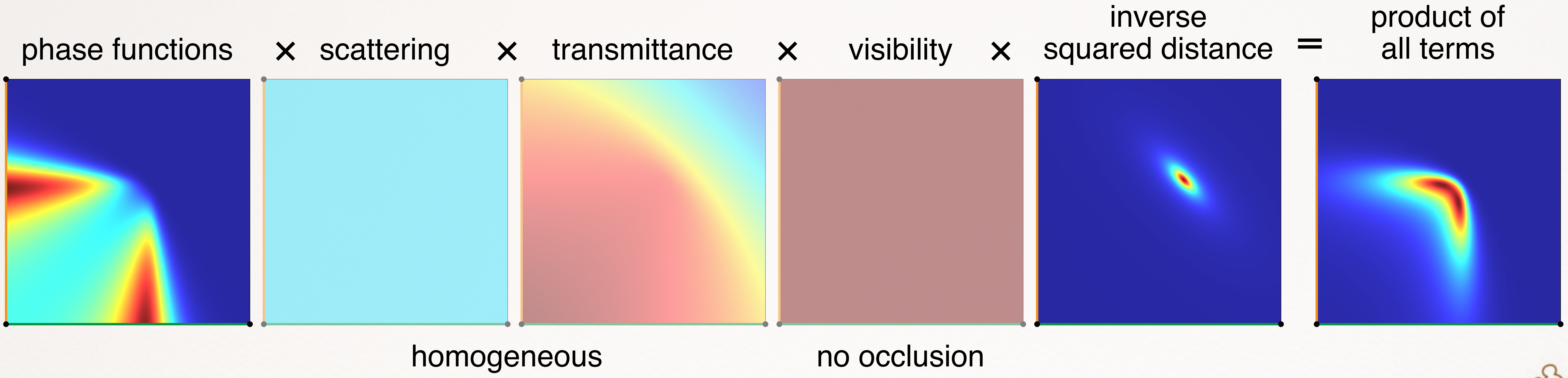
Simple cases first!



Importance sampling

How to (importance) sample?

Simple cases first!



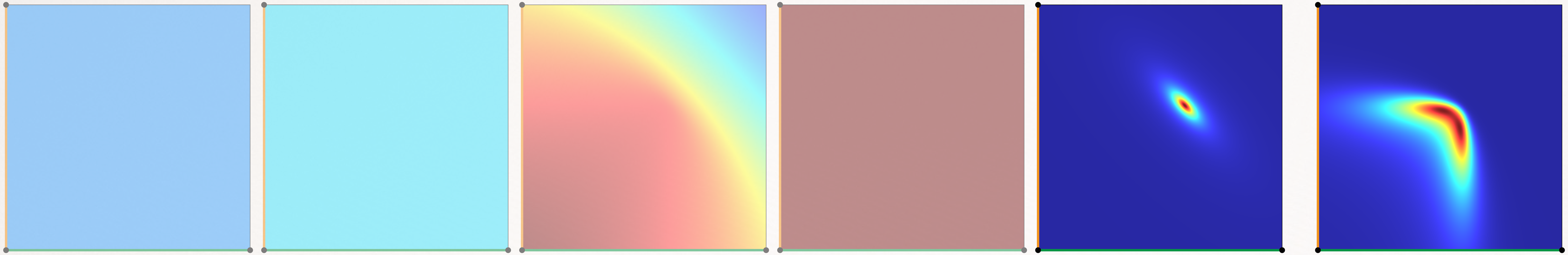
Importance sampling

SIGGRAPH2012

How to (importance) sample?

Simple cases first!

phase functions × scattering × transmittance × visibility × inverse squared distance = product of all terms



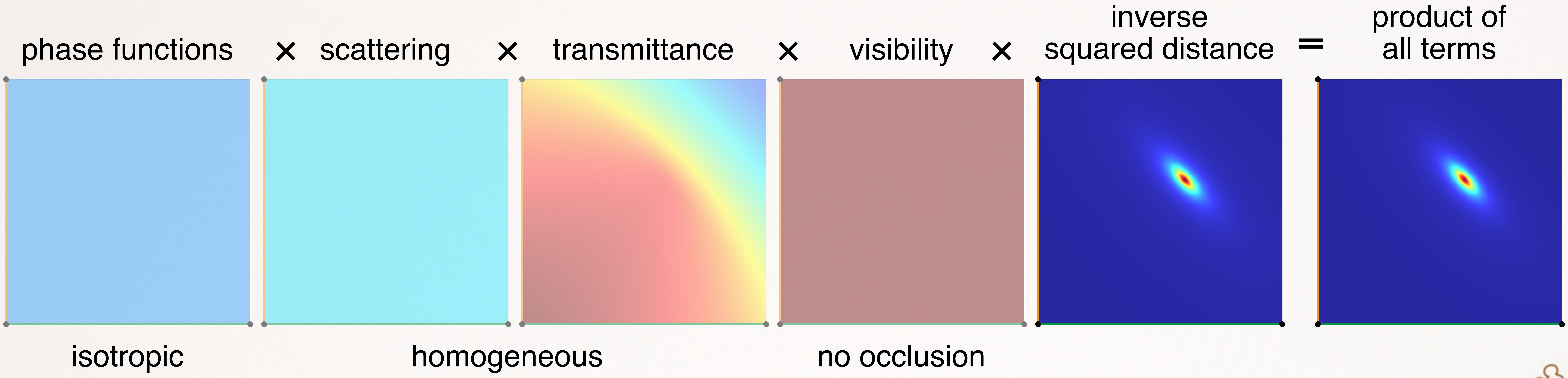
isotropic | homogeneous | no occlusion

Importance sampling

SIGGRAPH2012

How to (importance) sample?

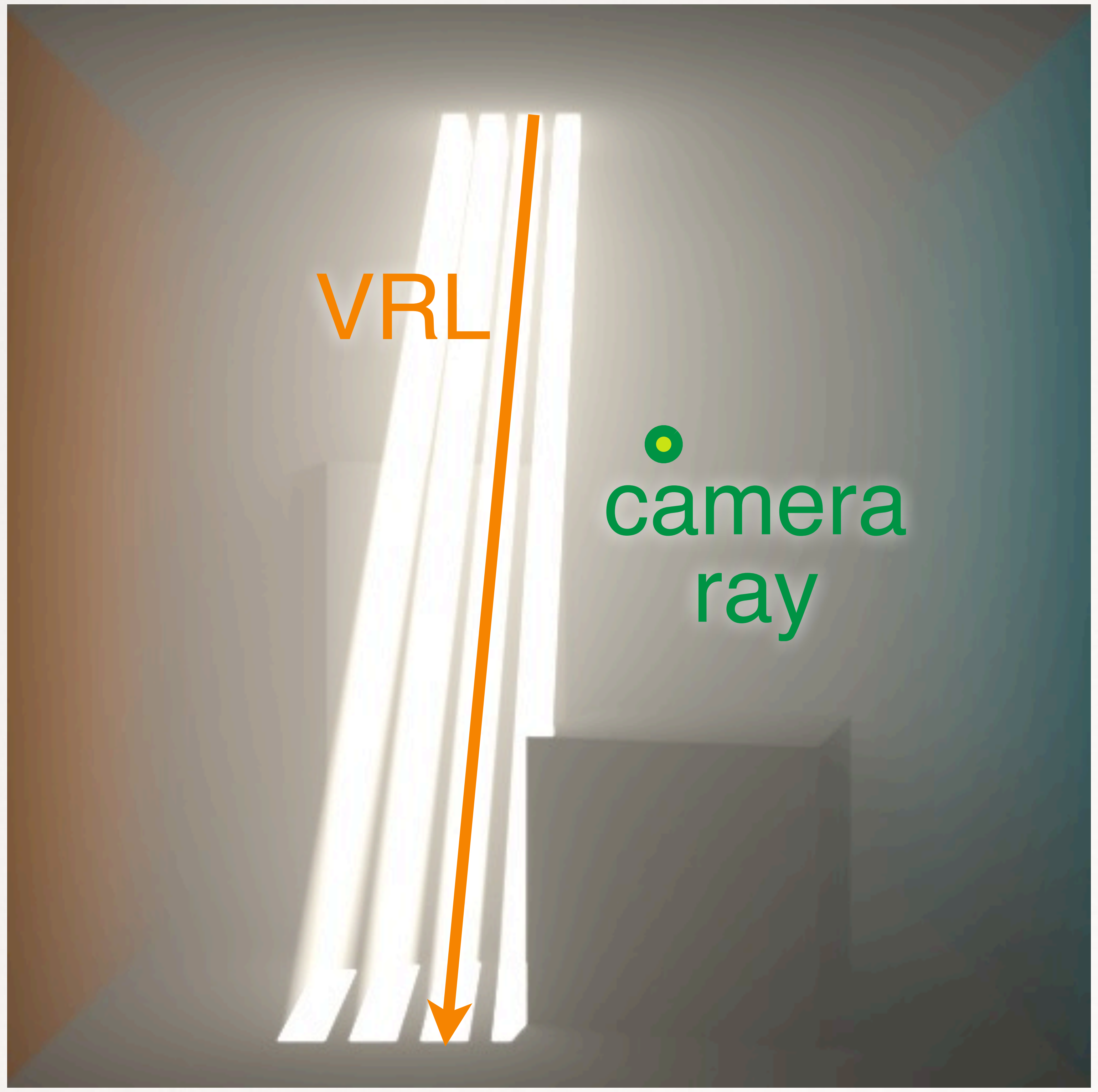
Simple cases first!



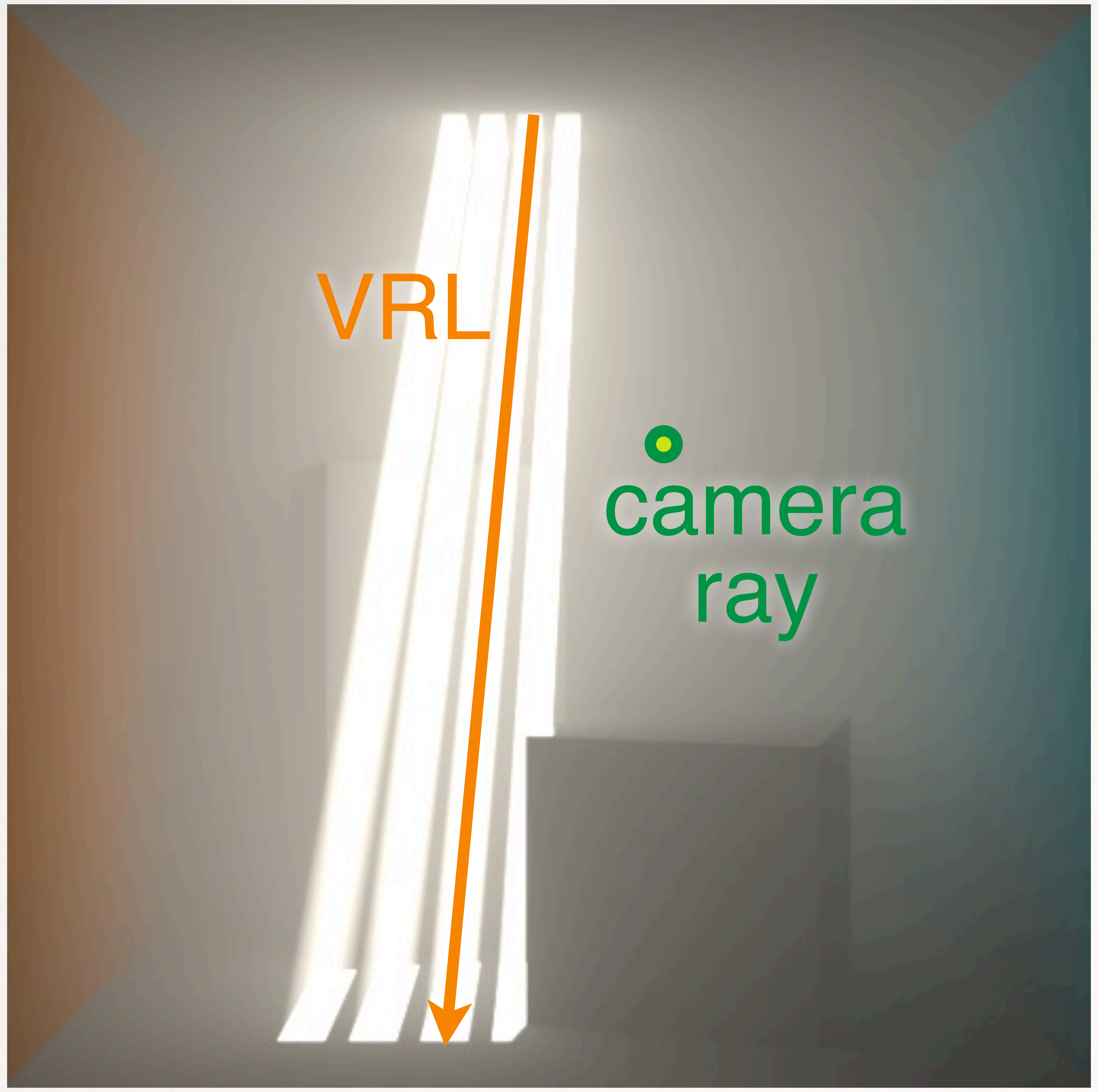
Isotropic media

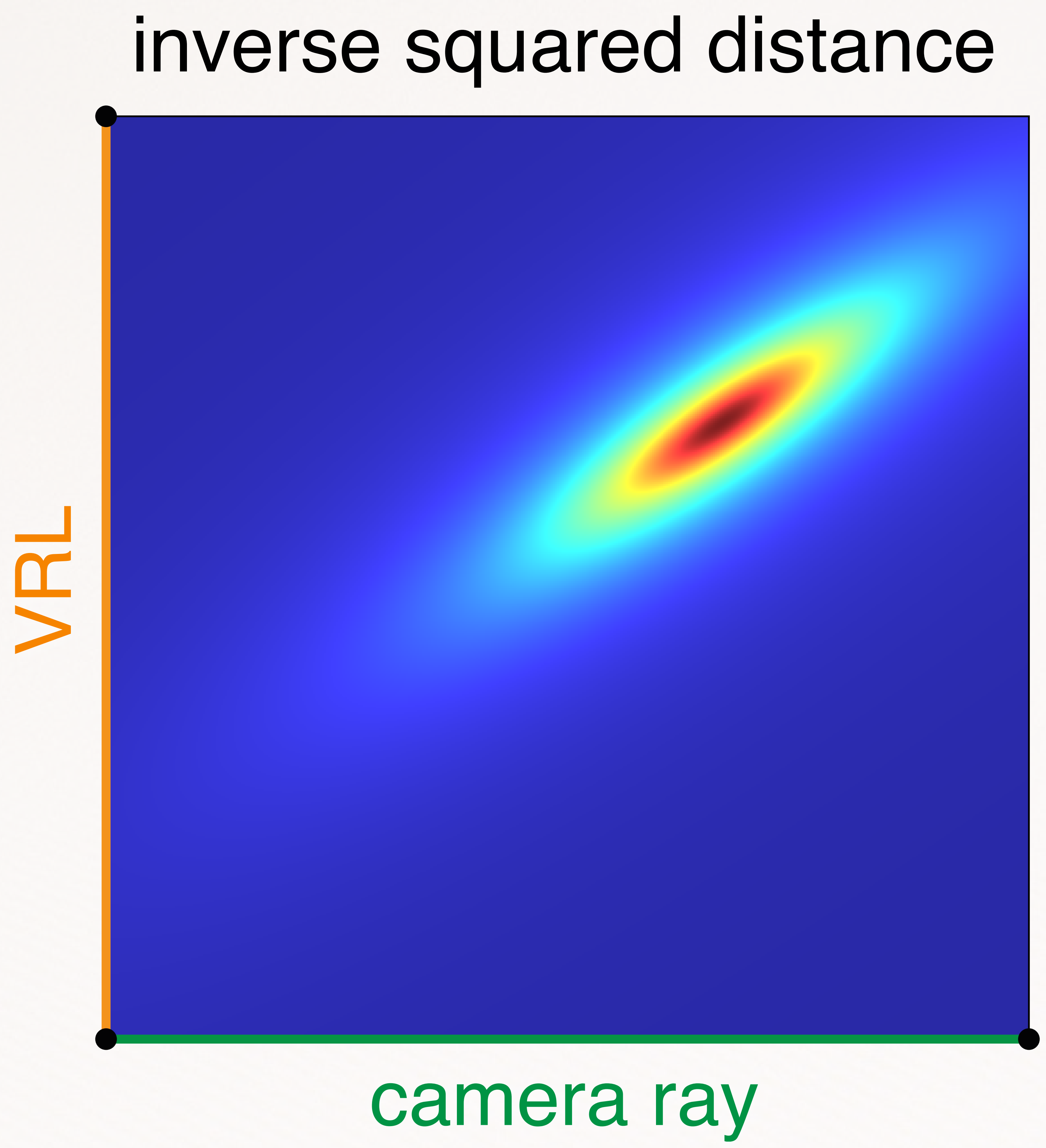
SIGGRAPH2012

Isotropic media

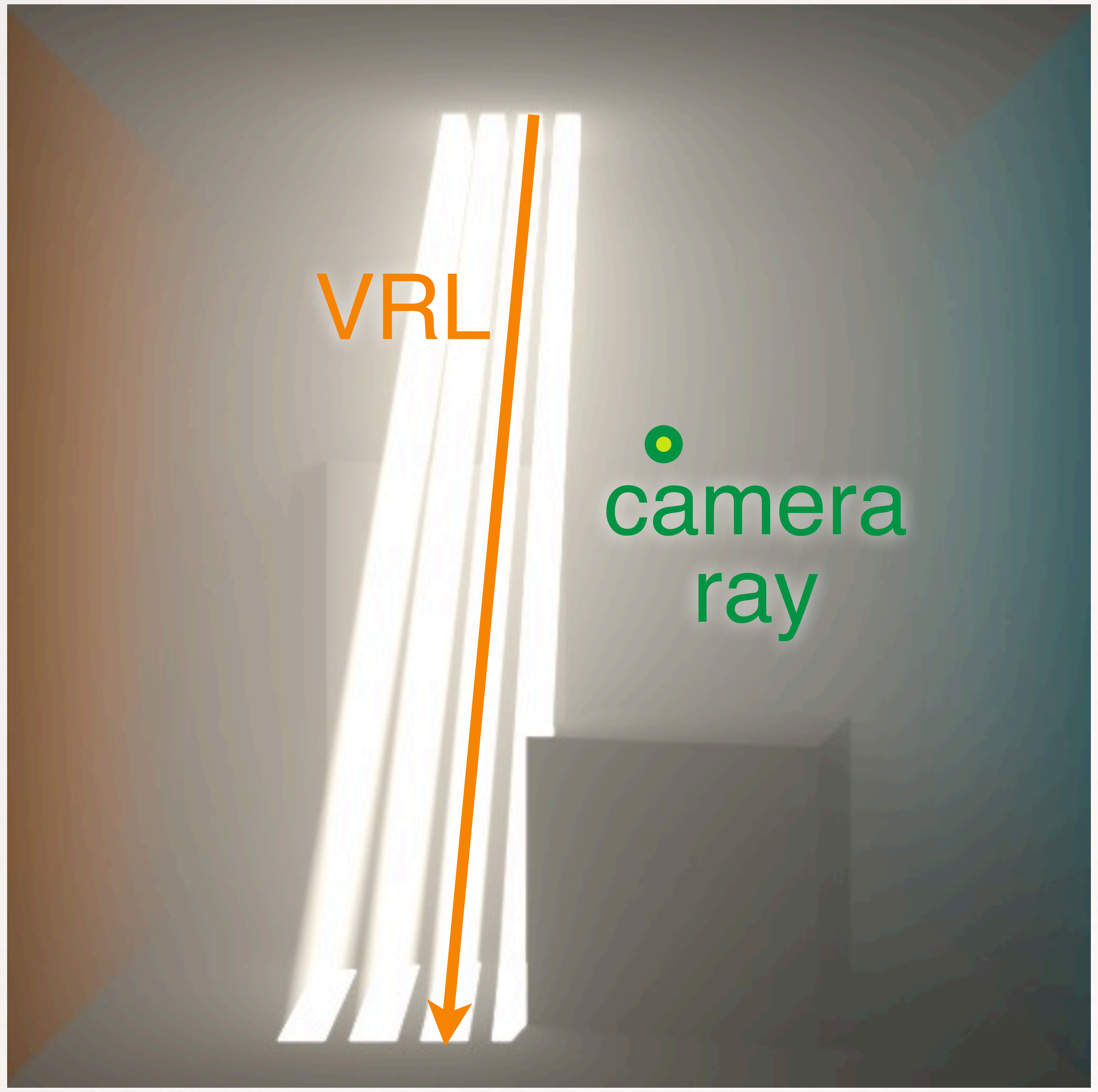


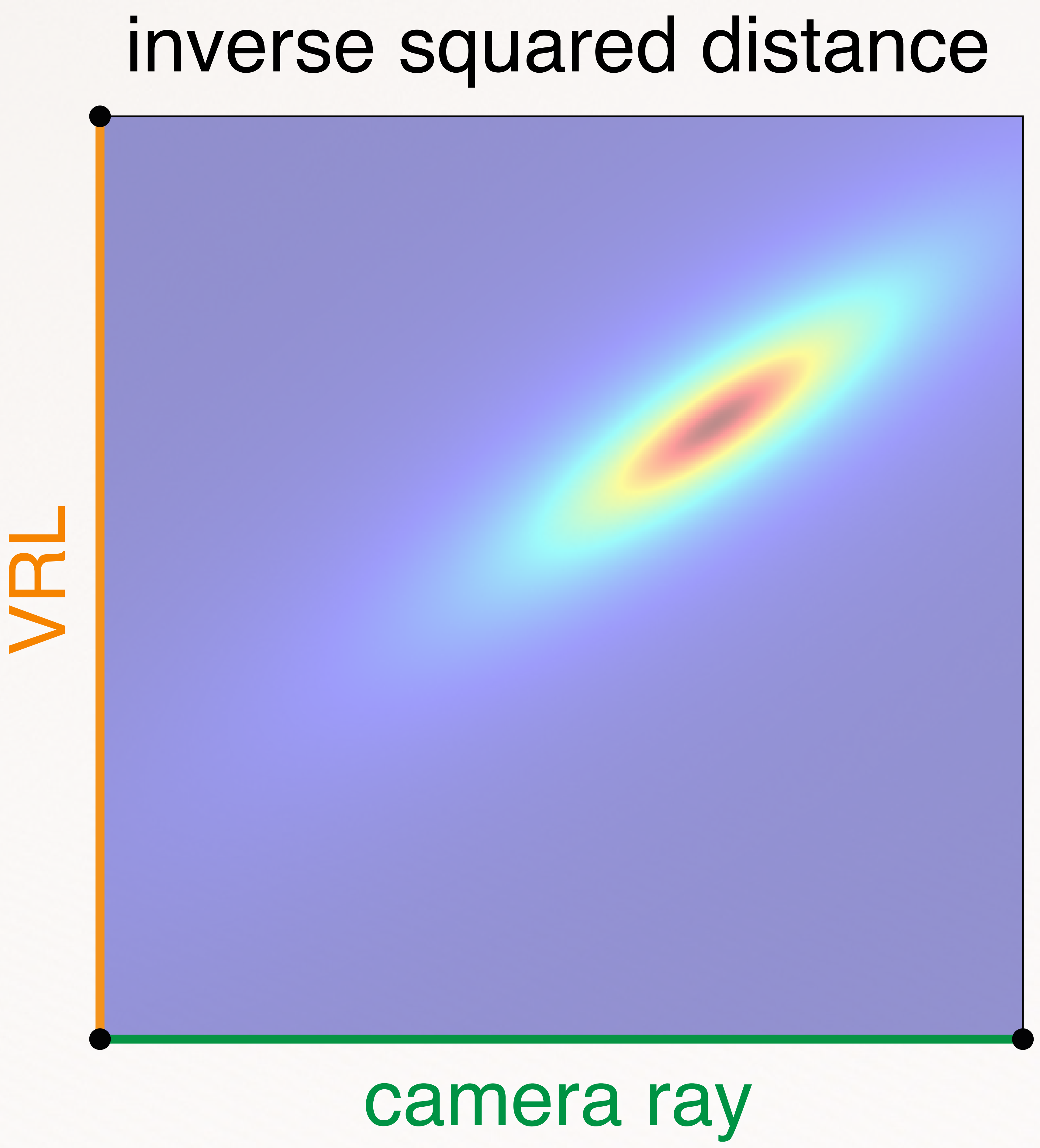
Isotropic media



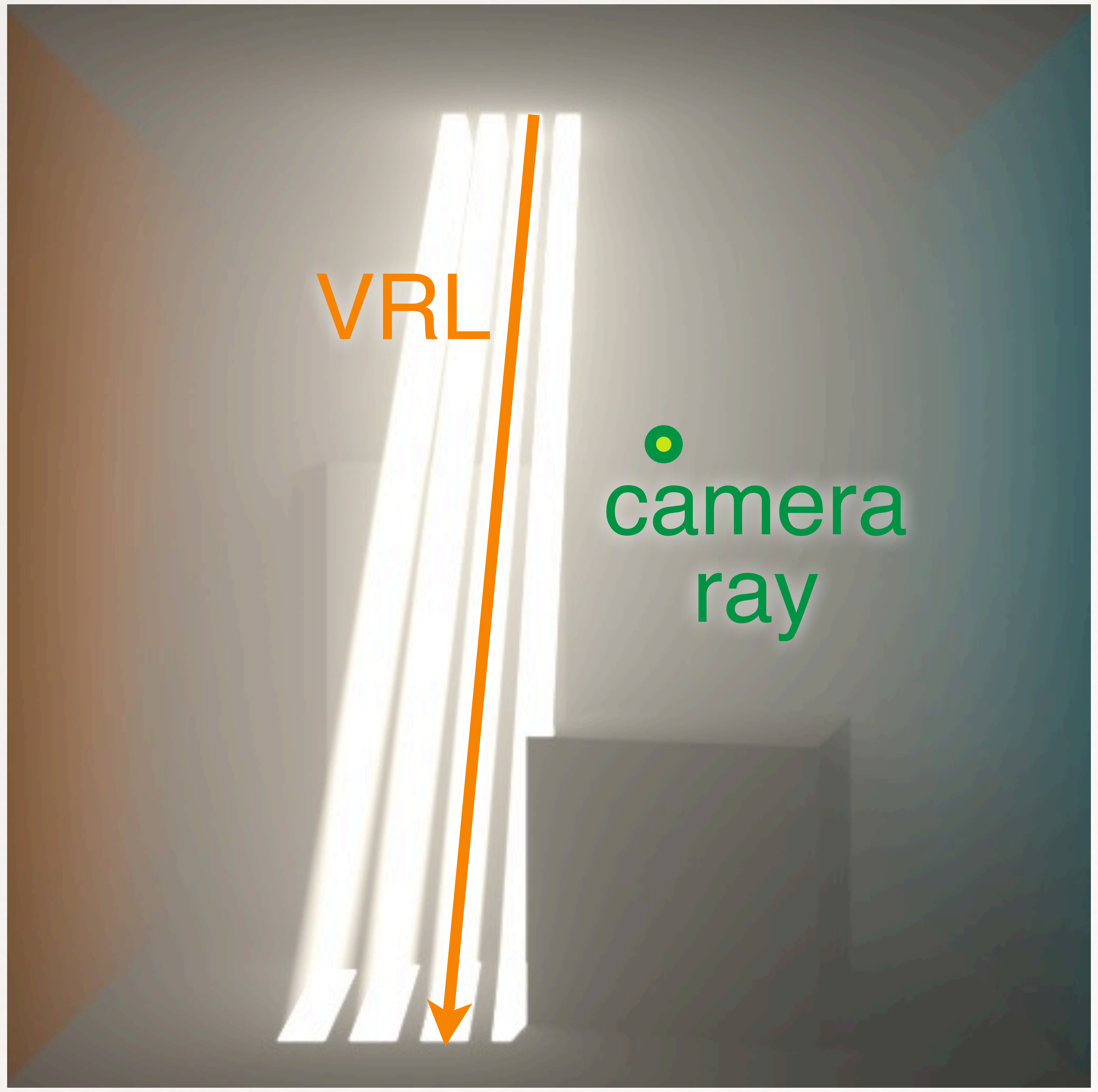


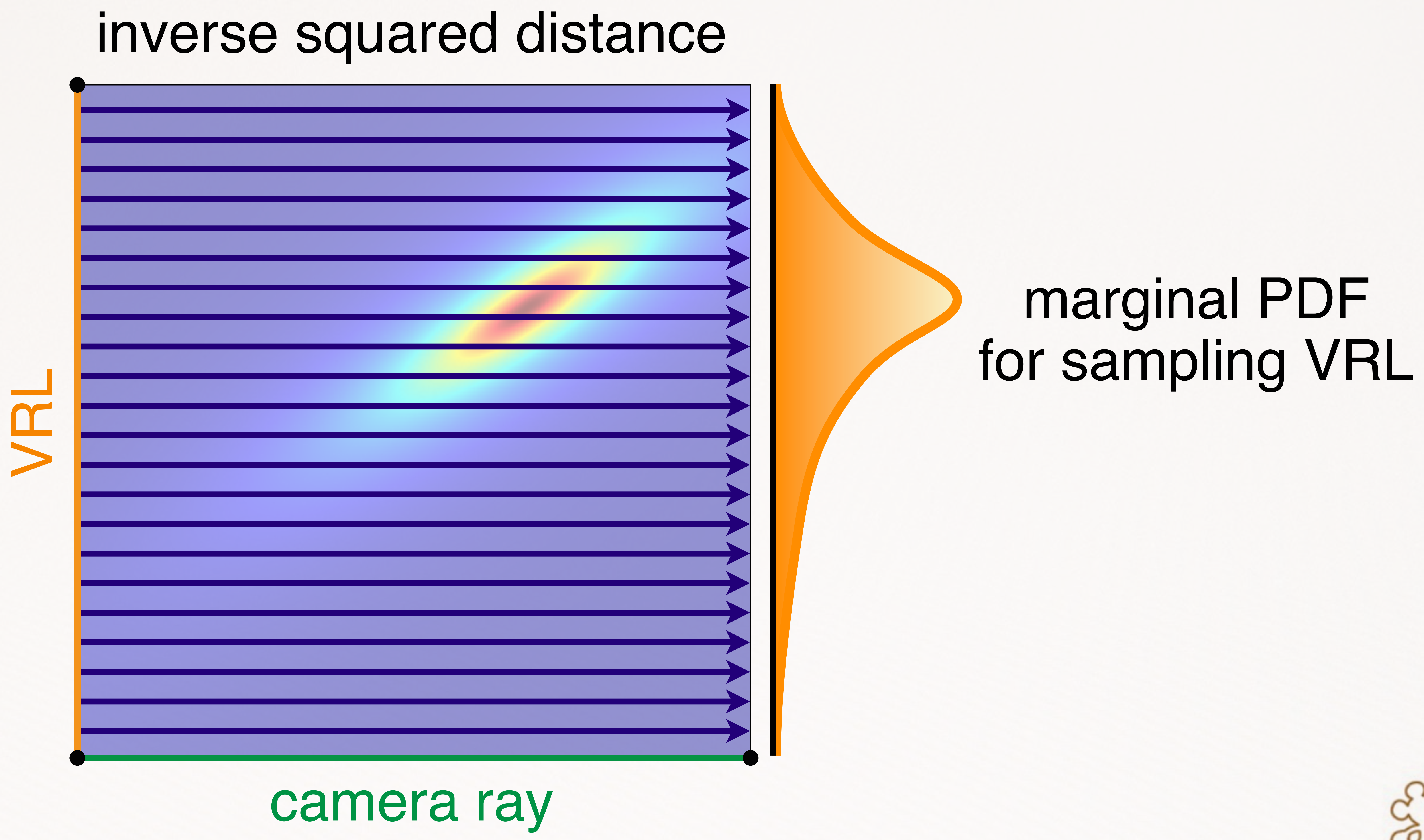
Isotropic media



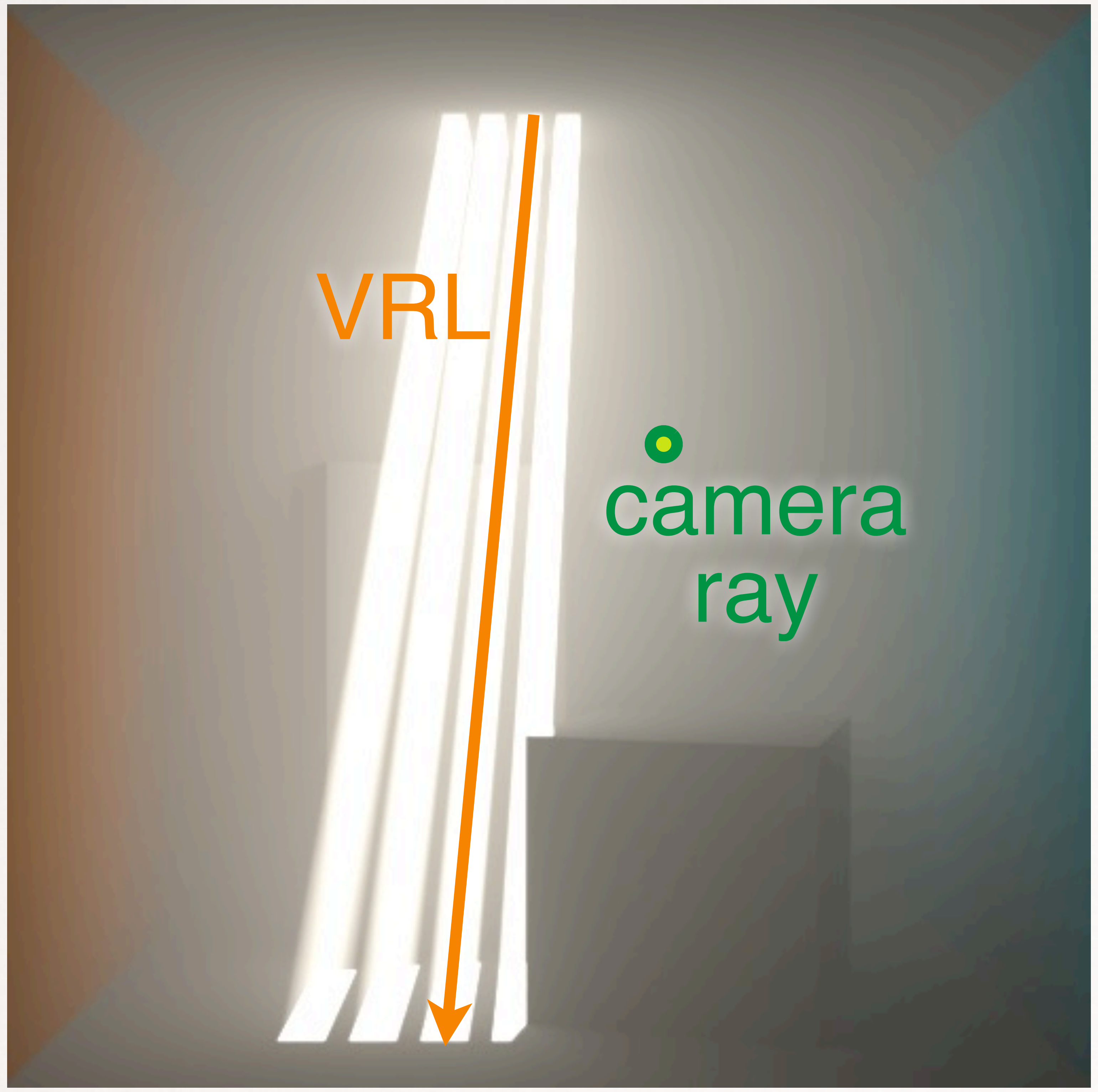


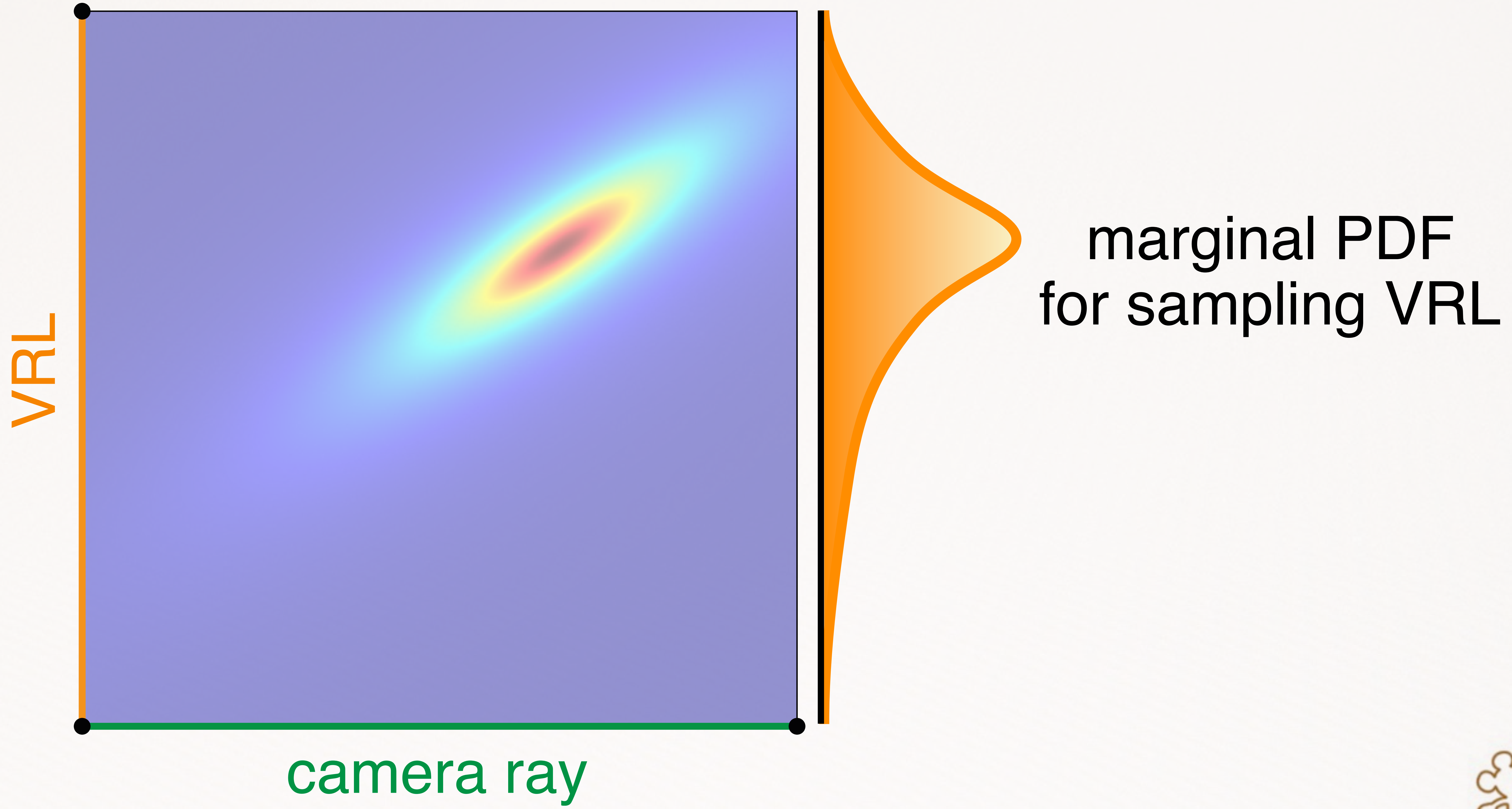
Isotropic media





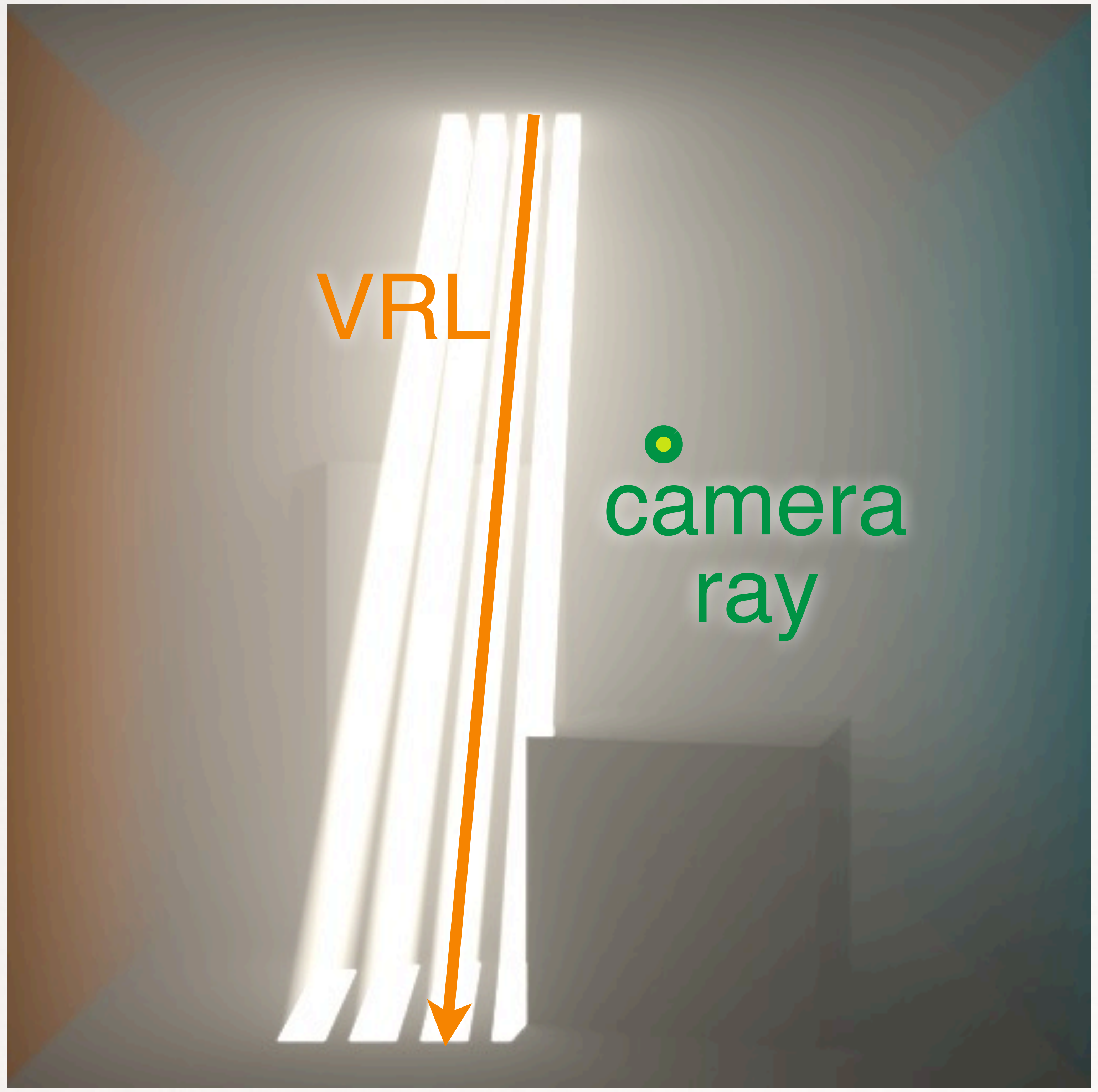
Isotropic media

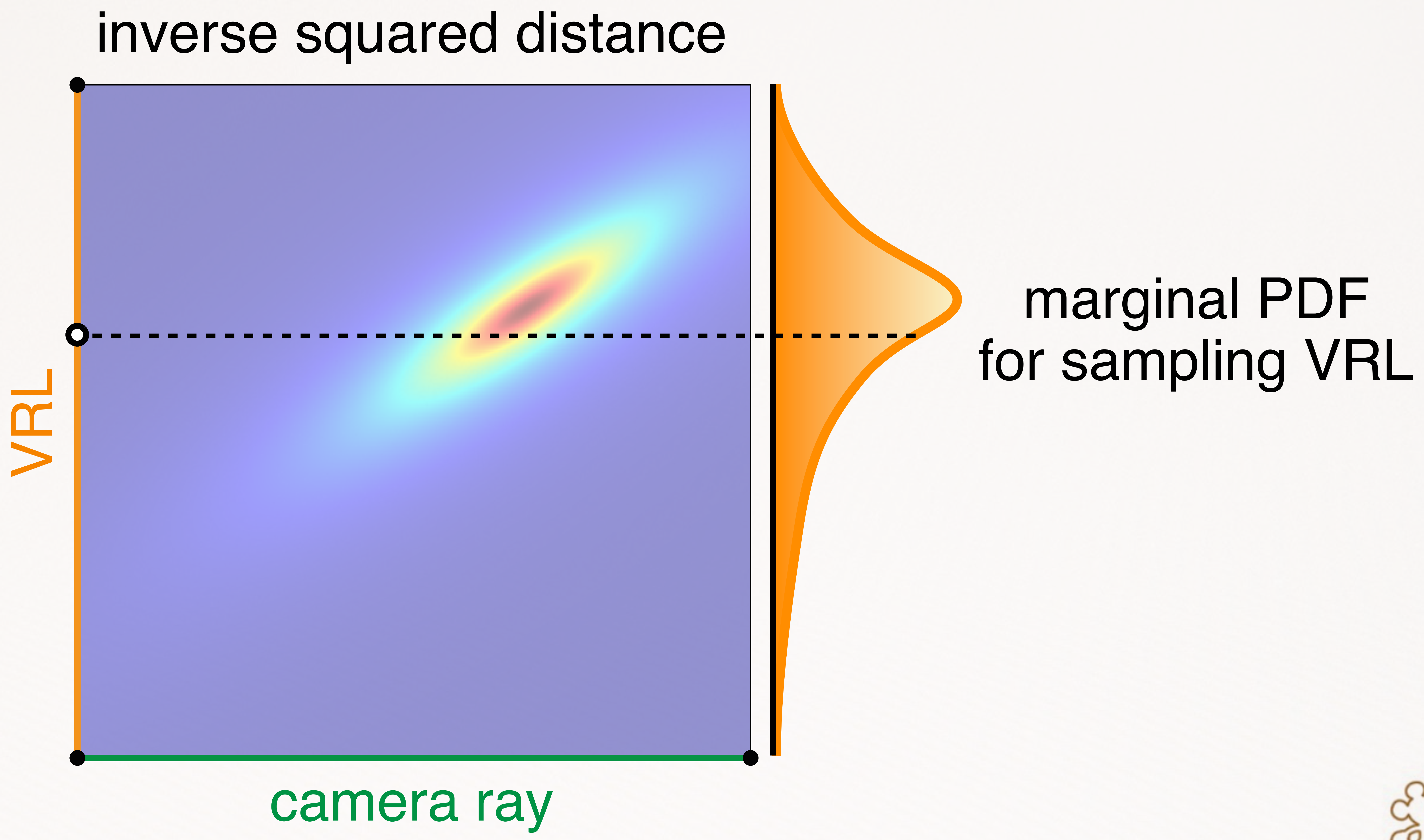




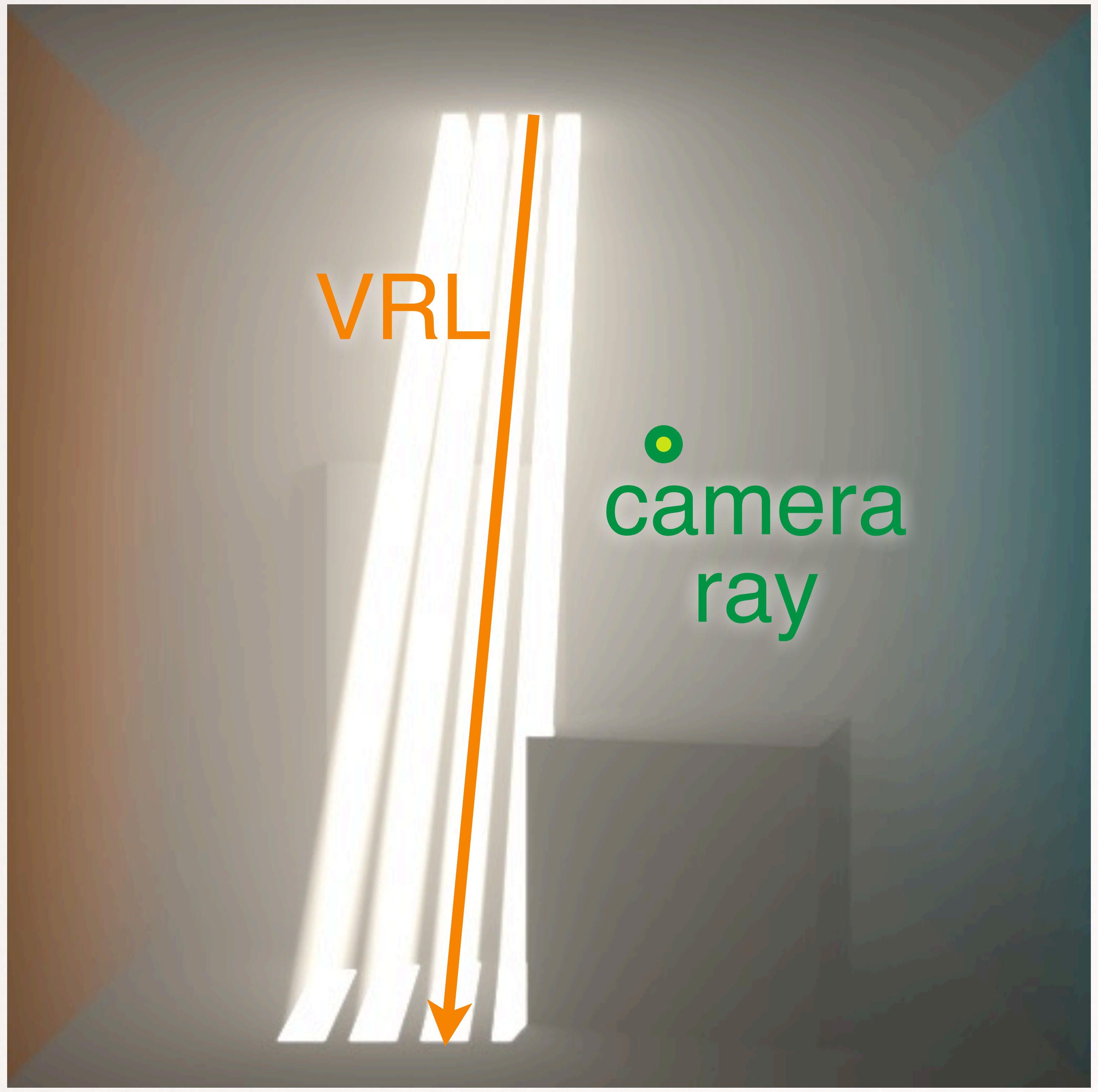
Isotropic media

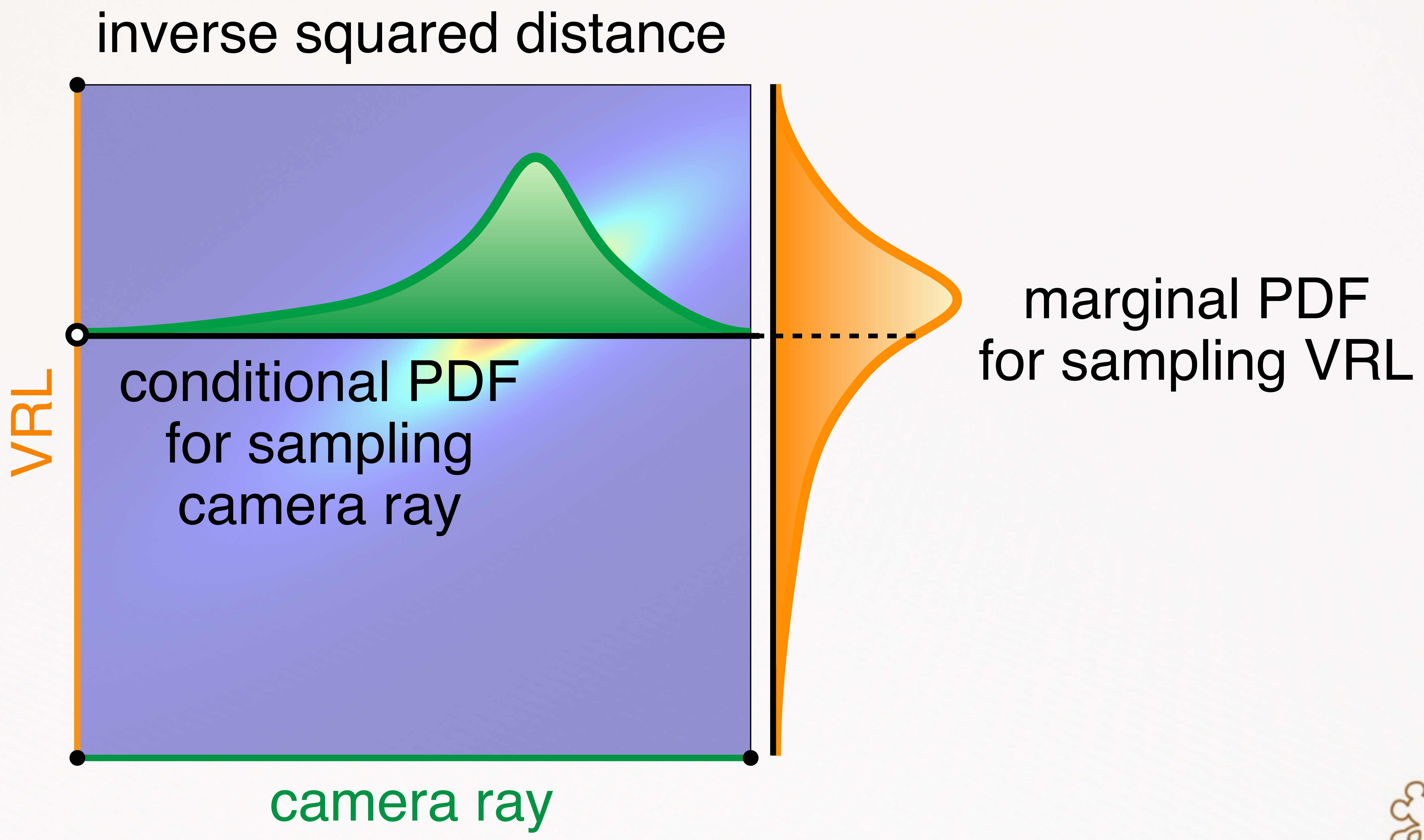
SIGGRAPH2012





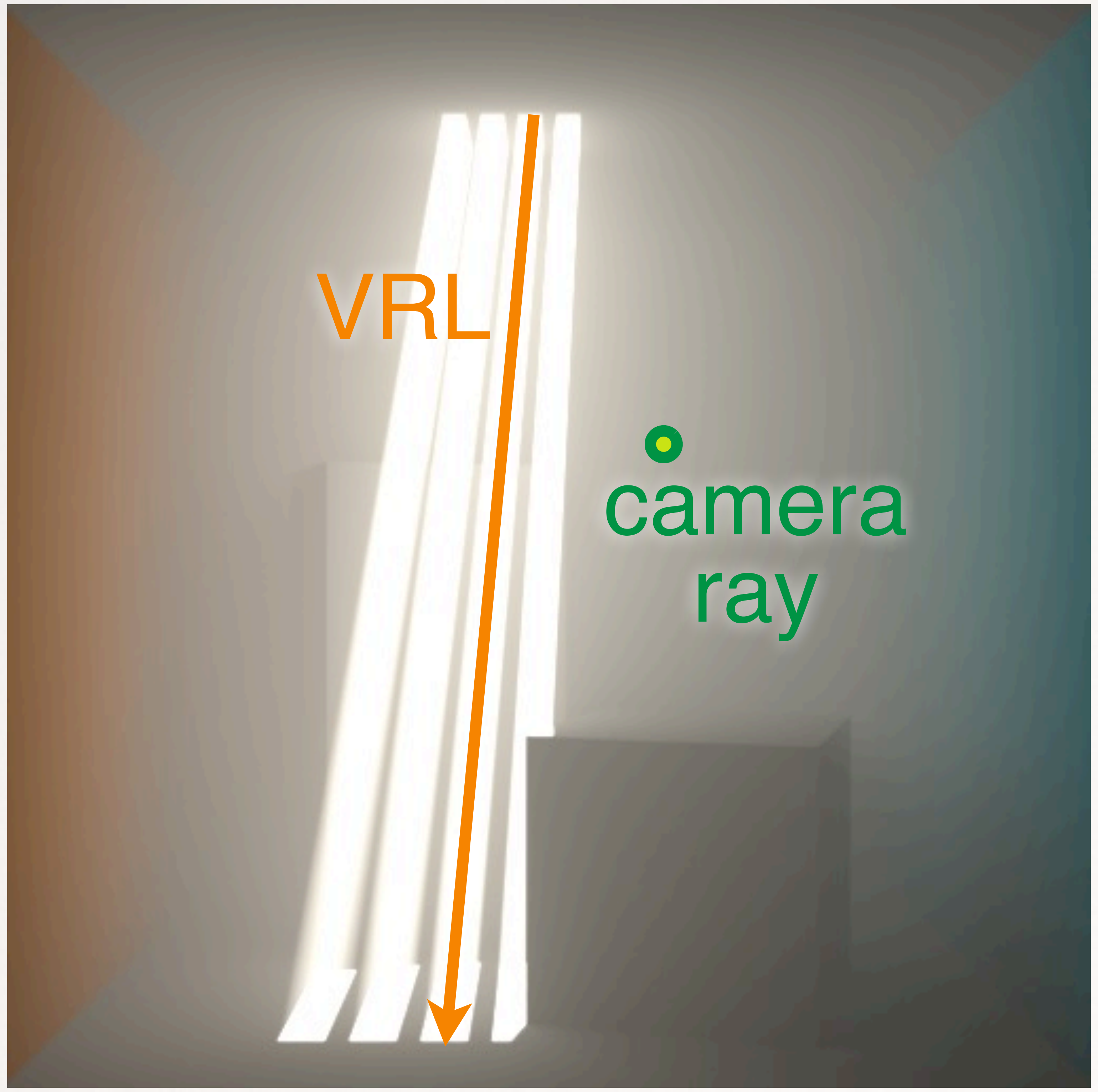
Isotropic media

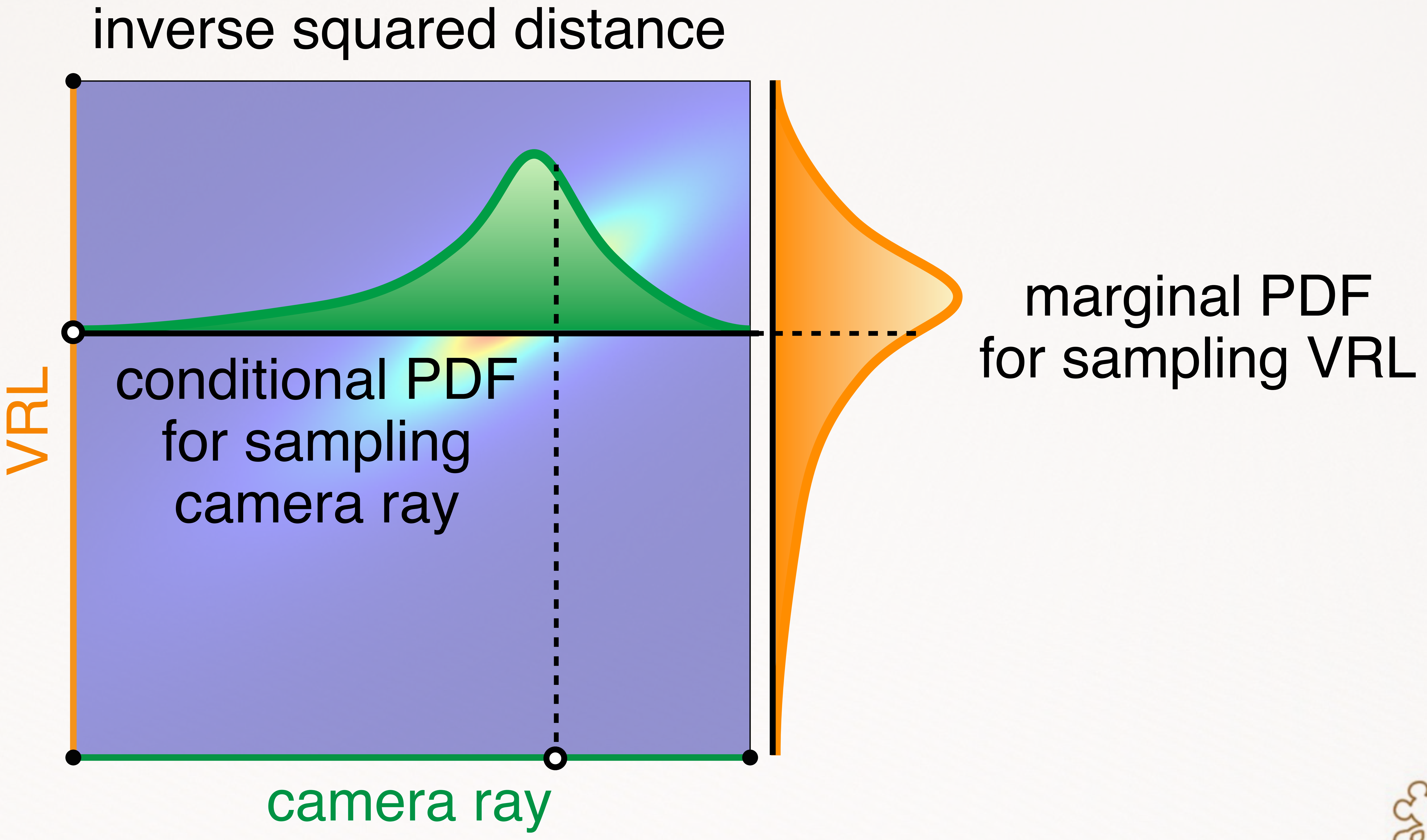




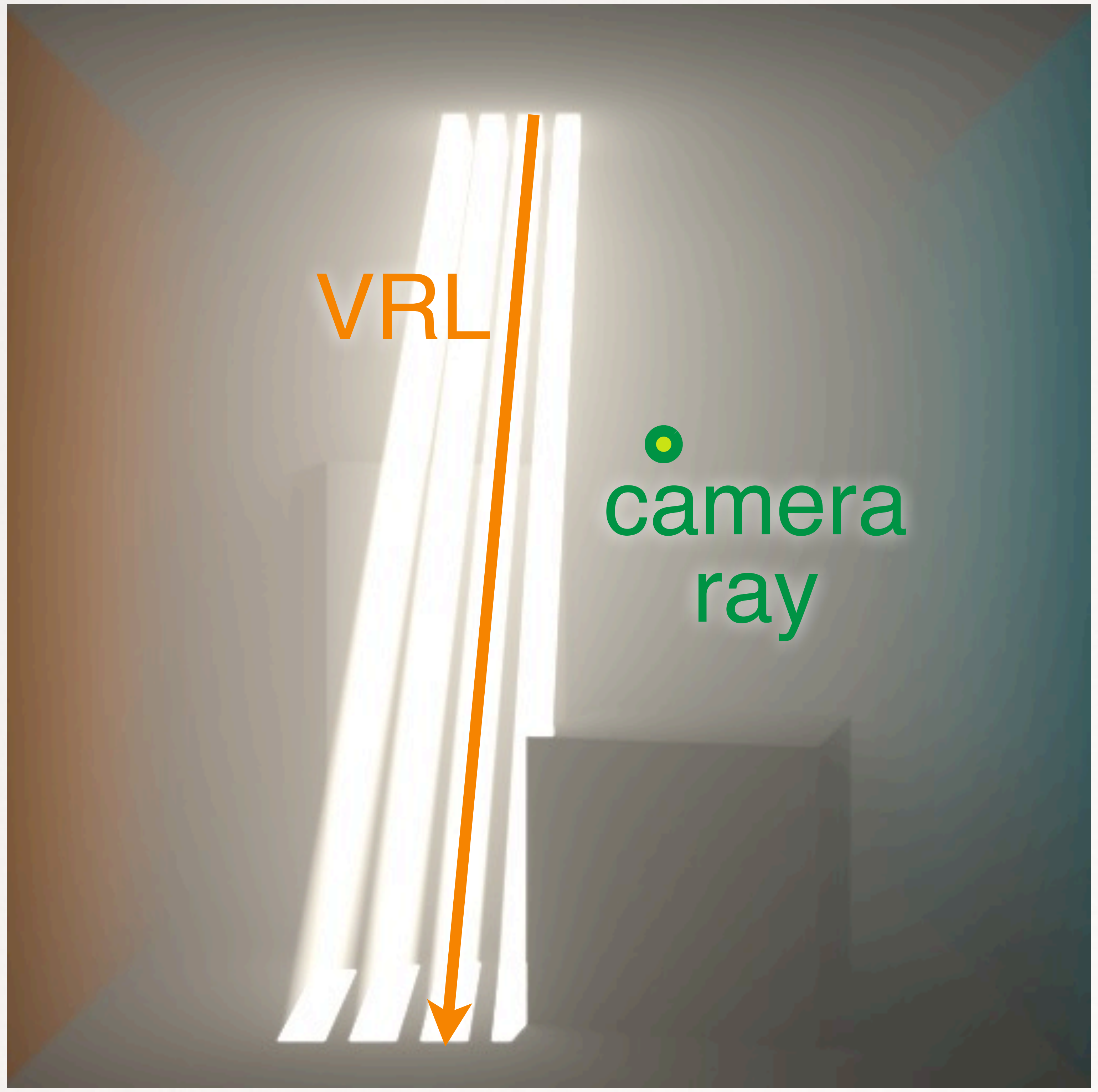
Isotropic media

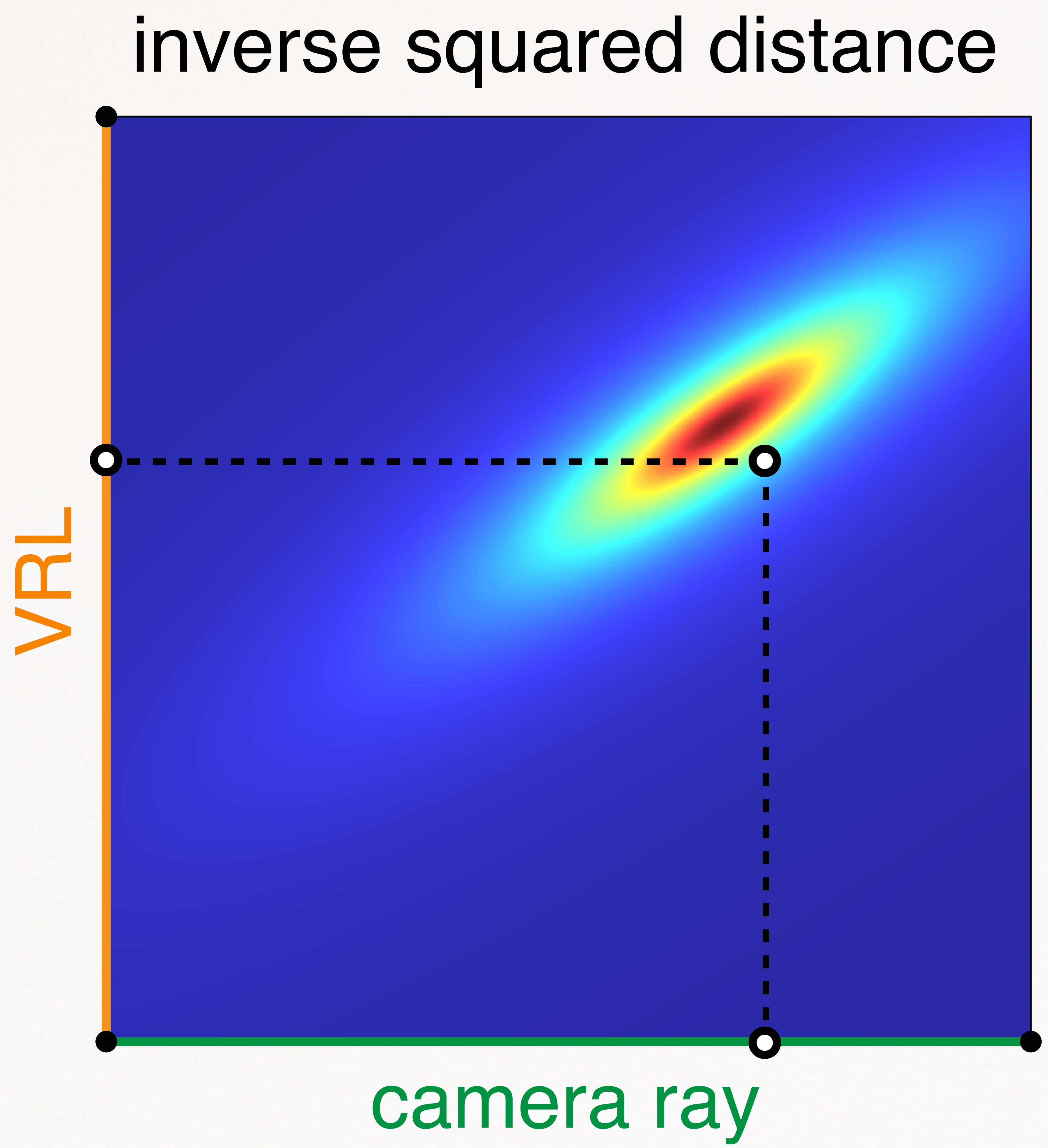
SIGGRAPH 2012





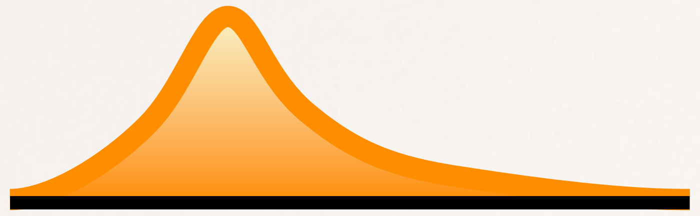
Isotropic media





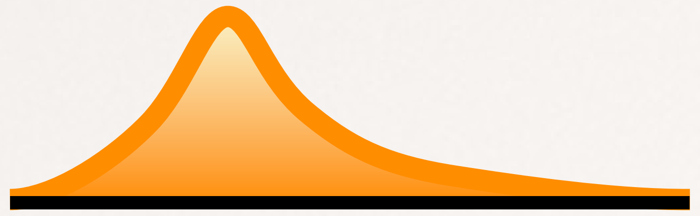
Isotropic media

SIGGRAPH2012

- **Marginal PDF** 

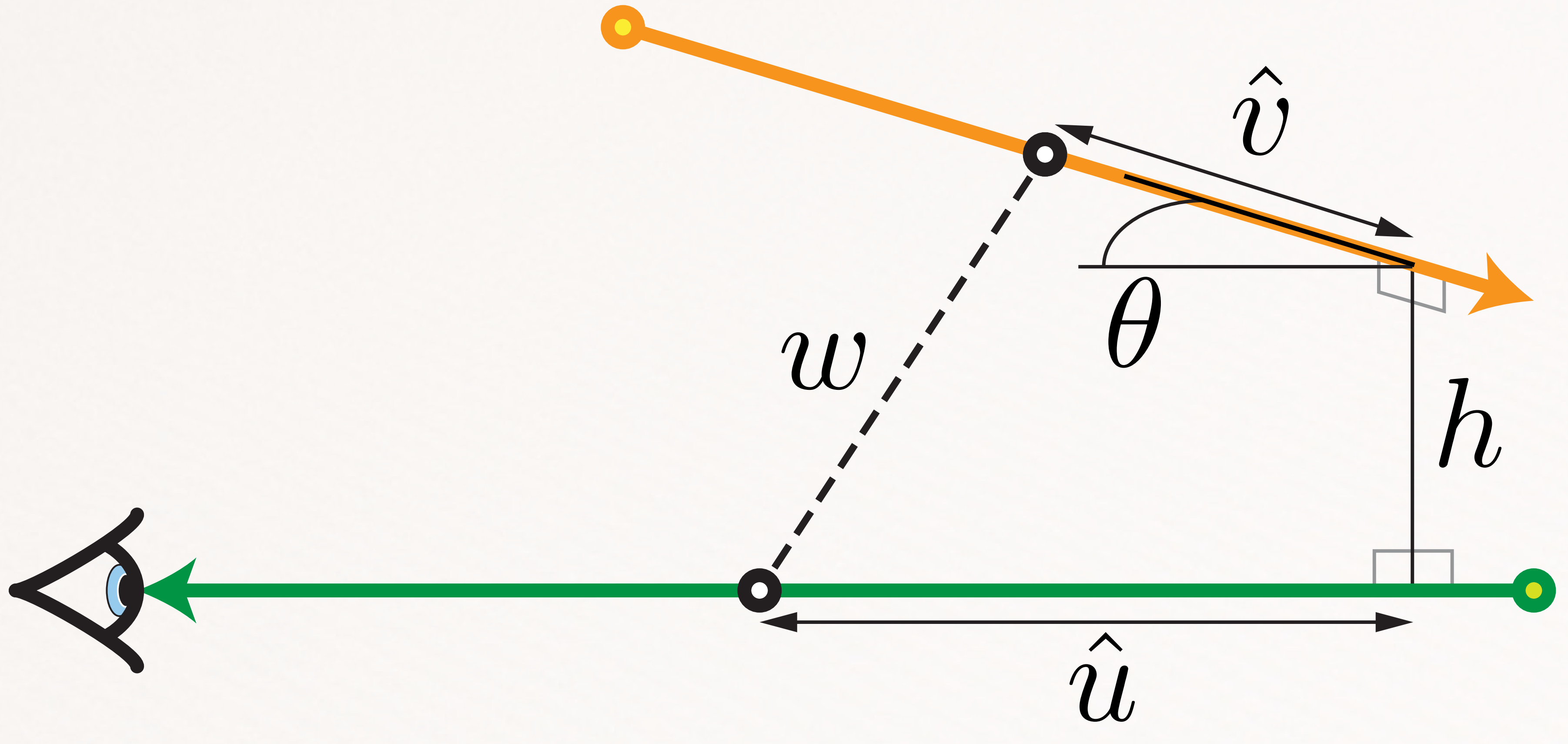
$$\mathrm{pdf}(v) = \frac{\int_0^s w^{-2}\,\mathrm{d}u}{\int_0^t \int_0^s w^{-2}\,\mathrm{d}u\mathrm{d}v}$$

Isotropic media

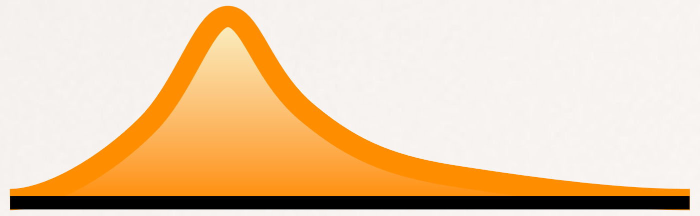
- **Marginal PDF** 

$$\mathrm{pdf}(v) = \frac{\int_0^s w^{-2}\,\mathrm{d}u}{\int_0^t \int_0^s w^{-2}\,\mathrm{d}u\mathrm{d}v}$$

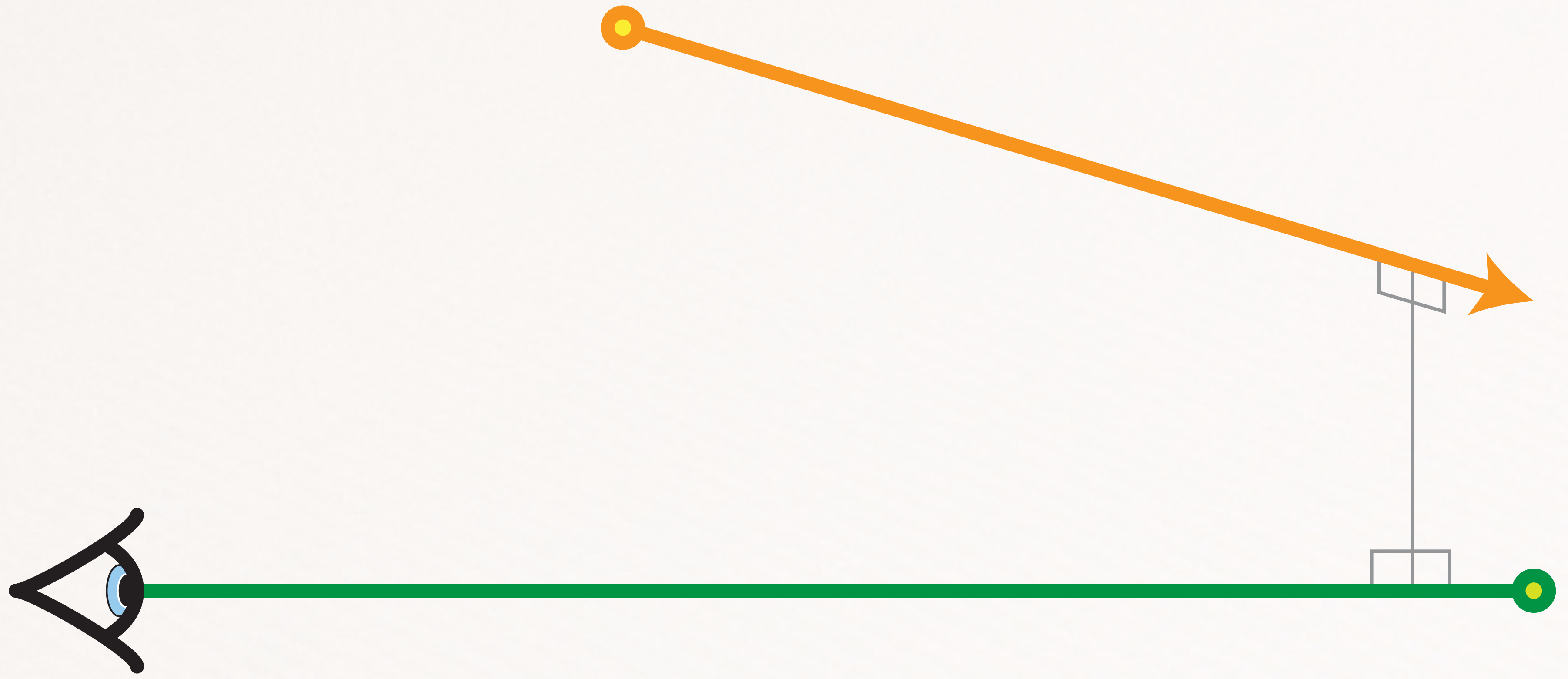
$$w = \sqrt{h^2 + \hat{u}^2 + \hat{v}^2 - 2\hat{u}\hat{v}\cos\theta}$$



Isotropic media

- **Marginal PDF** 

$$\mathrm{pdf}(v) = \frac{\int_0^s w^{-2}\, \mathrm{d}u}{\int_0^t \int_0^s w^{-2}\, \mathrm{d}u\mathrm{d}v} \approx \frac{\int_{-\infty}^{\infty} w^{-2}\, \mathrm{d}u}{\int_0^t \int_{-\infty}^{\infty} w^{-2}\, \mathrm{d}u\mathrm{d}v}$$

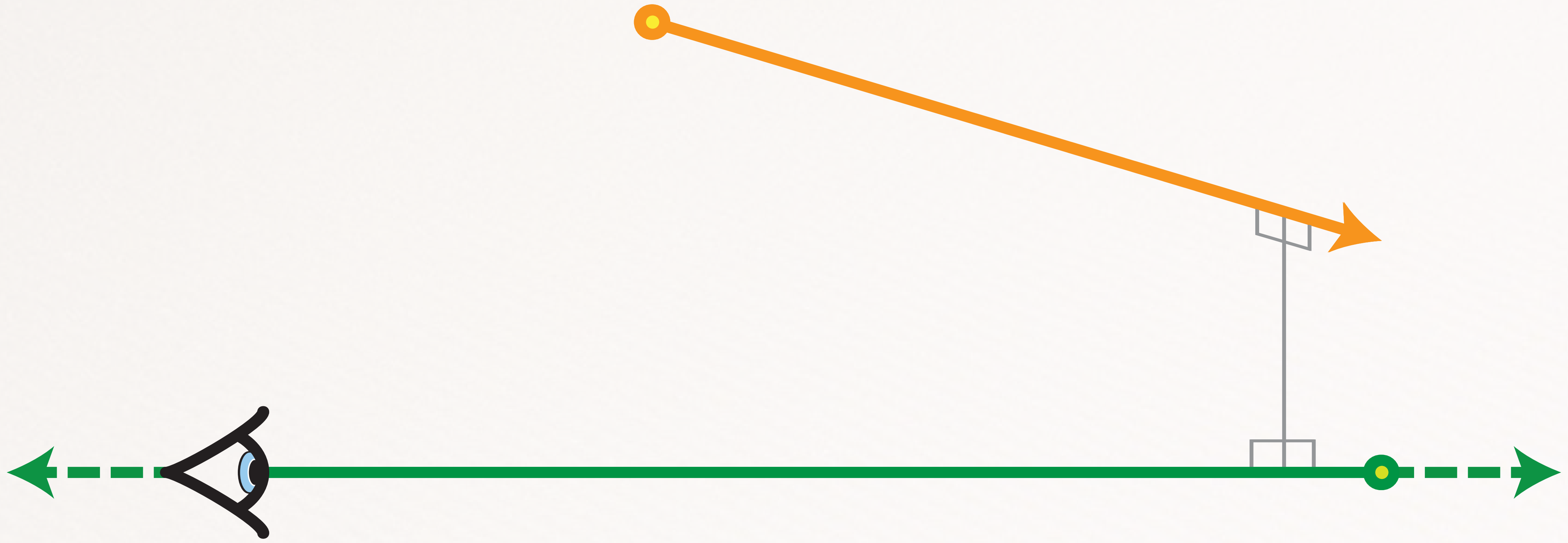


Isotropic media

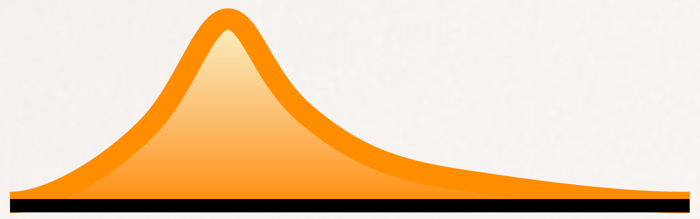
- **Marginal PDF**

$$\mathrm{pdf}(v) = \frac{\int_0^s w^{-2}\, du}{\int_0^t \int_0^s w^{-2}\, du dv} \approx \frac{\int_{-\infty}^{\infty} w^{-2}\, du}{\int_0^t \int_{-\infty}^{\infty} w^{-2}\, du dv}$$

assume infinite camera ray



Isotropic media

- **Marginal PDF** 

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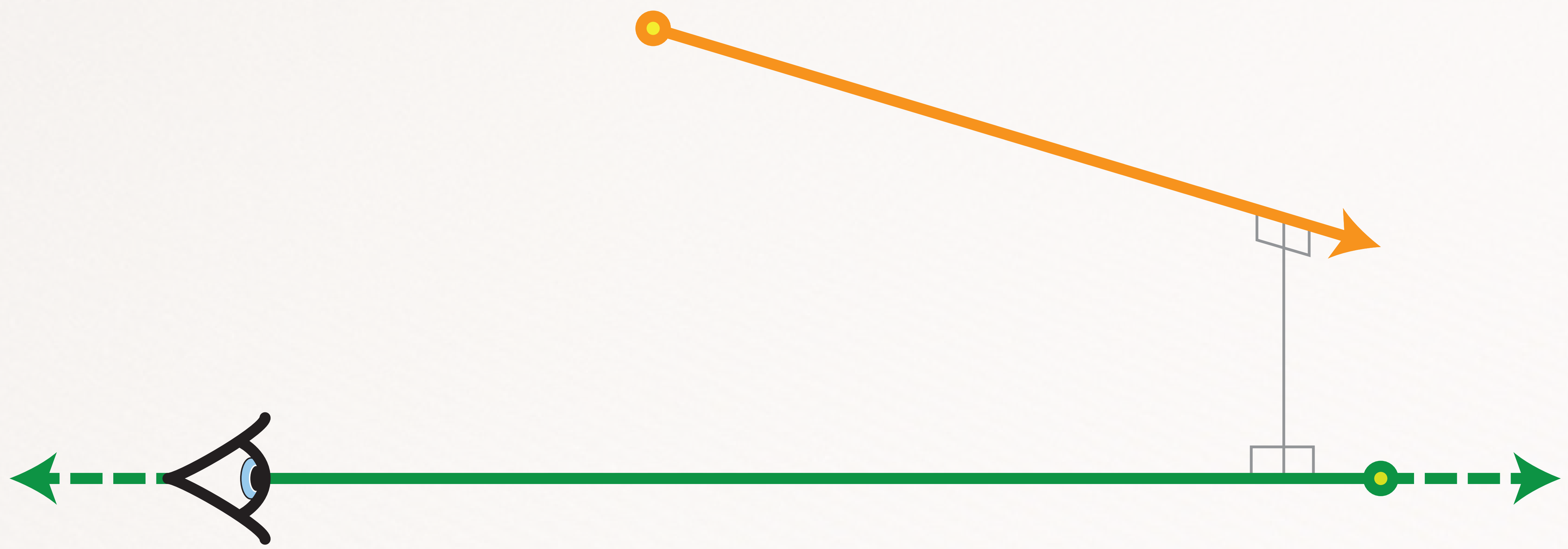
assume infinite
camera ray



Isotropic media

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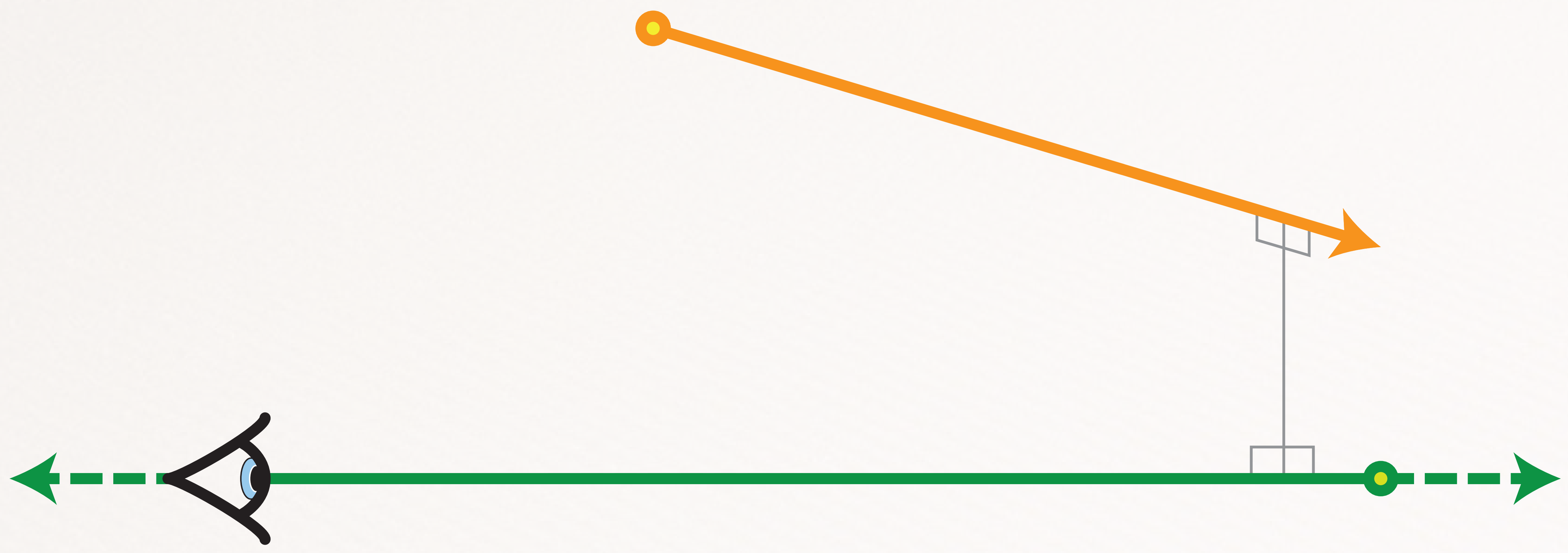
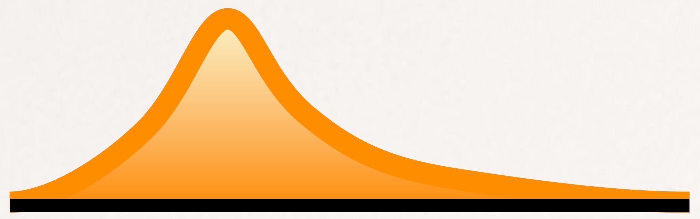
assume infinite camera ray

$$A(x) = \sinh^{-1}\left(\frac{x}{h}\sin\theta\right)$$



Isotropic media

- **Marginal PDF** 

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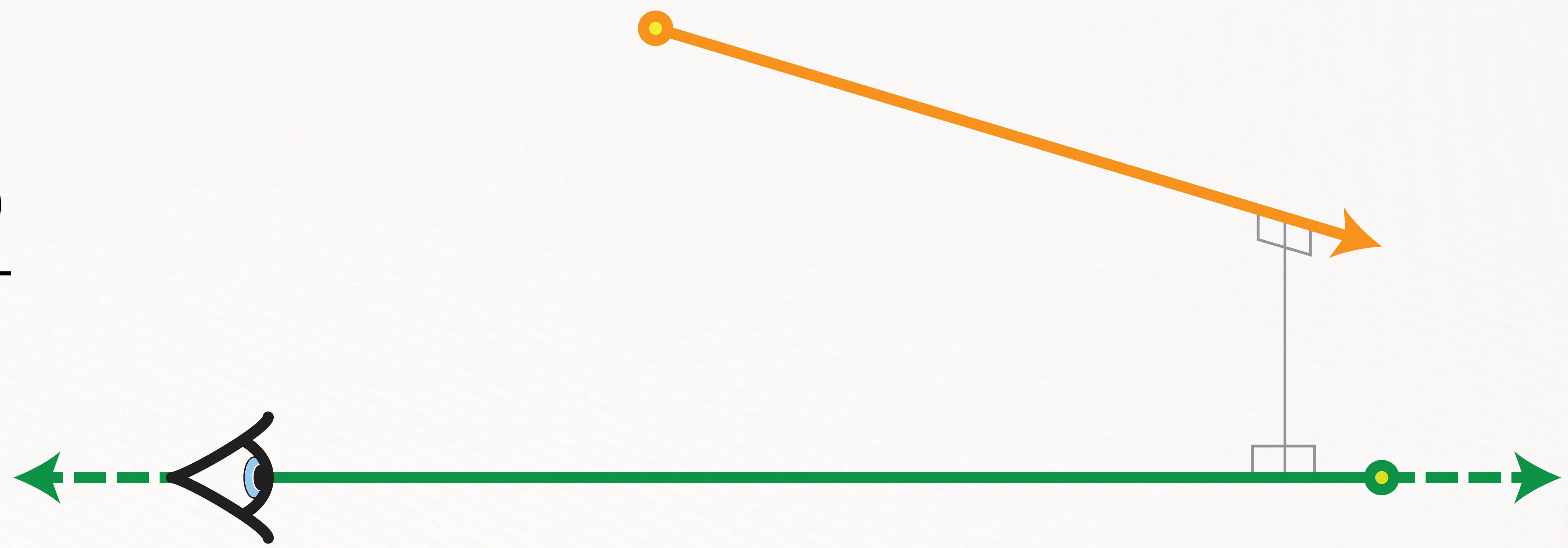
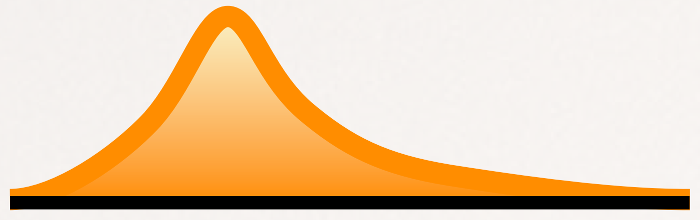
assume infinite camera ray

$$A(x) = \sinh^{-1}\left(\frac{x}{h}\sin\theta\right)$$

$$\mathrm{cdf}^{-1}(\xi) = \frac{h \sinh(\mathrm{lerp}(A(\hat{v}_0), A(\hat{v}_1), \xi))}{\sin\theta}$$



Isotropic media

- **Marginal PDF** 

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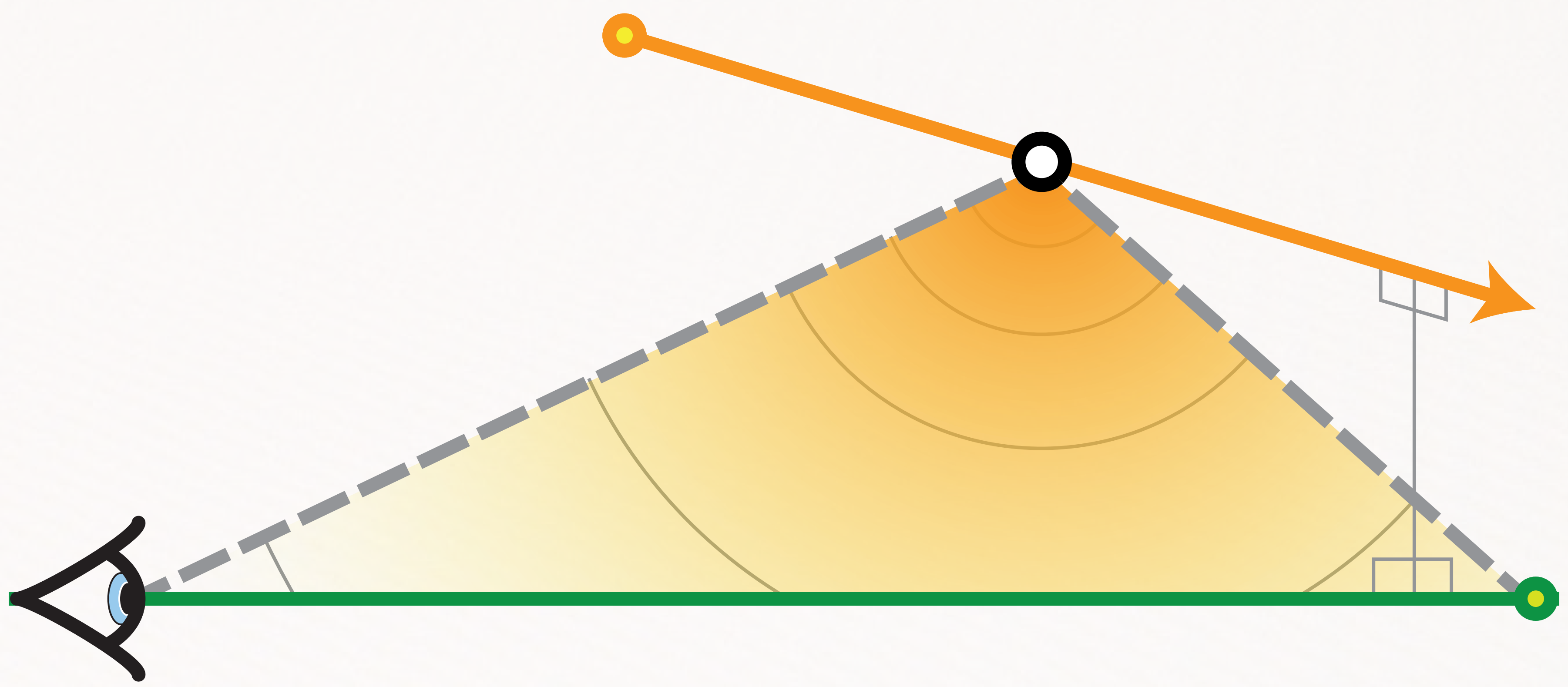
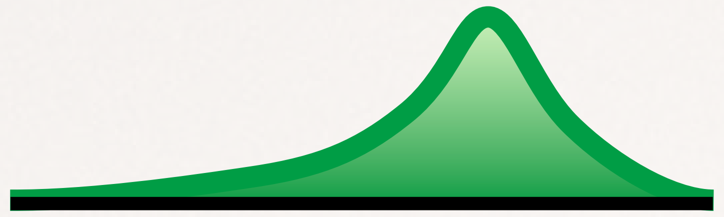
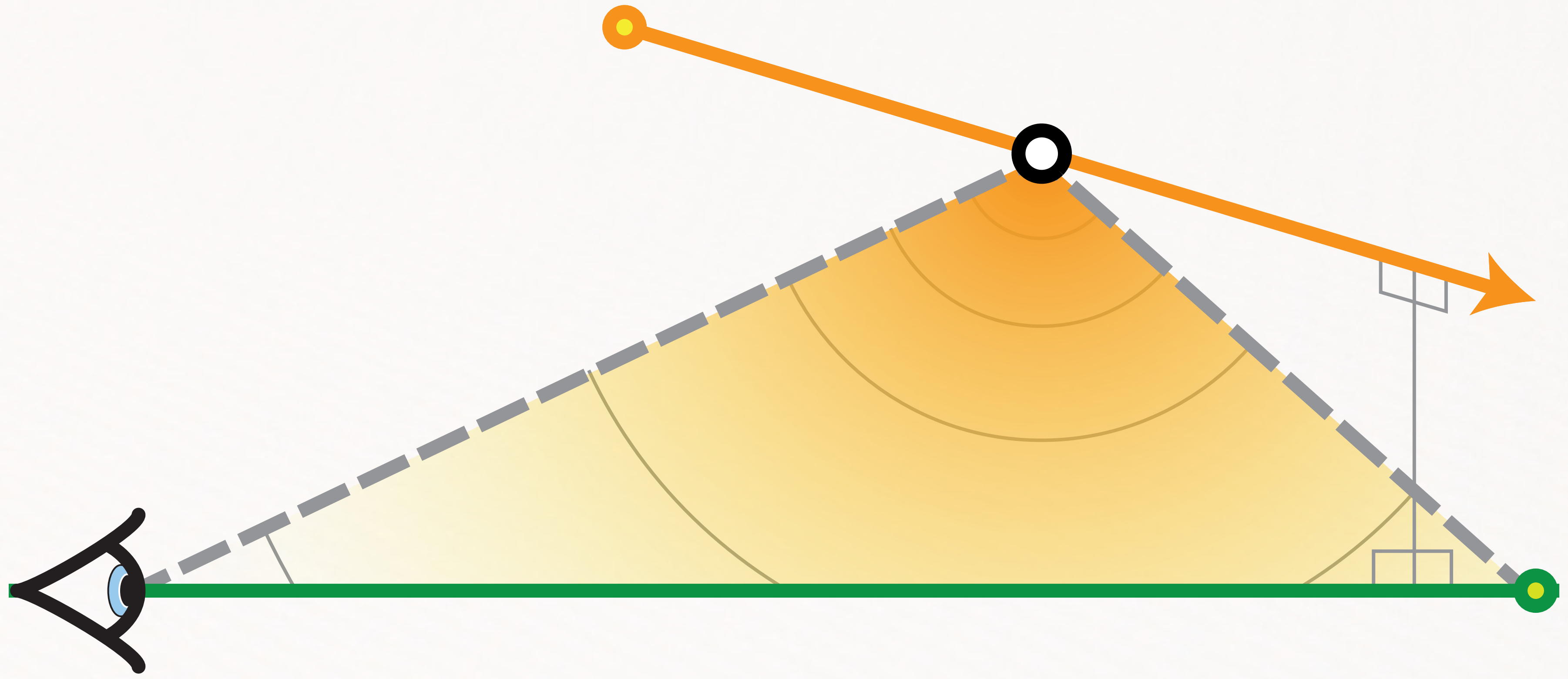


Isotropic media

- Conditional PDF 



Isotropic media

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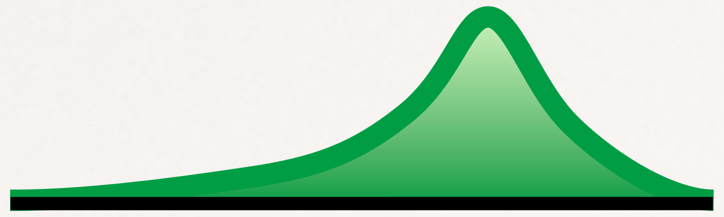
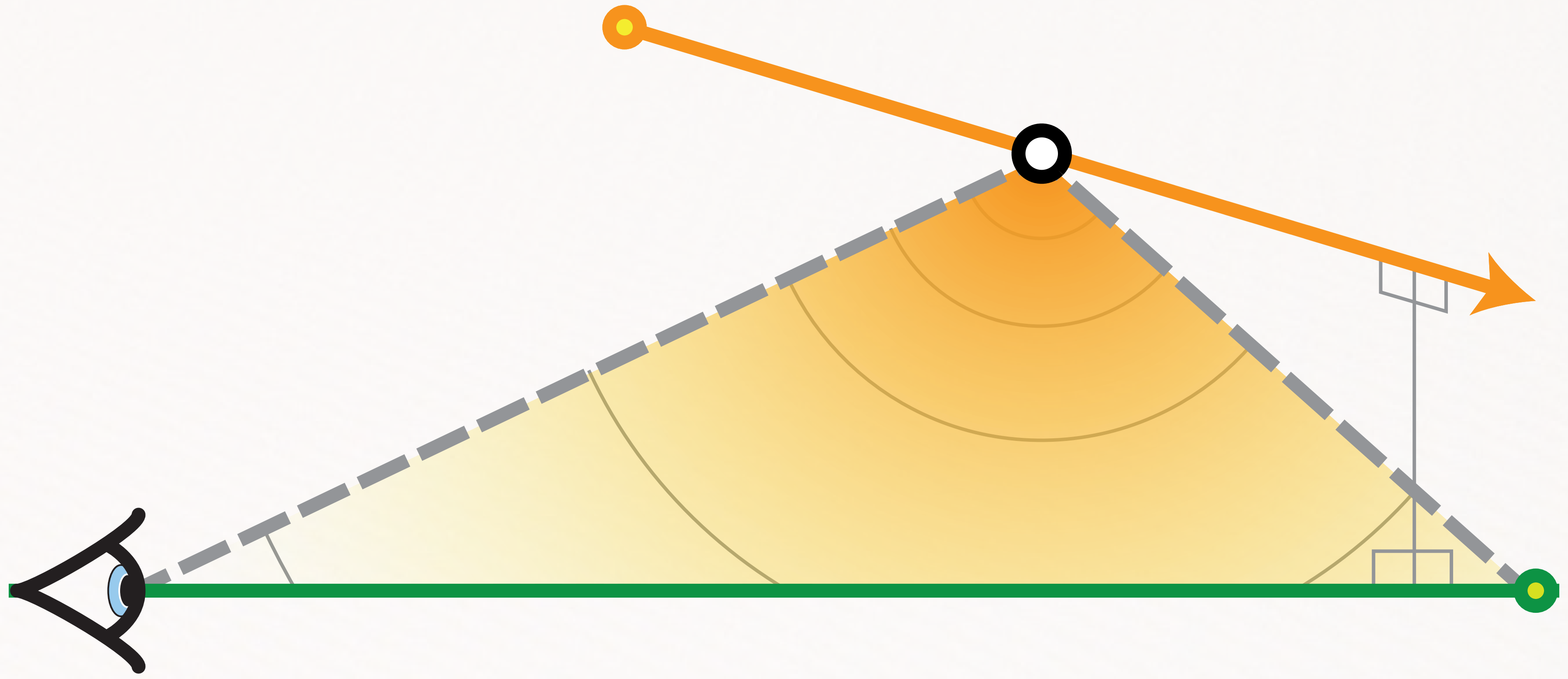
- **Conditional PDF** 
  - sample the camera ray w.r.t the **inverse squared distance** to the VRL point



Isotropic media

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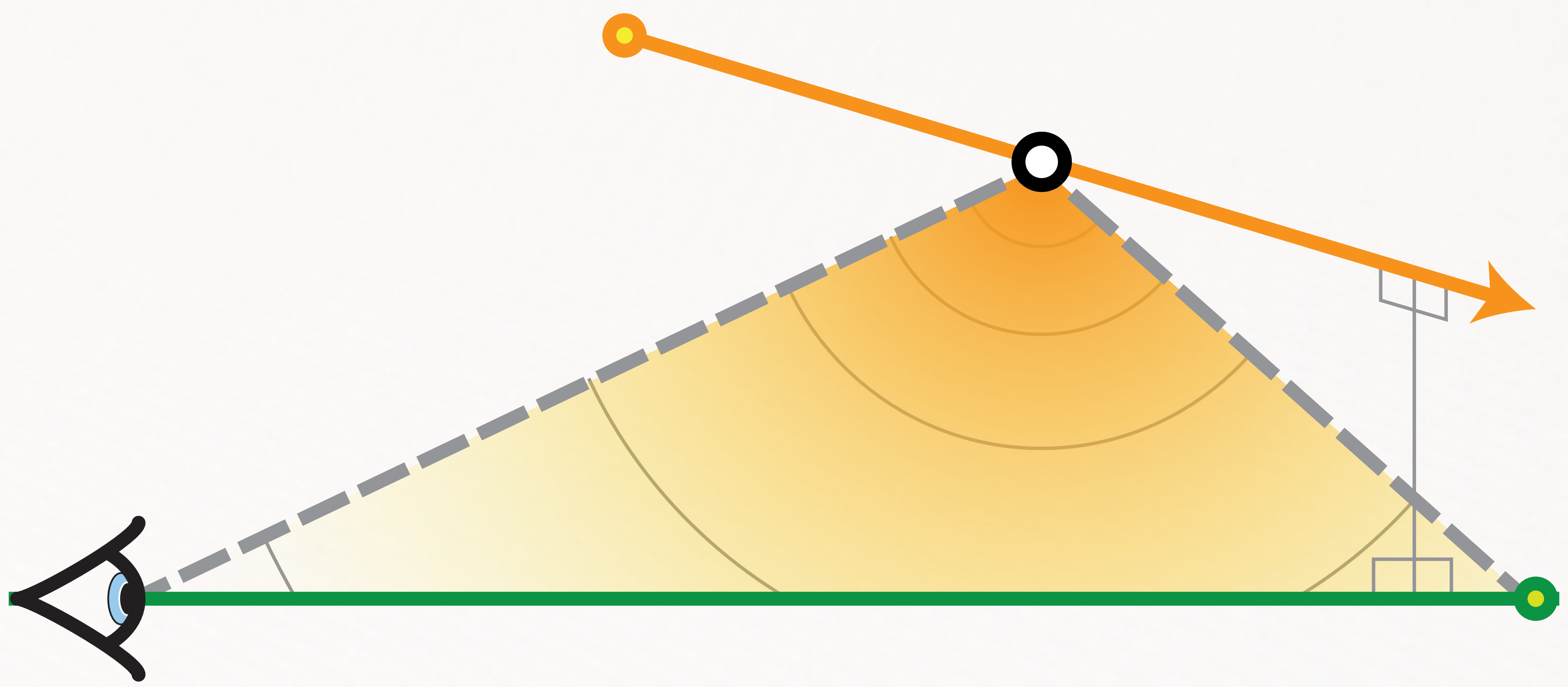
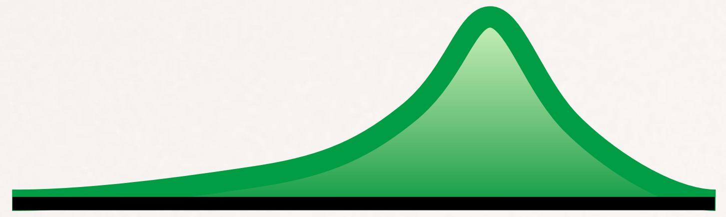
- **Conditional PDF**
  - sample the camera ray w.r.t the **inverse squared distance** to the VRL point
  - **equi-angular** sampling [Kulla and Fajardo 2011, 2012]



Isotropic media

- **Conditional PDF** 
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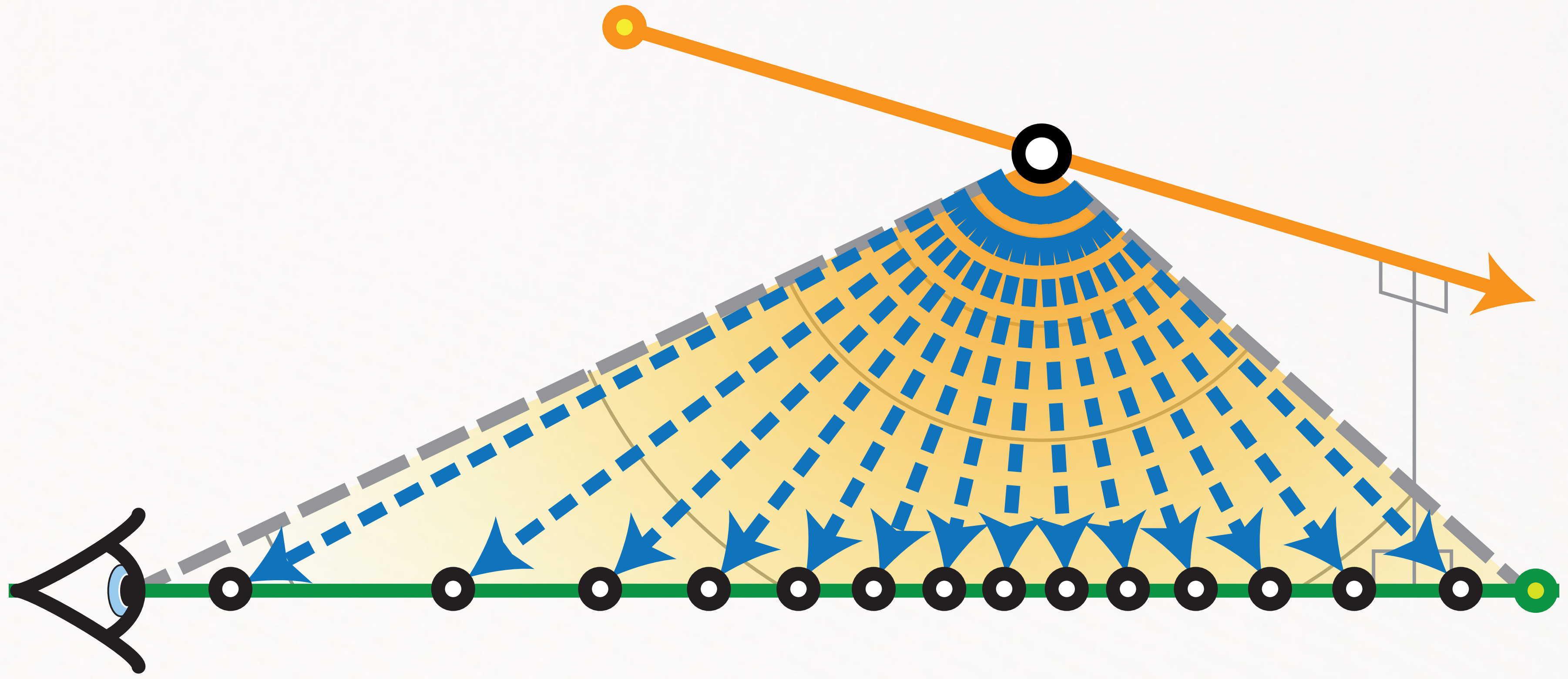

Isotropic media

Summary of isotropic media:

Isotropic media

Summary of isotropic media:

- **Marginal** of the **Conditional** PDFs
- inverse squared distance
- fully analytic = fast and efficient

Isotropic media

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Summary of isotropic media:

- **Marginal** of the **Conditional** PDFs
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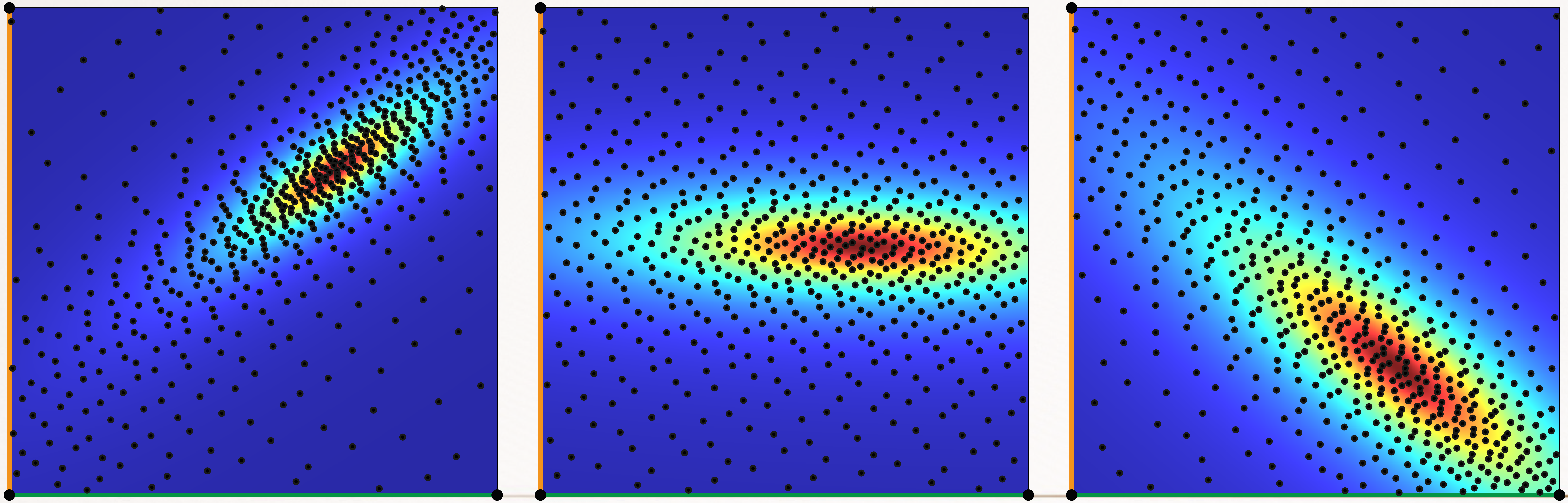
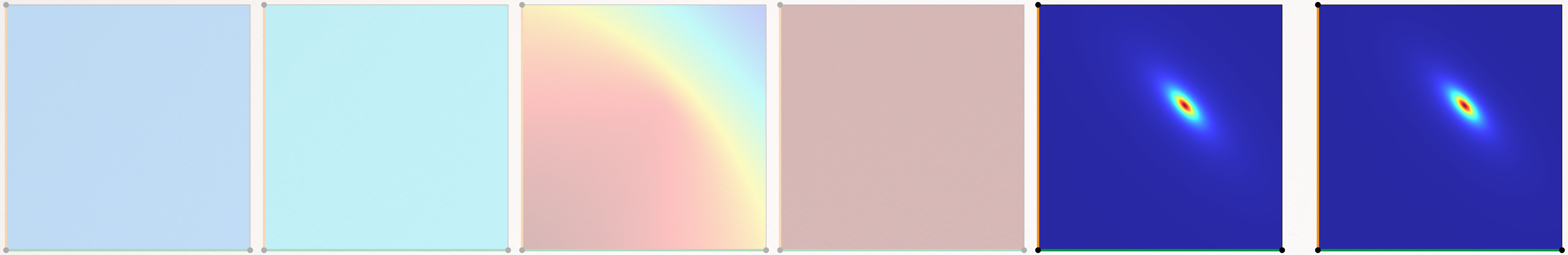


Importance sampling

How to (importance) sample?

phase functions × scattering × transmittance × visibility × inverse squared distance = product of all terms



isotropic homogeneous no occlusion

Importance sampling

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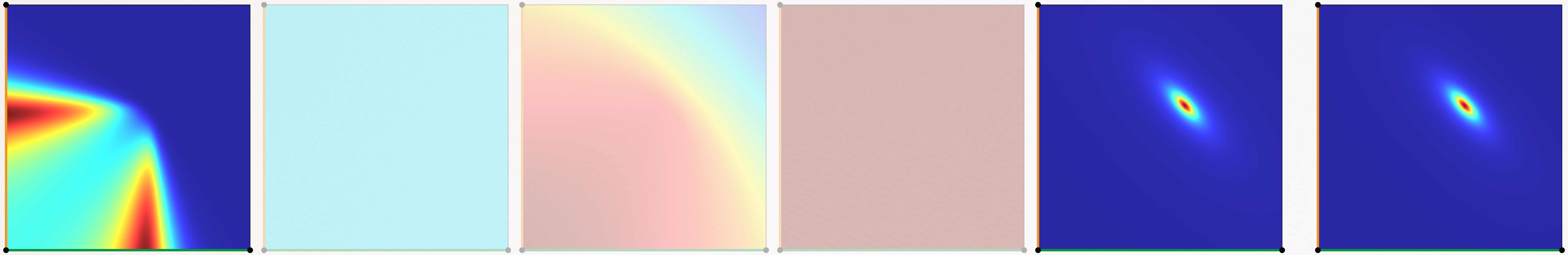
How to (importance) sample?

phase functions × scattering × transmittance × visibility × inverse squared distance = product of all terms



anisotropic   homogeneous   no occlusion

Importance sampling

How to (importance) sample?

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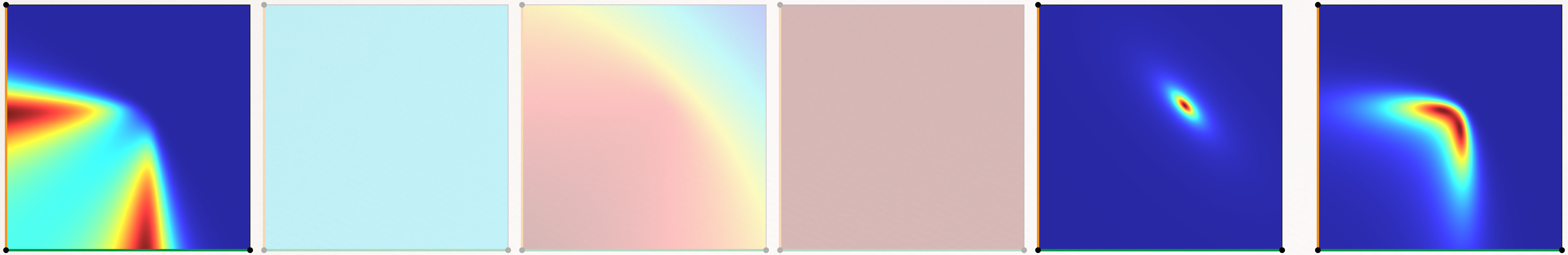
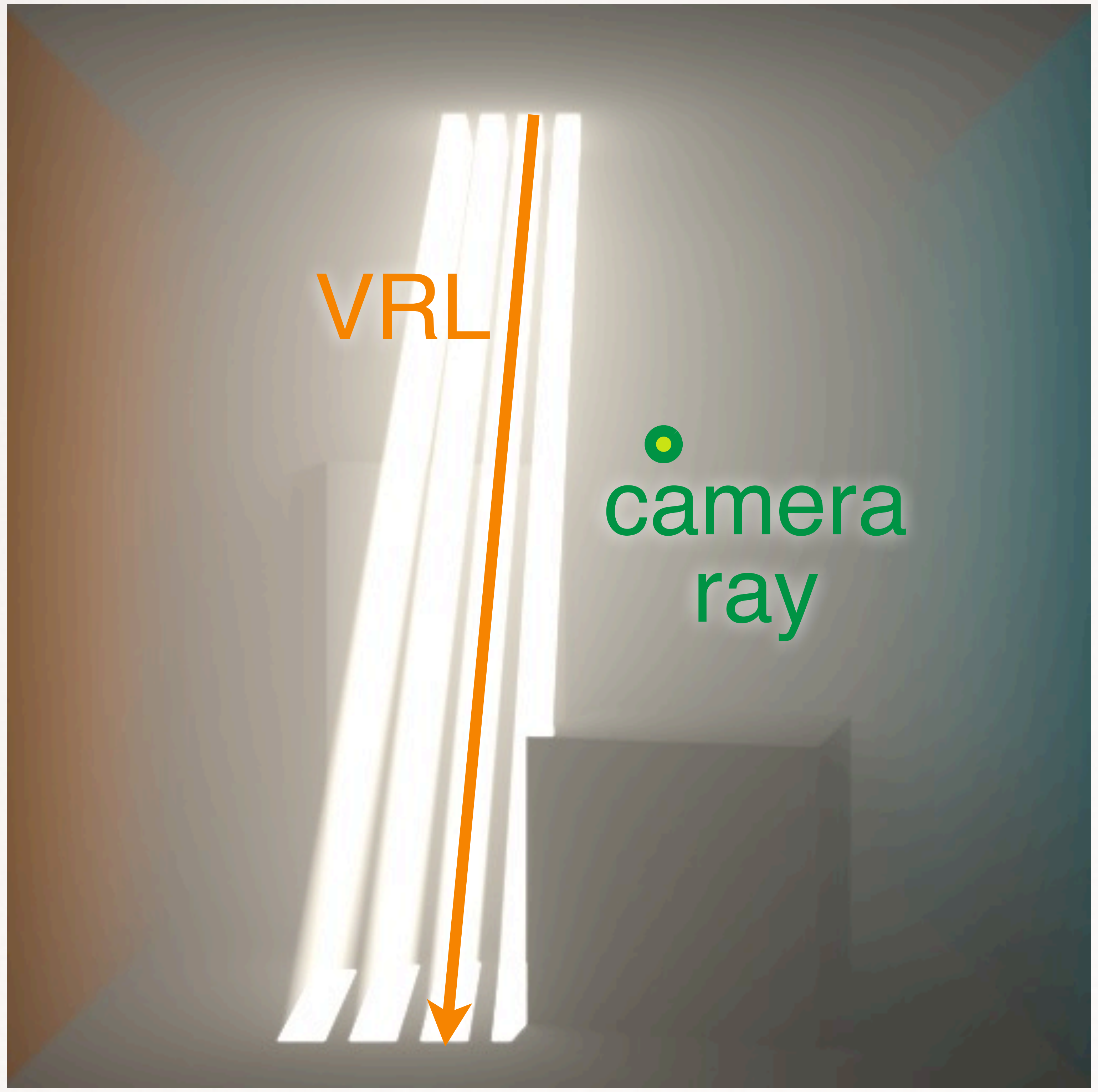


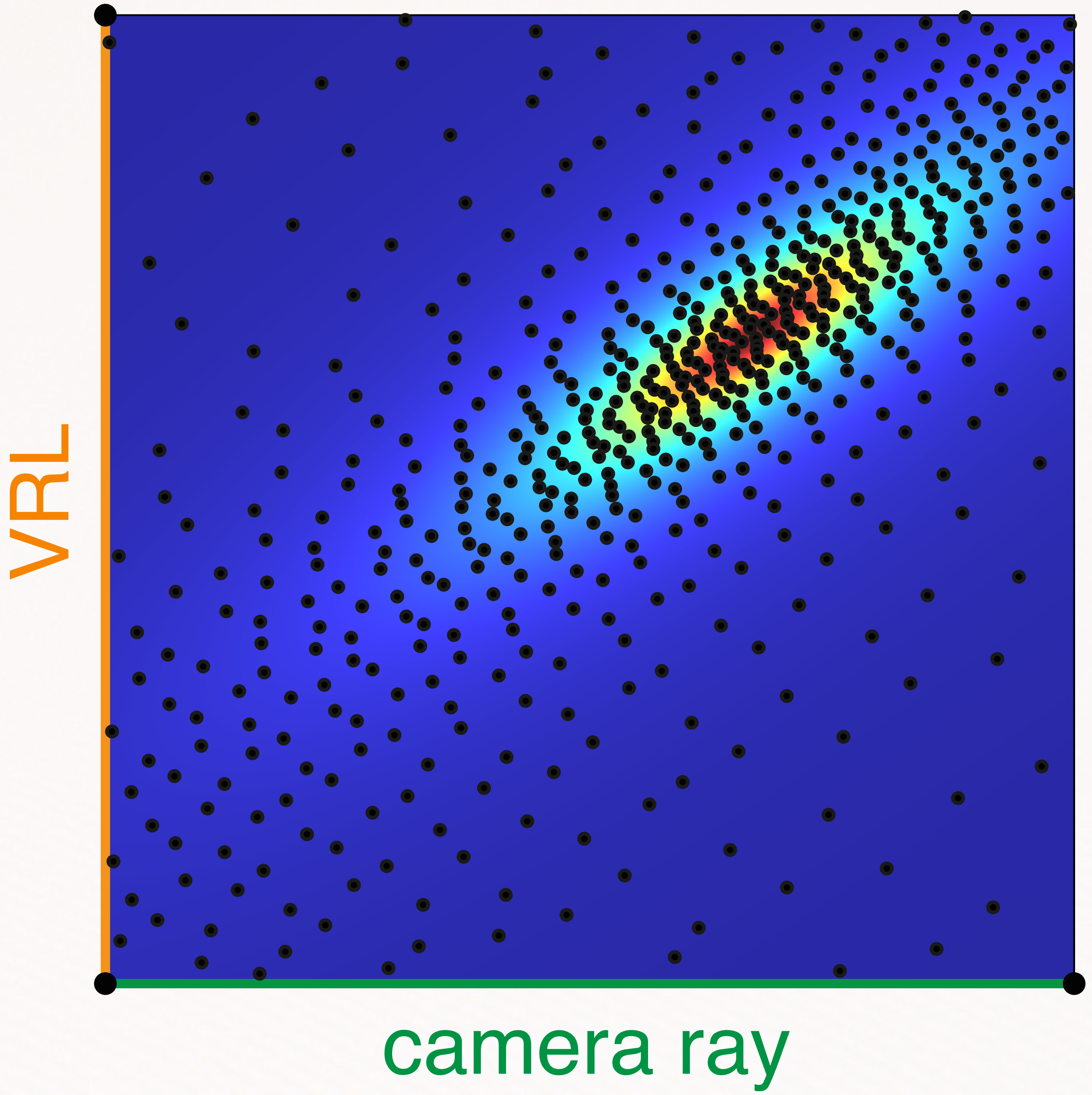
anisotropic | homogeneous | no occlusion

Anisotropic media

isotropic



inverse squared distance



Anisotropic media

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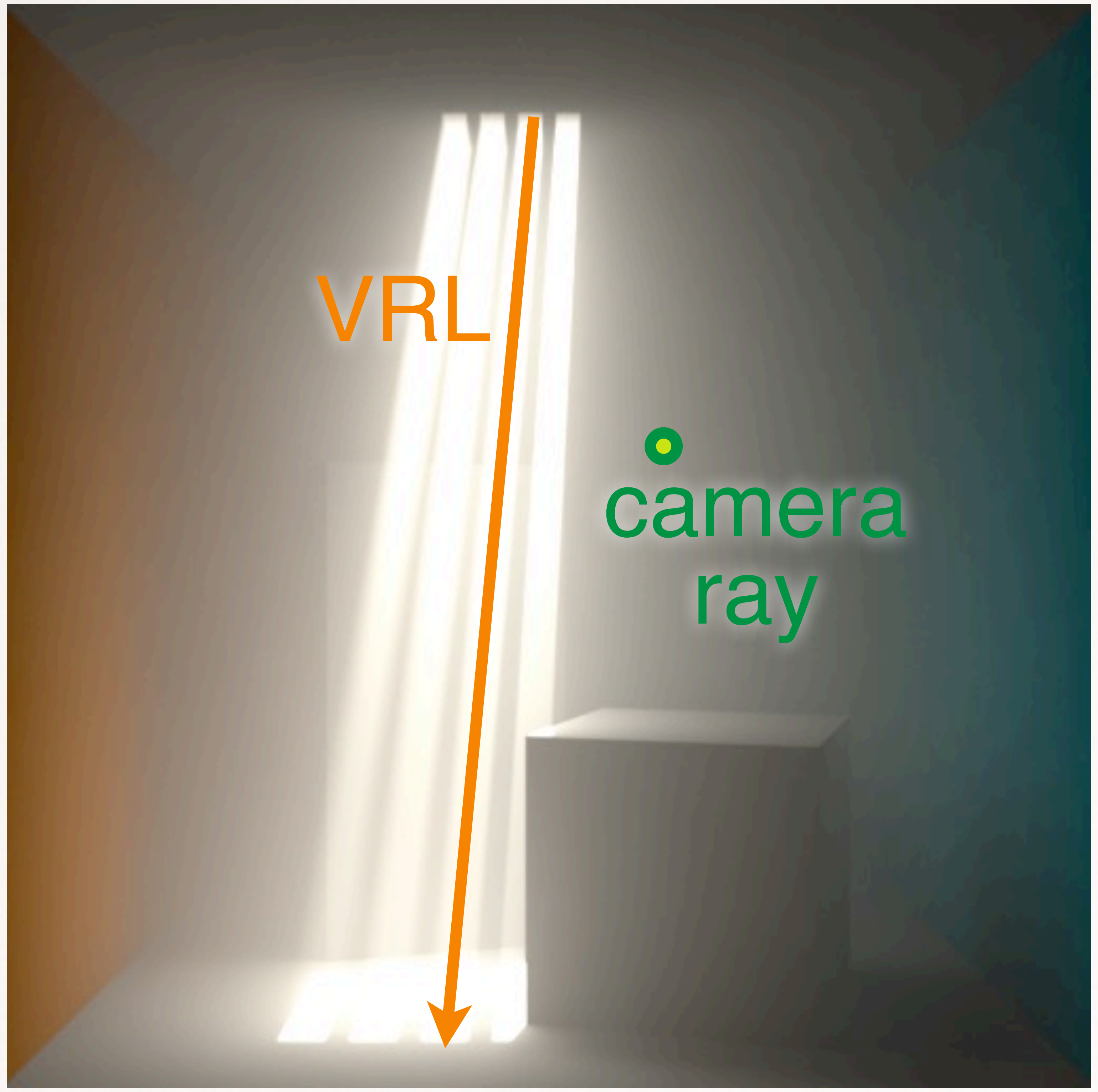
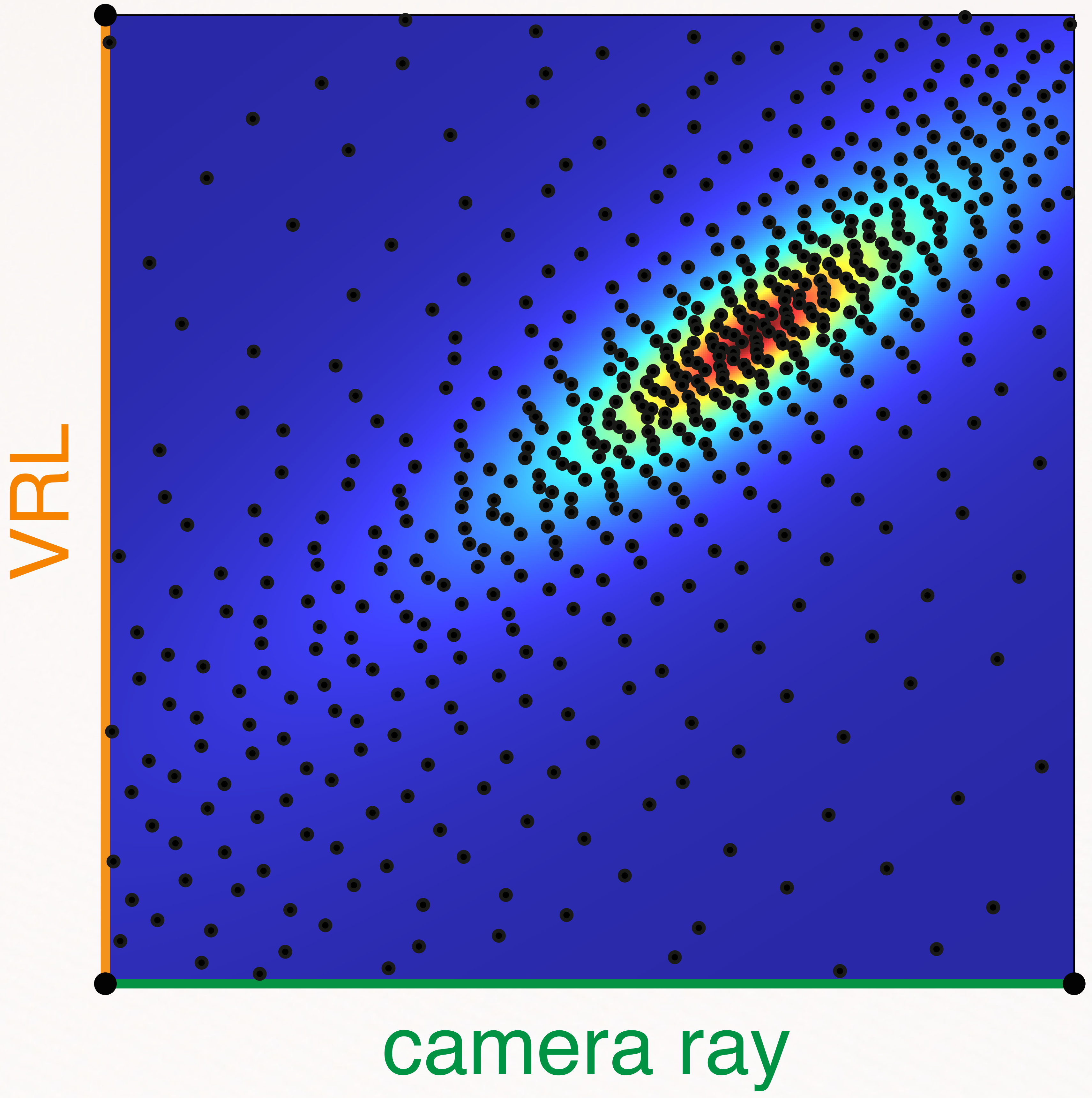
anisotropic

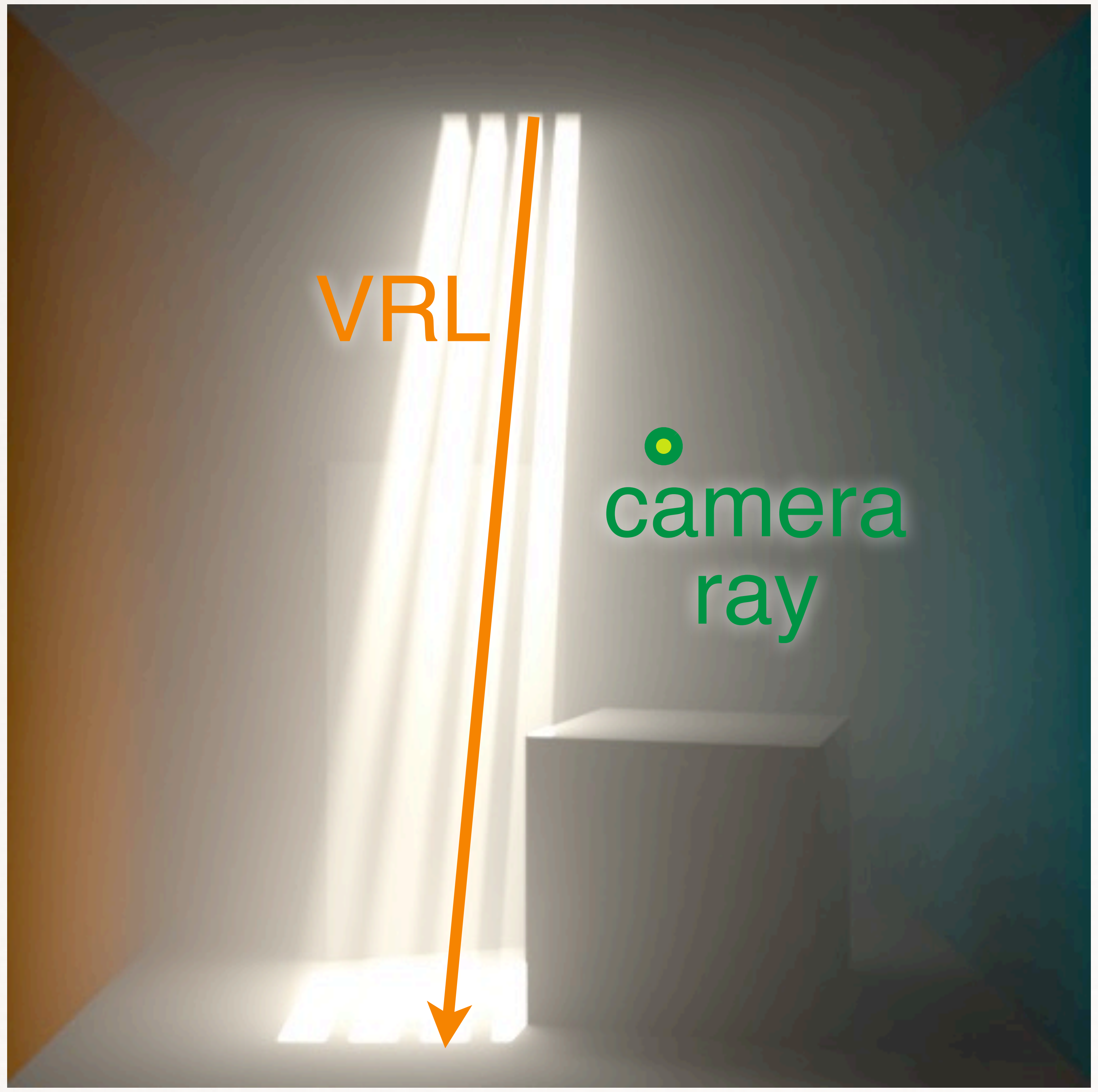


inverse squared distance

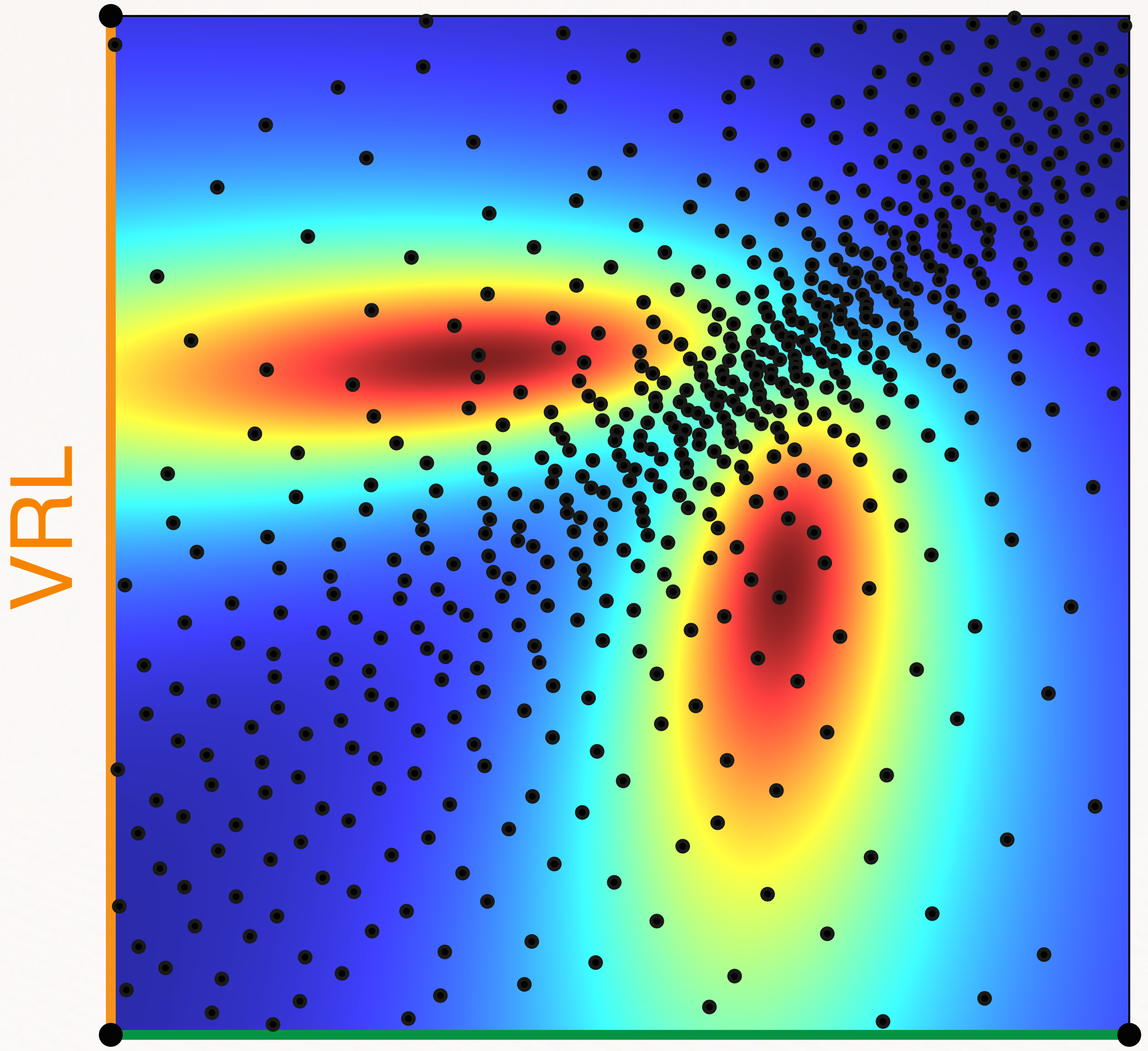


Anisotropic media

anisotropic

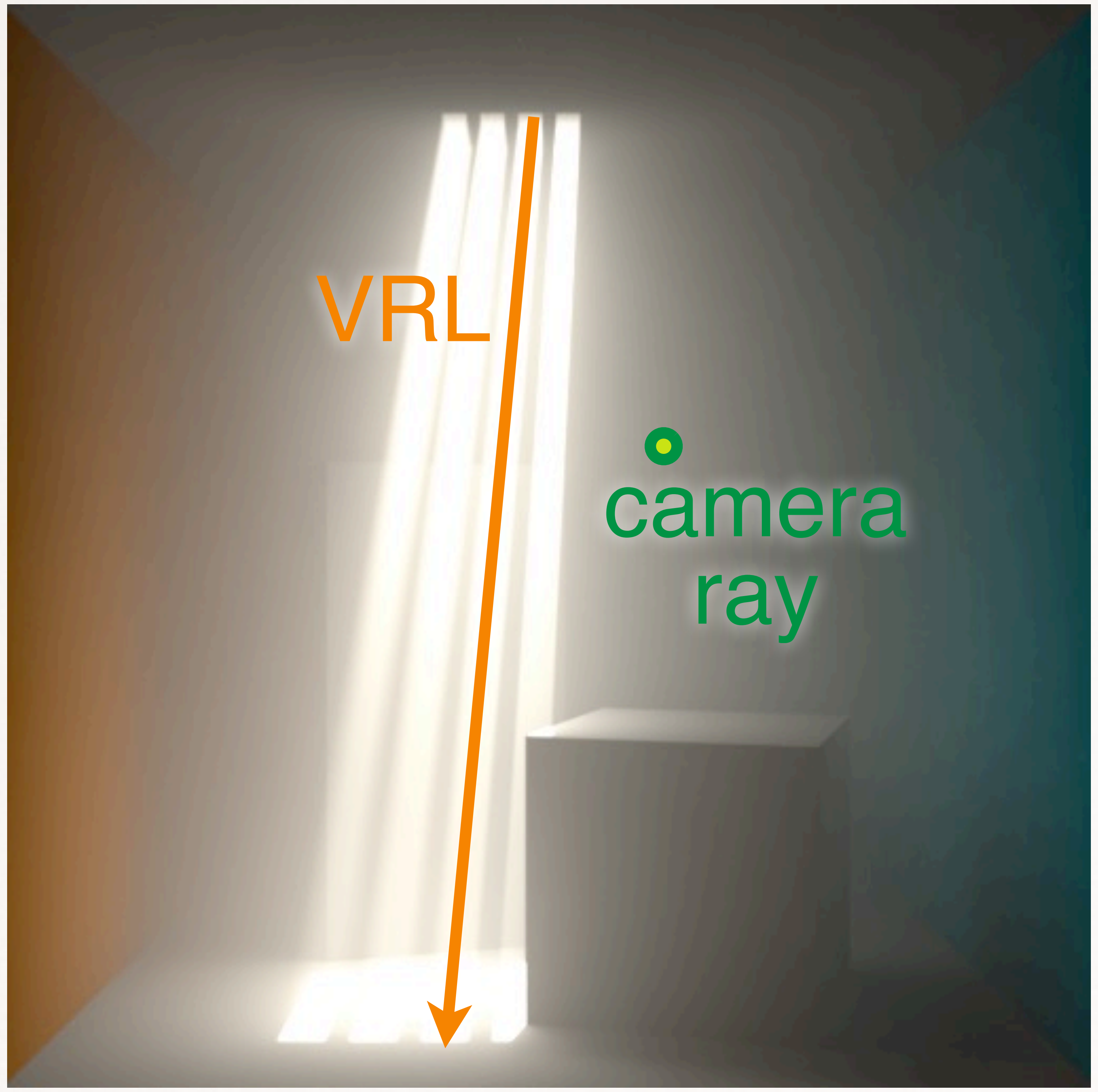


PF product / squared distance



Anisotropic media

anisotropic



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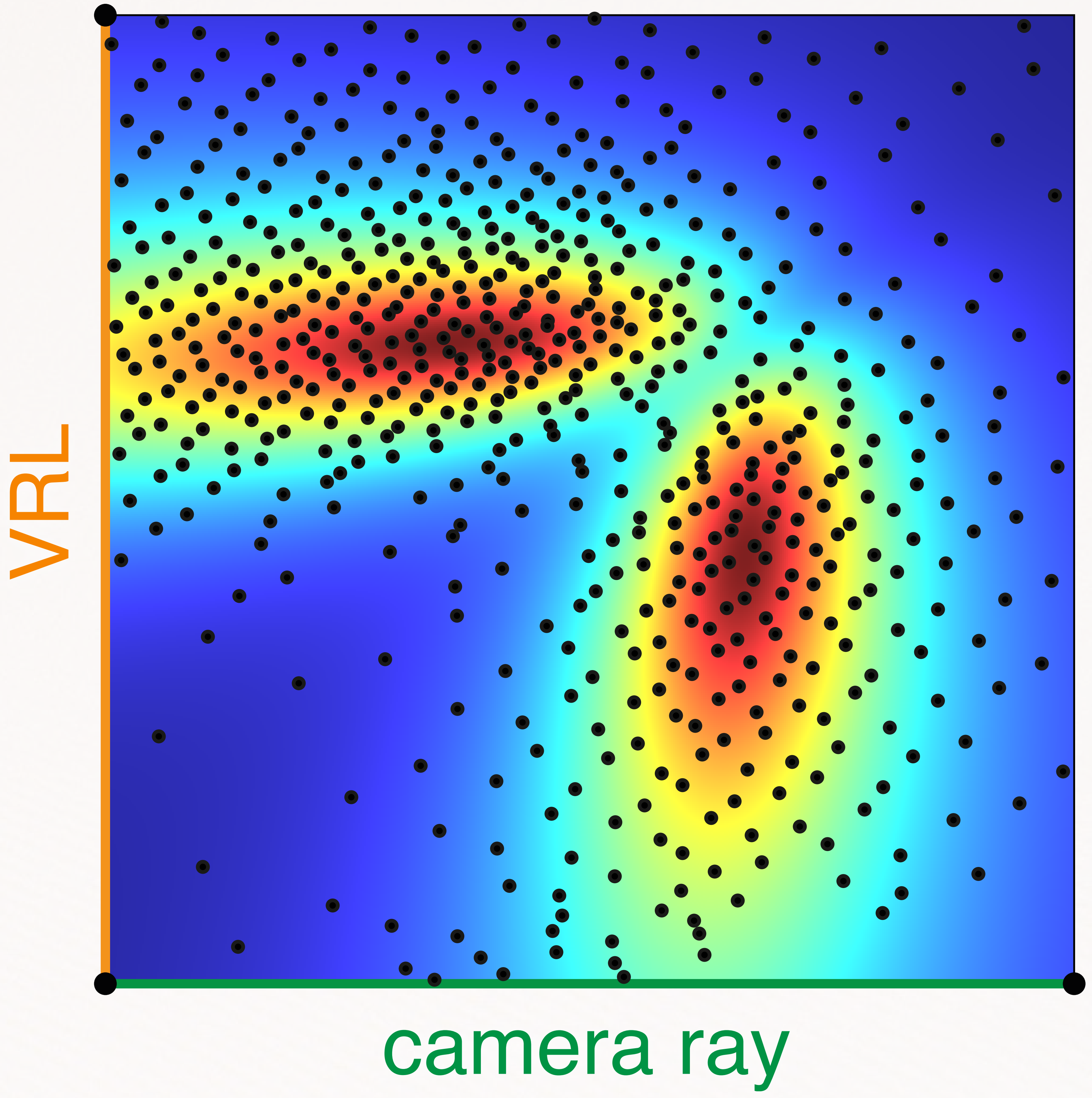
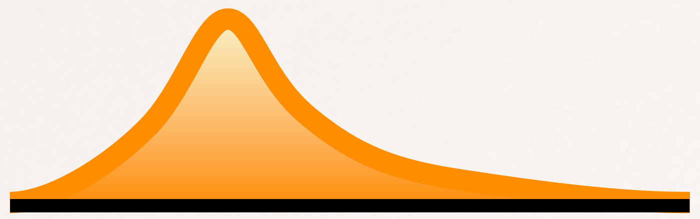
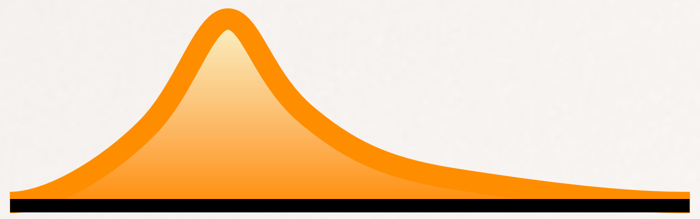


Anisotropic media

- **Marginal PDF** 

$$\mathrm{pdf}(v) = \frac{\int_0^s f_s(u) f_s(v)\, w^{-2}\, \mathrm{d}u}{\int_0^t \int_0^s f_s(u) f_s(v)\, w^{-2}\, \mathrm{d}u\, \mathrm{d}v}$$

Anisotropic media

- **Marginal PDF** 

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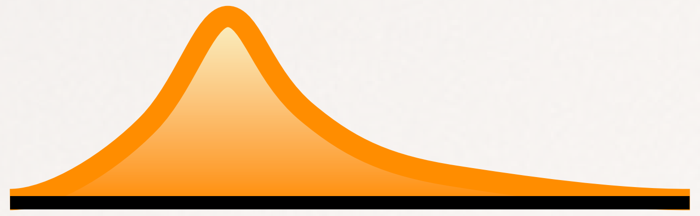
Anisotropic media

- **Marginal PDF** 

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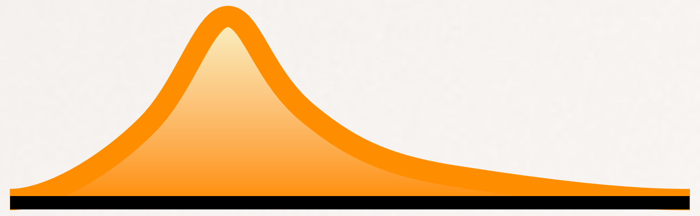
Anisotropic media

SIGGRAPH2012

- **Marginal PDF** 

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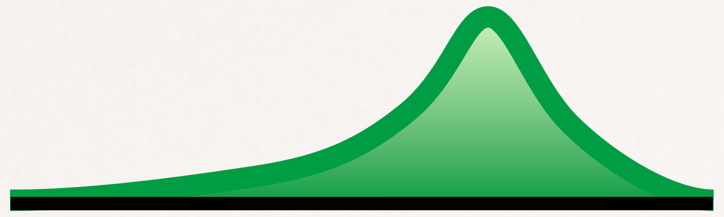
identical to isotropic medium

Anisotropic media

Anisotropic media

- Conditional PDF 

Anisotropic media

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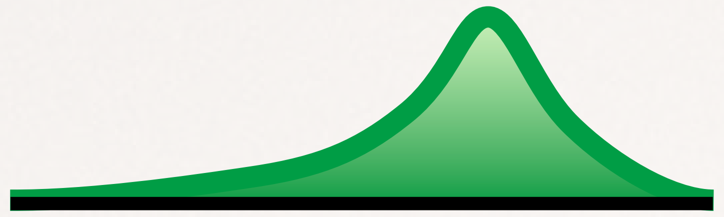
- **Conditional PDF** 
  - replace equi-angular sampling by **importance sampling the PF product**

Anisotropic media

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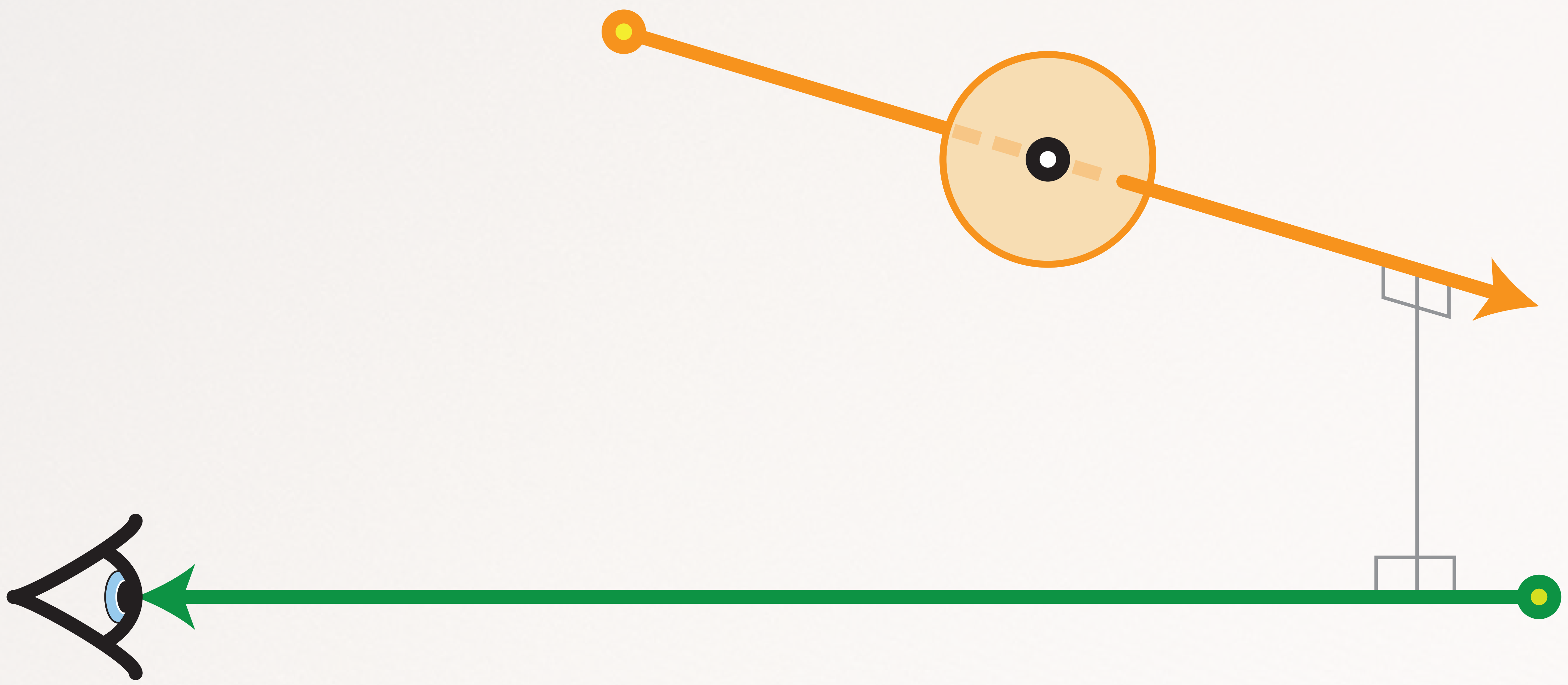

isotropic ~ equi-angular

Anisotropic media

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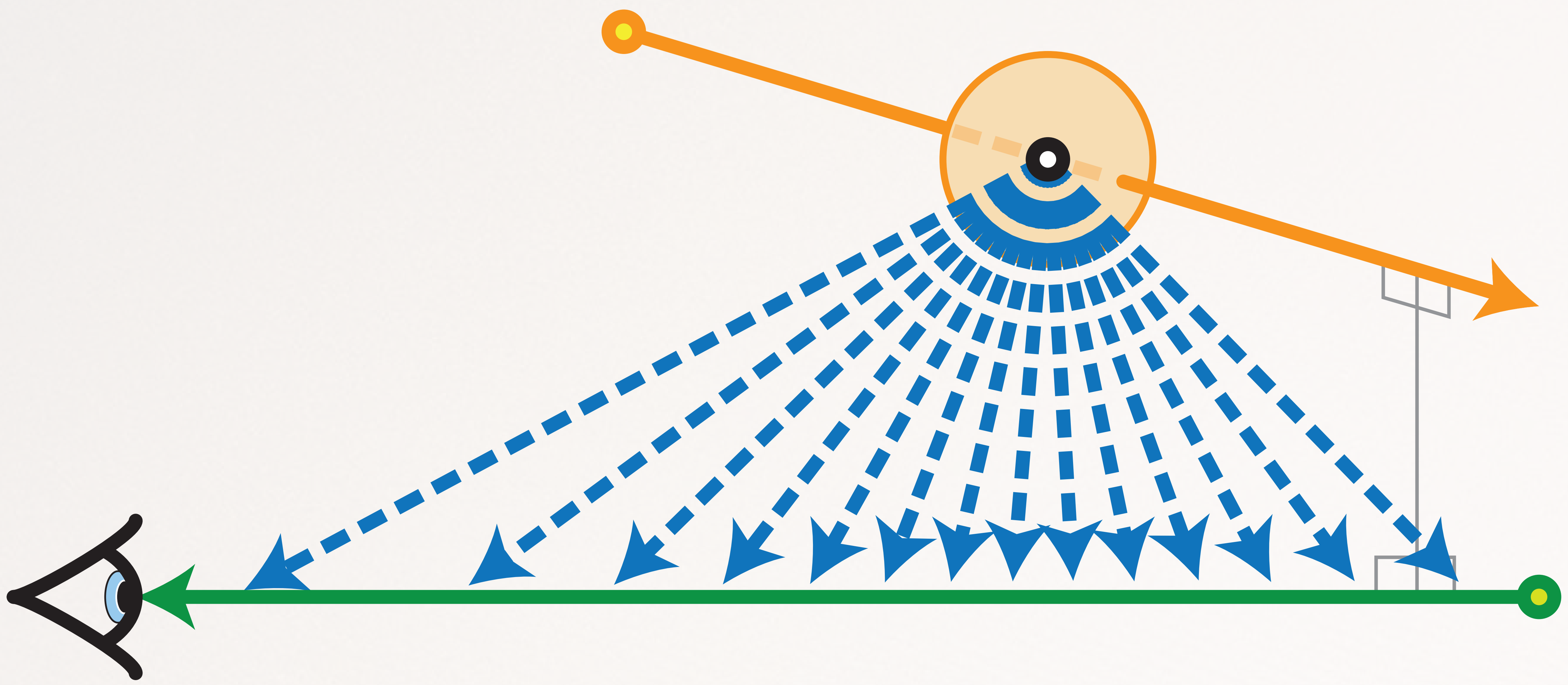

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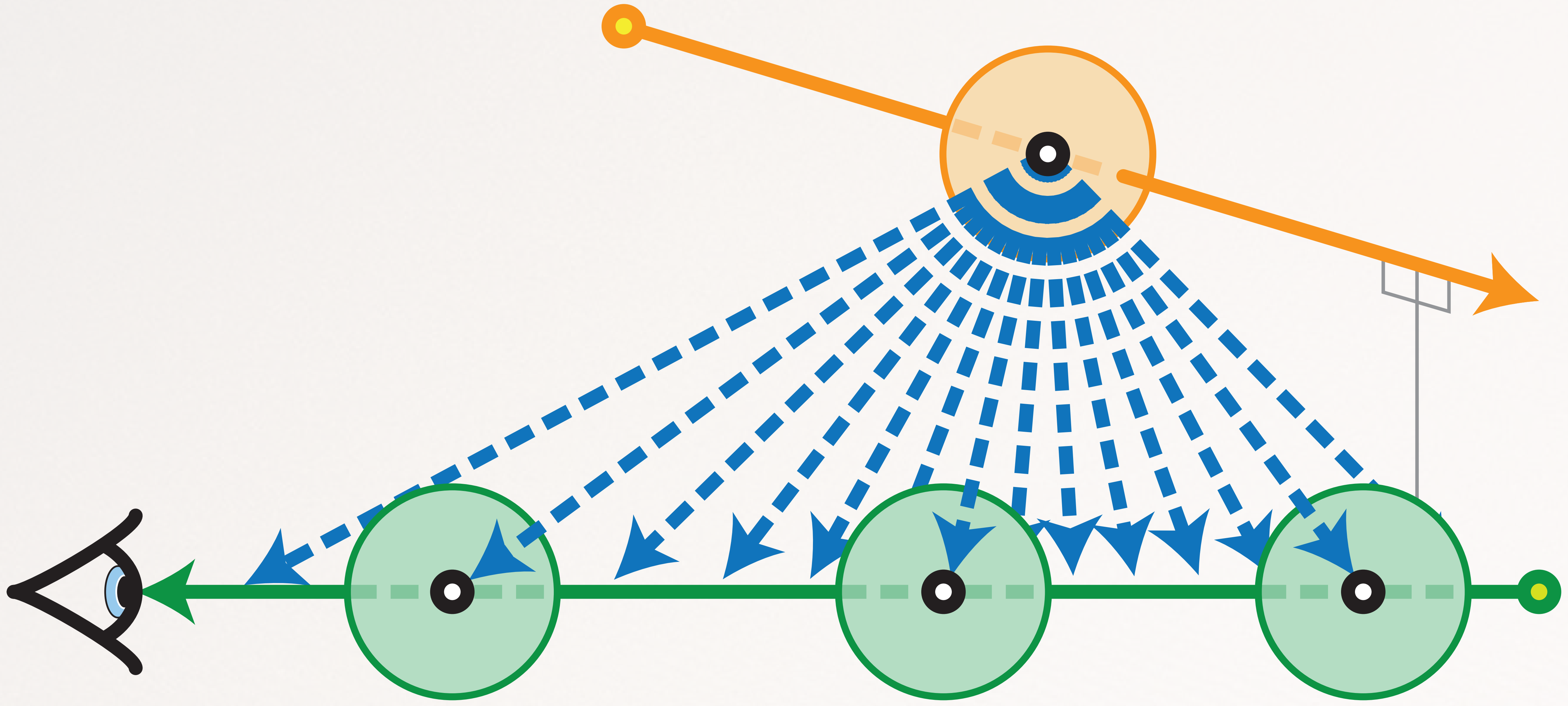

isotropic ~ equi-angular

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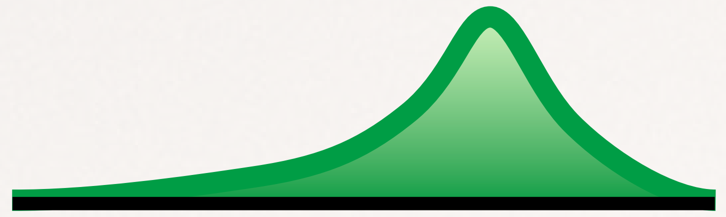
SIGGRAPH2012

- **Conditional PDF** 
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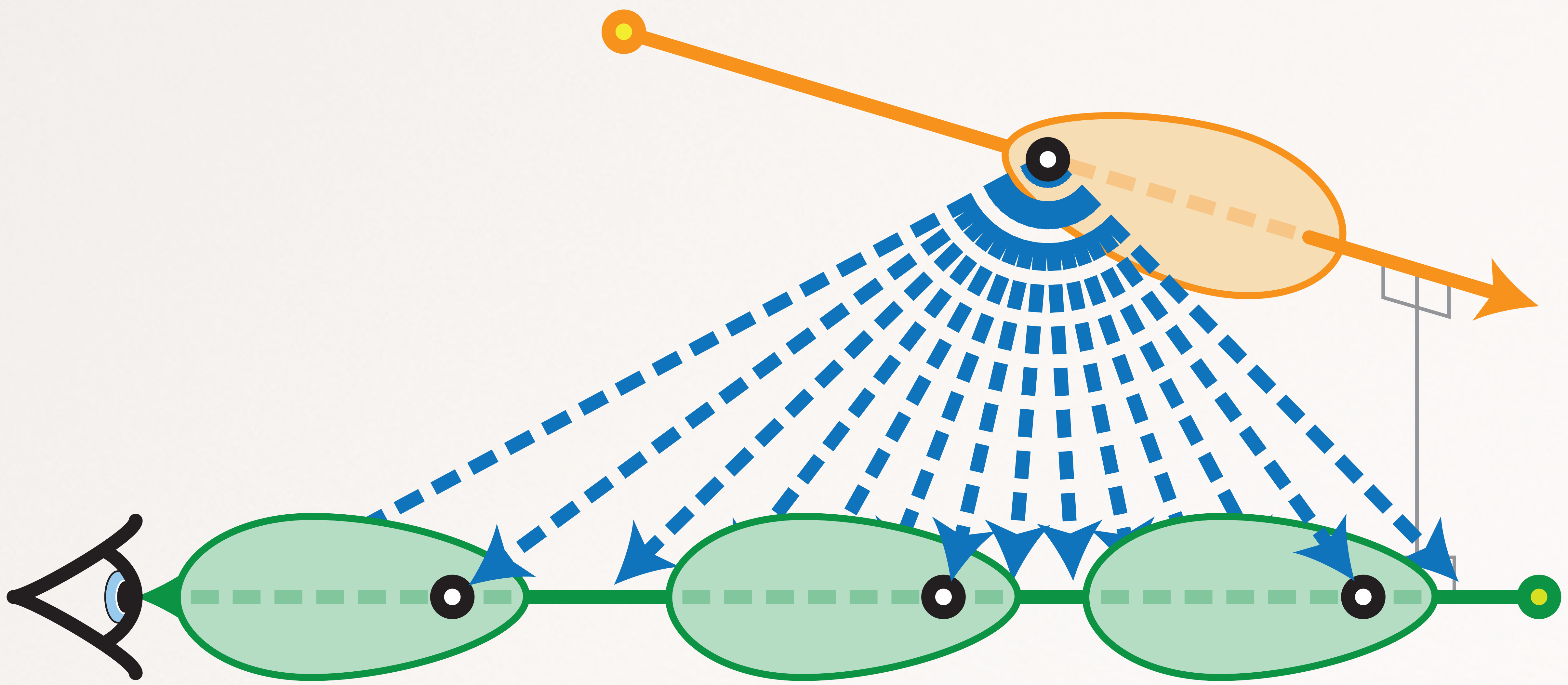
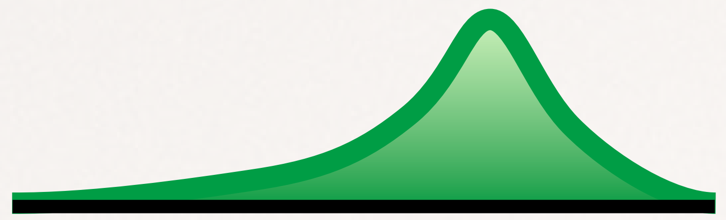


anisotropic

Anisotropic media

- **Conditional PDF** 
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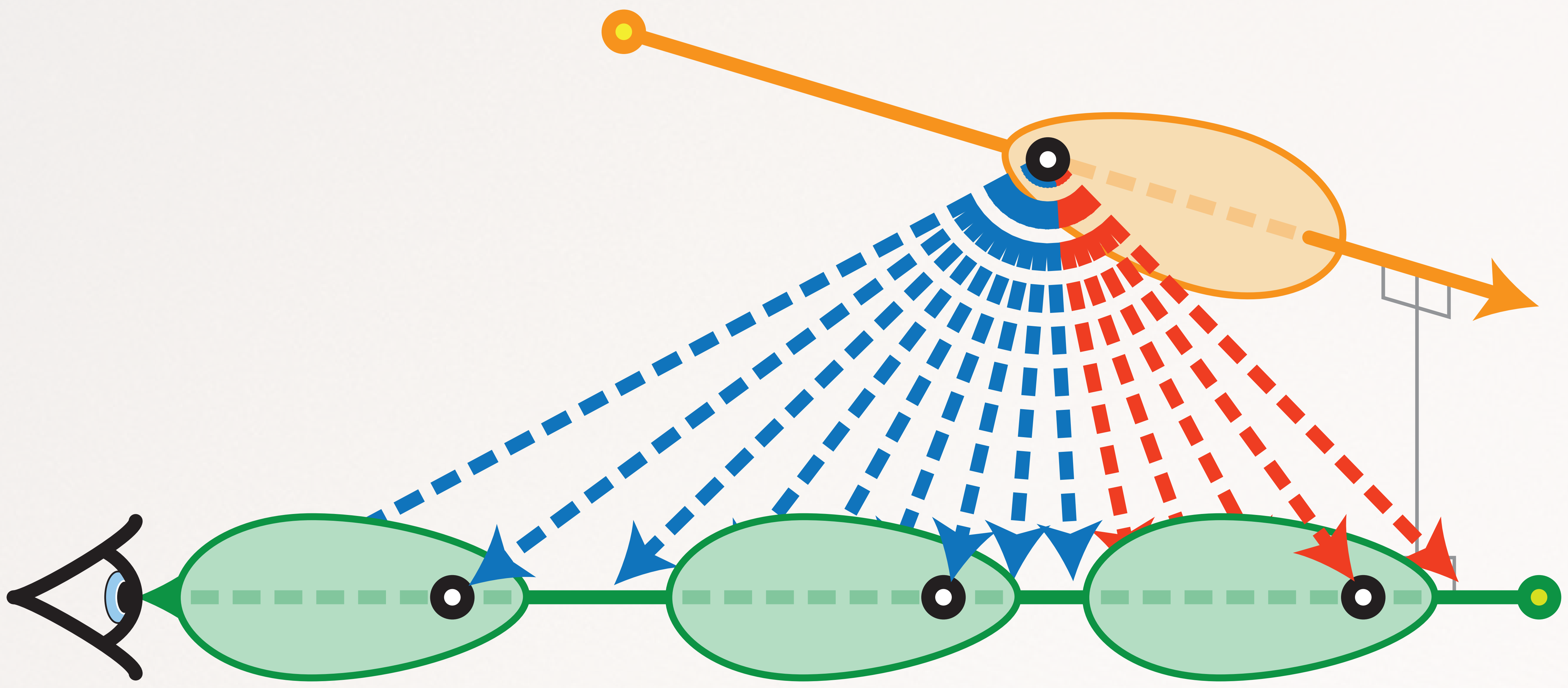

anisotropic

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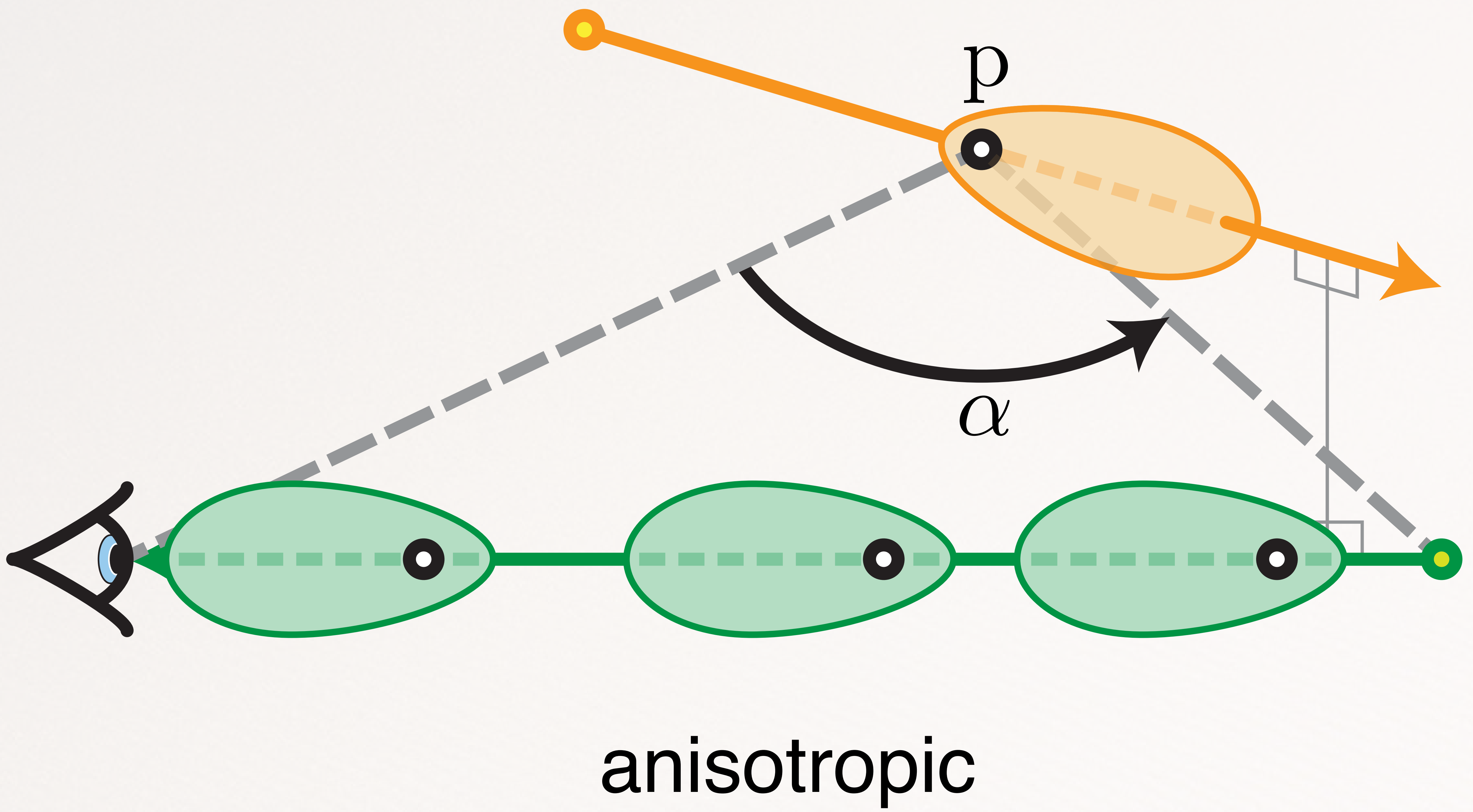

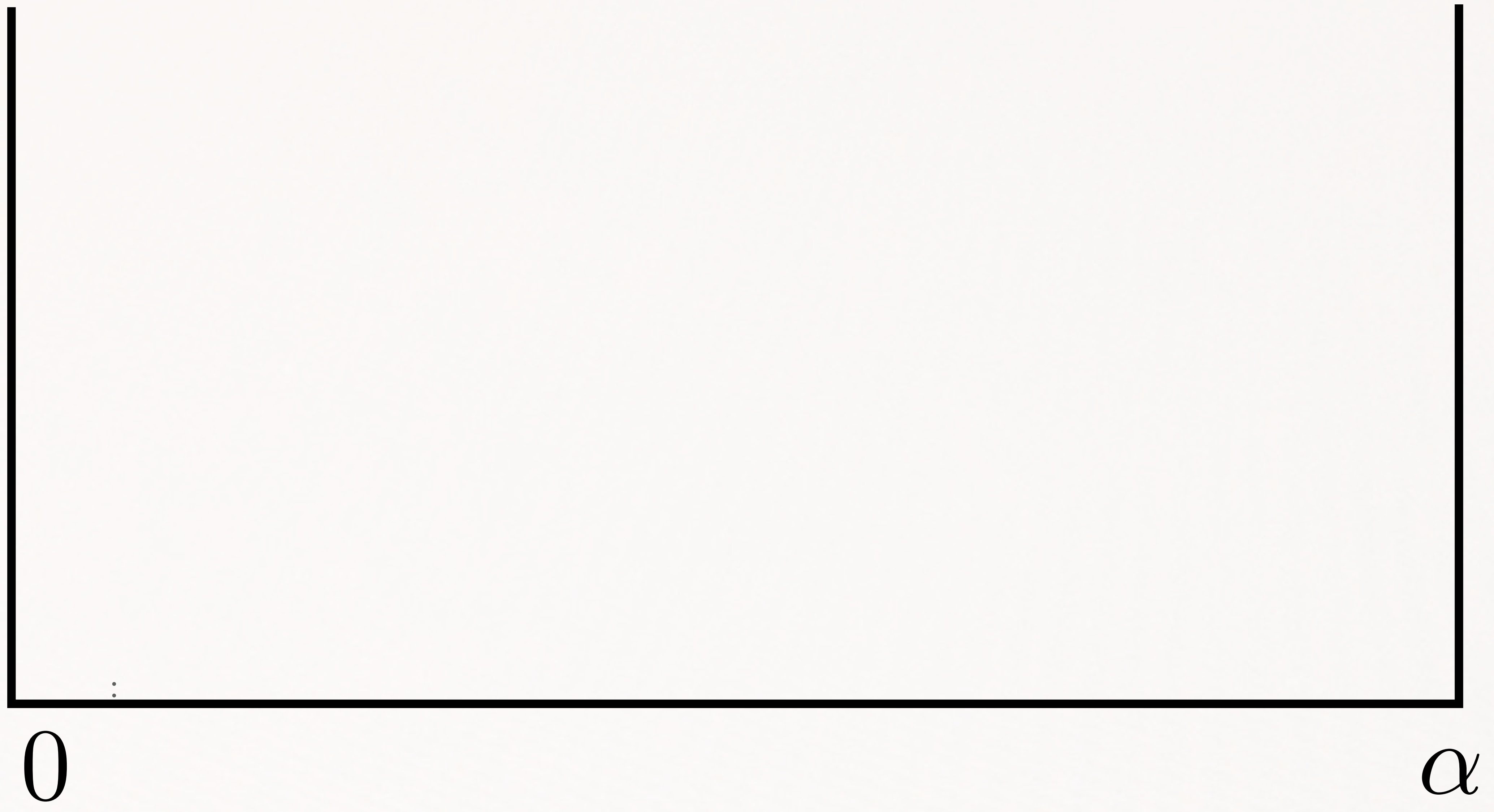

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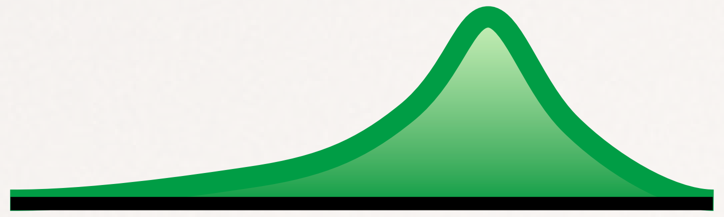
- **Conditional PDF** 
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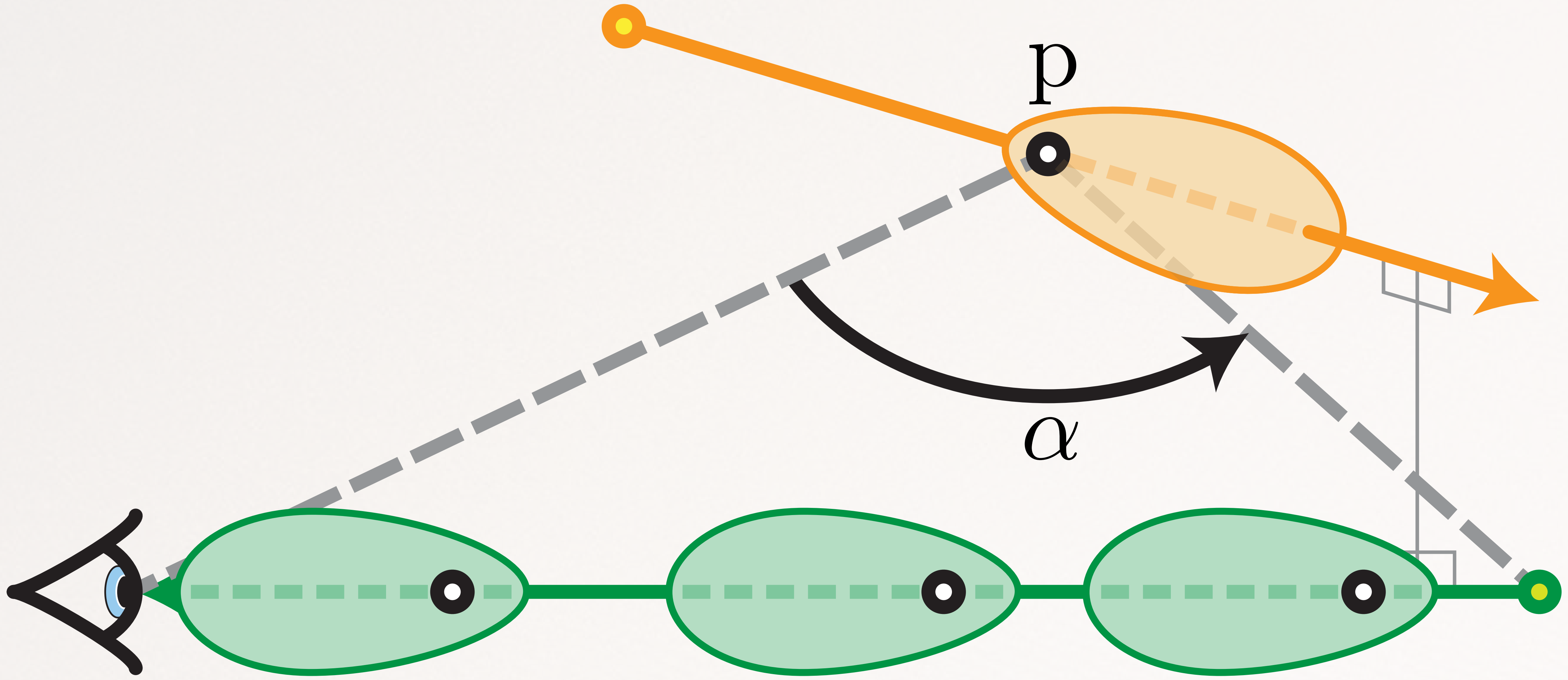

anisotropic

angular domain about p

Anisotropic media

SIGGRAPH2012

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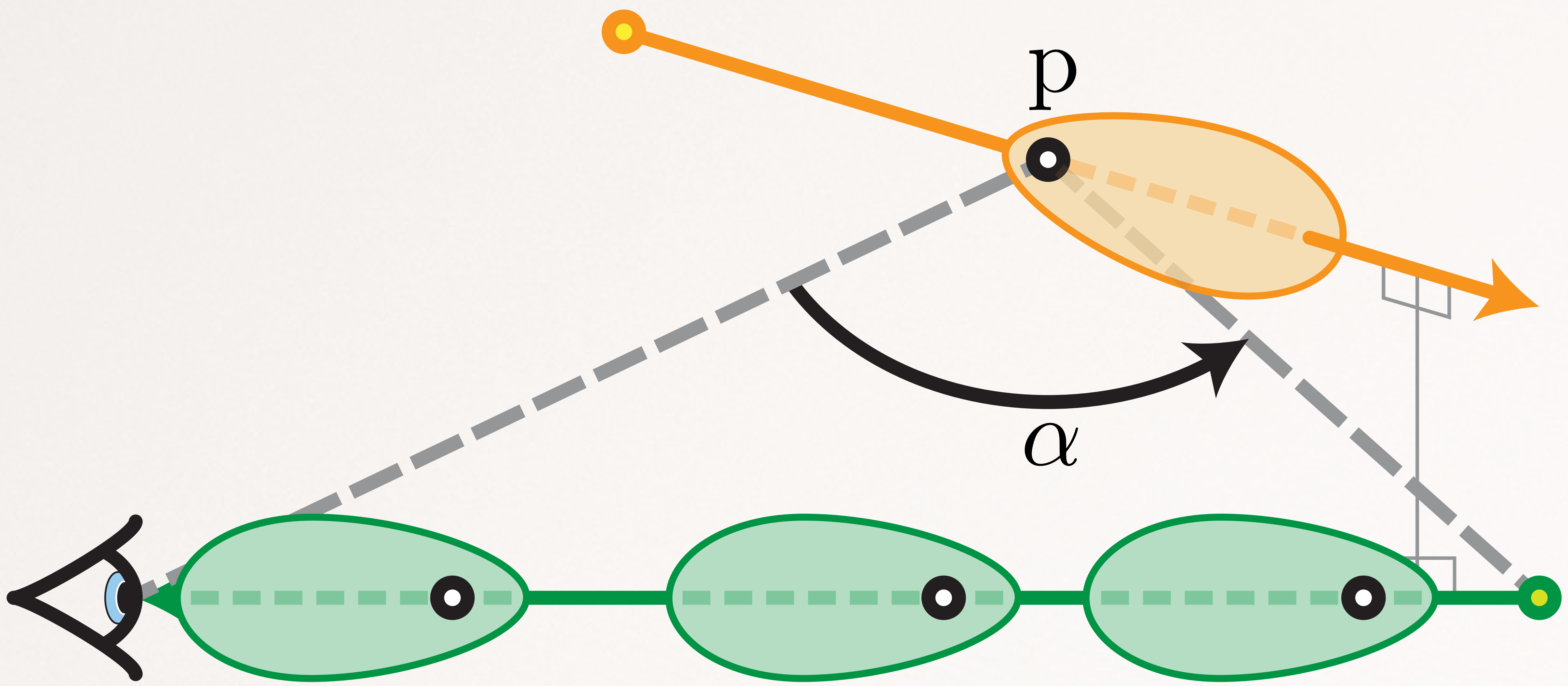
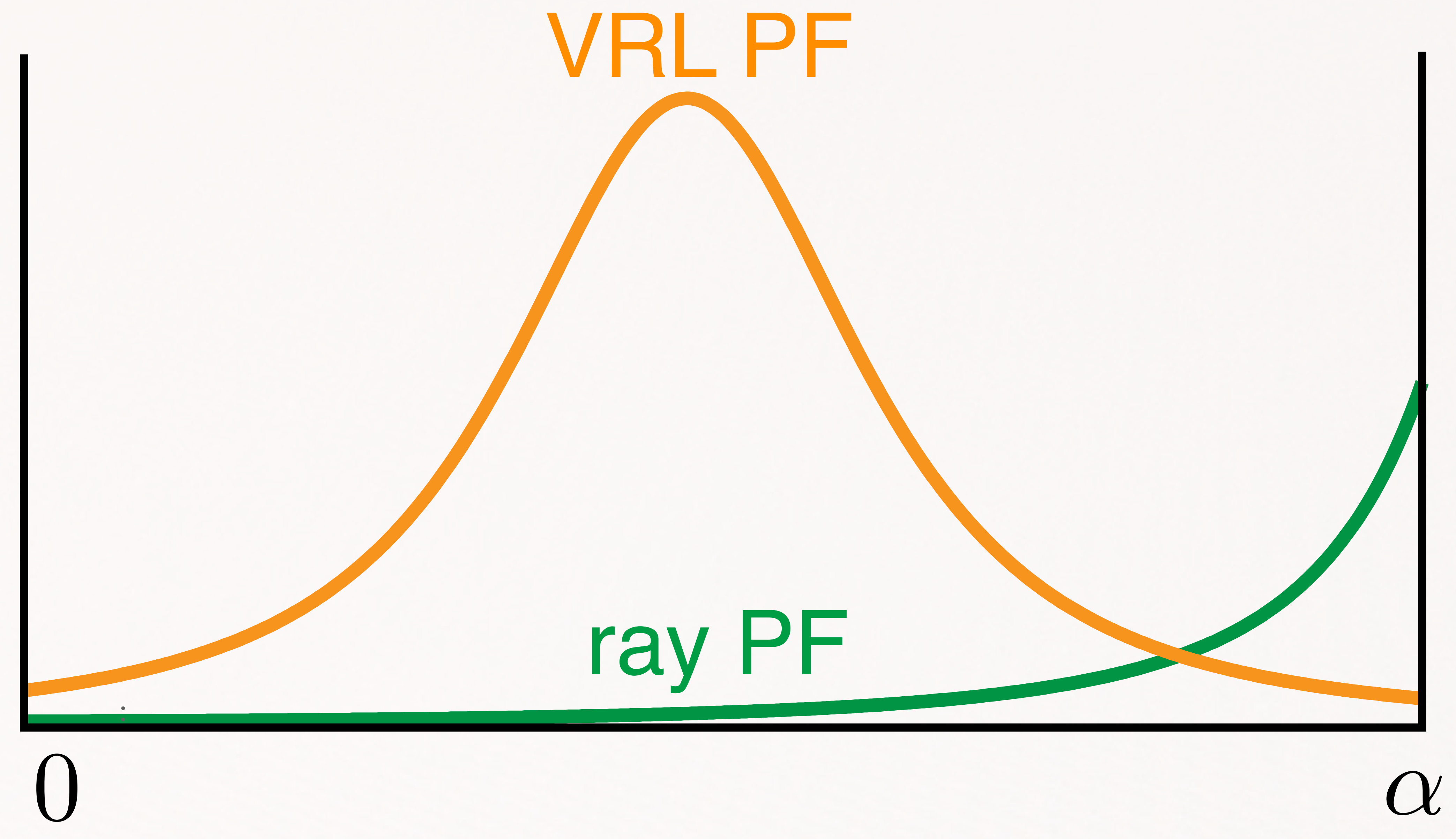


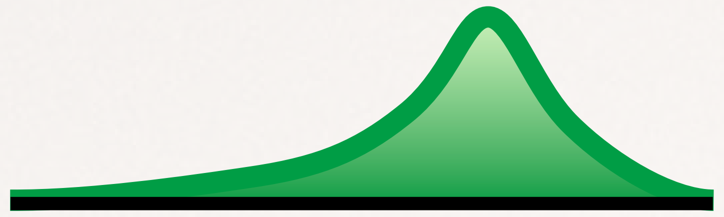
anisotropic

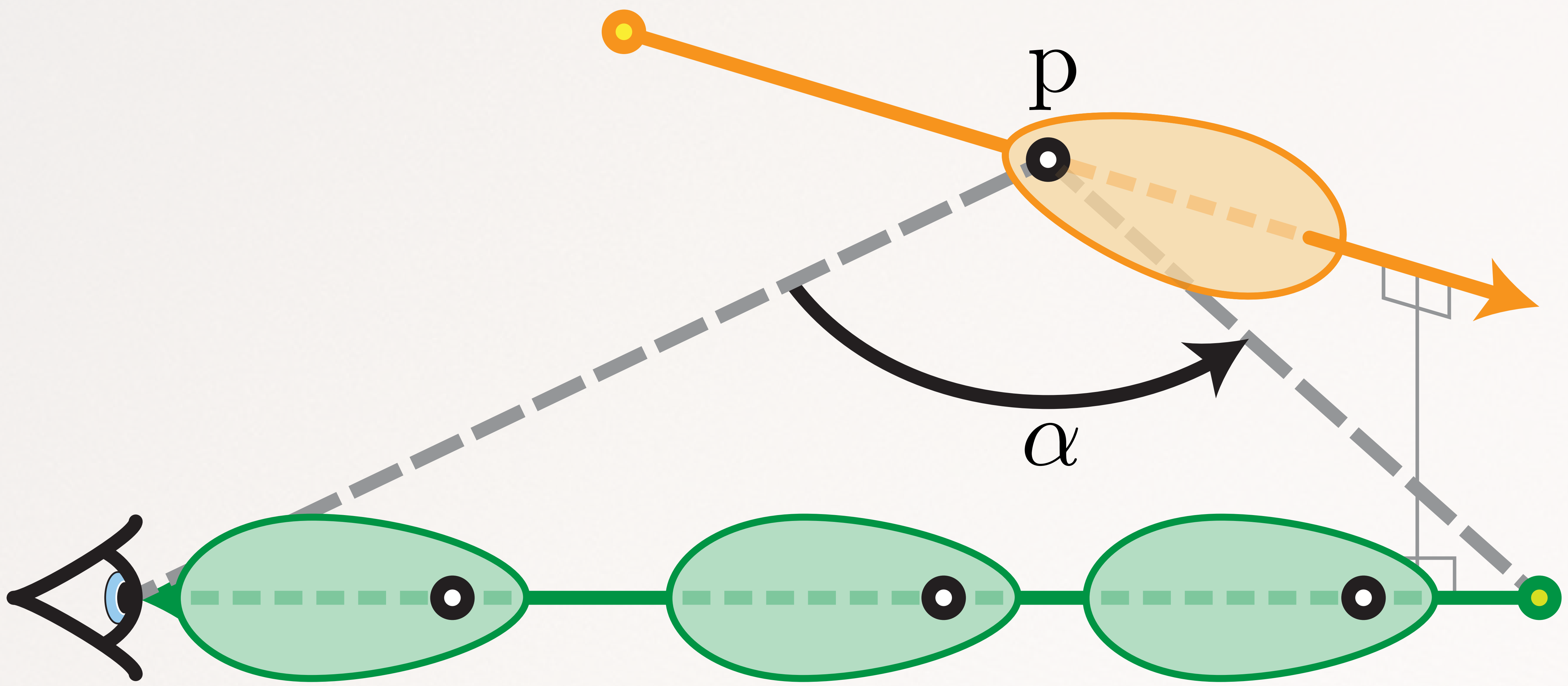


angular domain about p

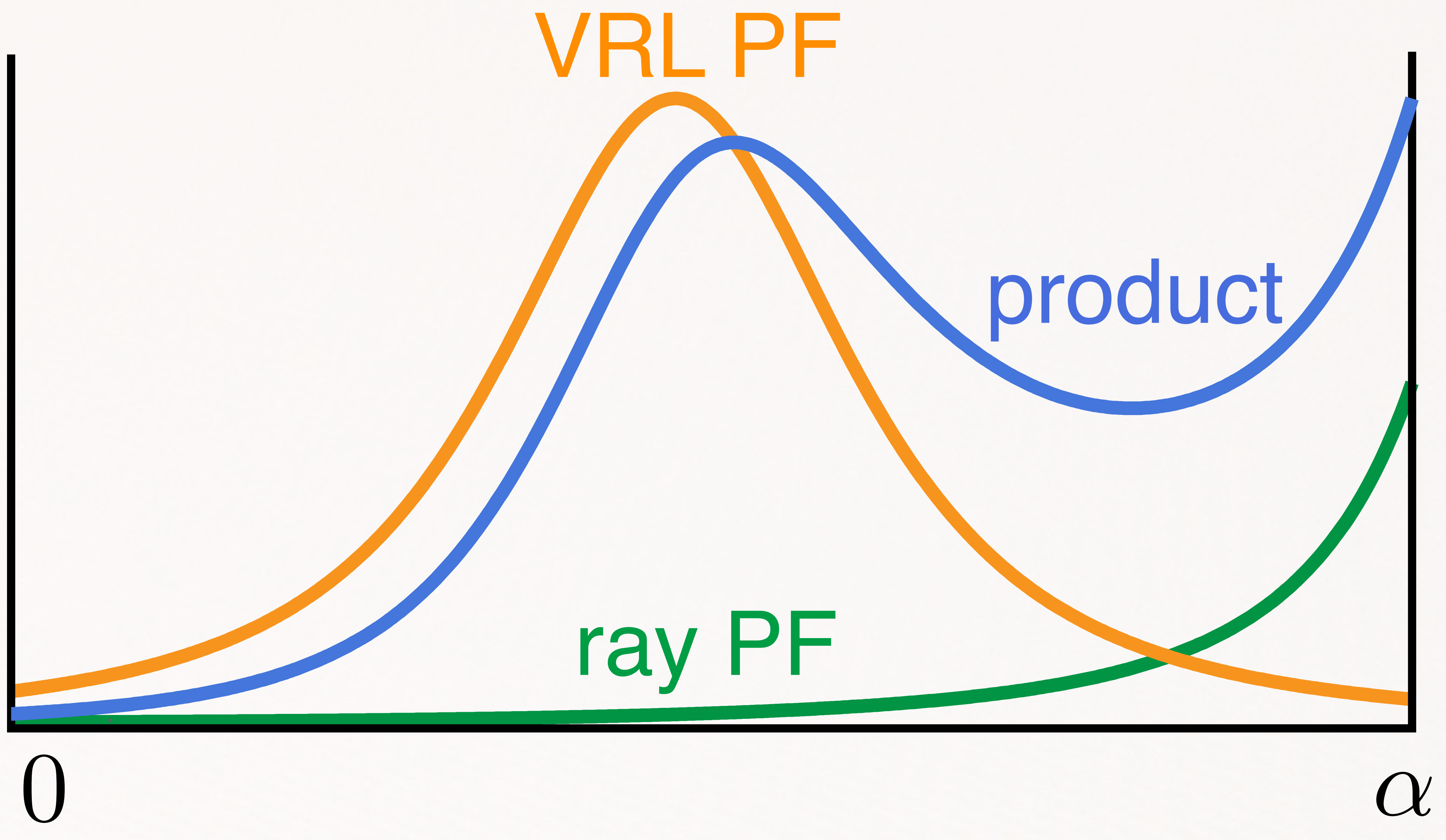
Anisotropic media

SIGGRAPH2012

- **Conditional PDF** 
  - replace equi-angular sampling by **importance sampling the PF product**



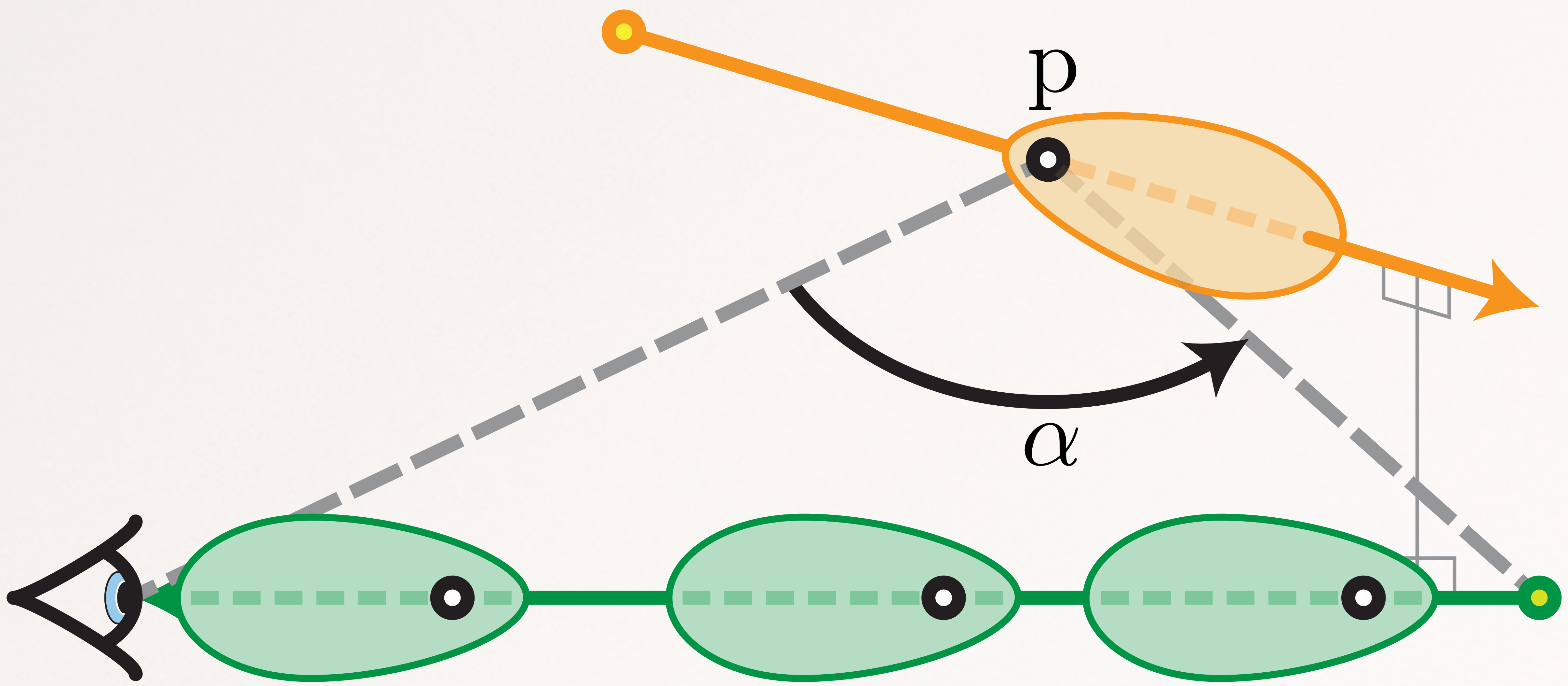
anisotropic



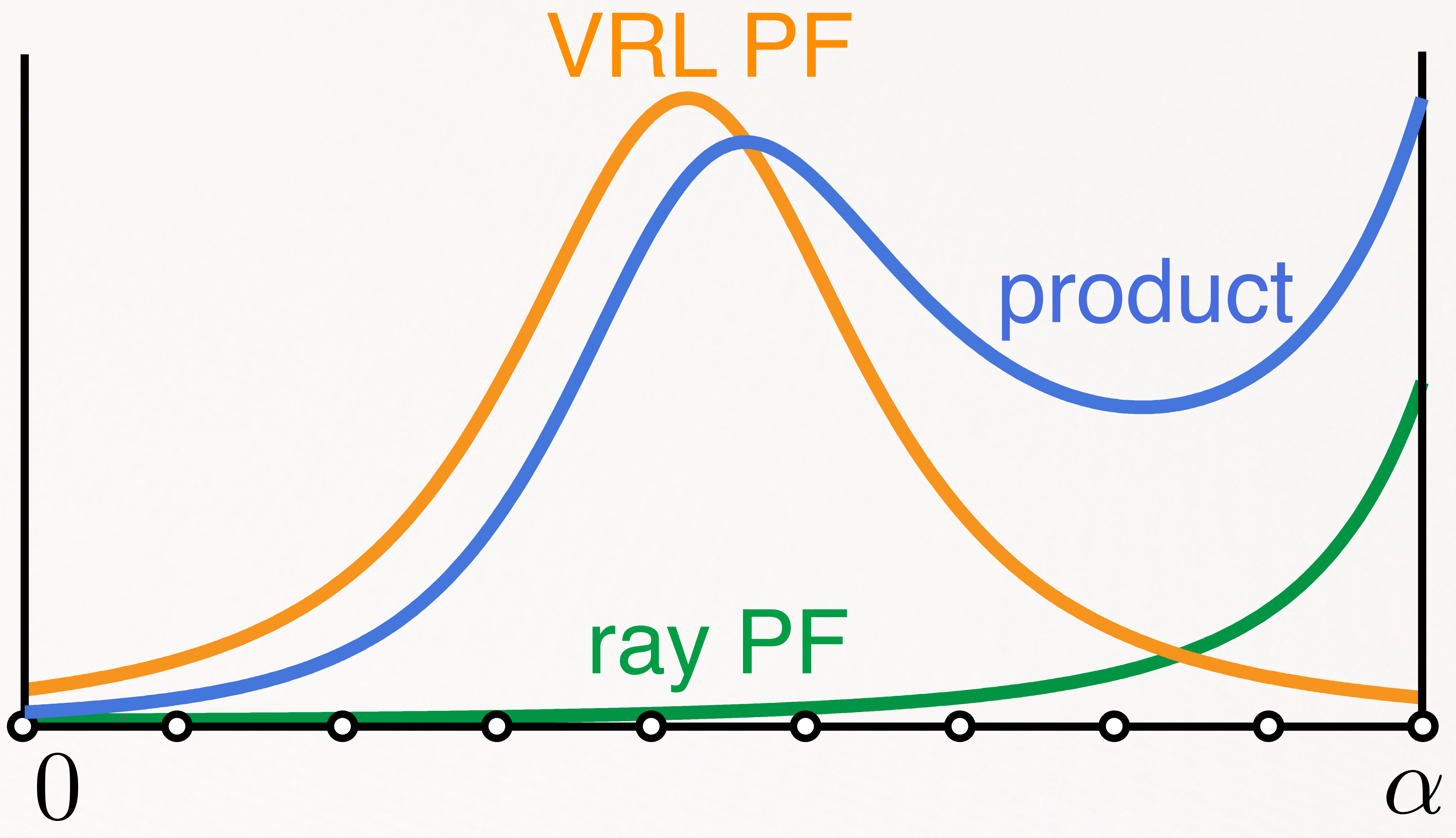
angular domain about p

Anisotropic media

- **Conditional PDF**
  - replace equi-angular sampling by **importance sampling the PF product**



anisotropic

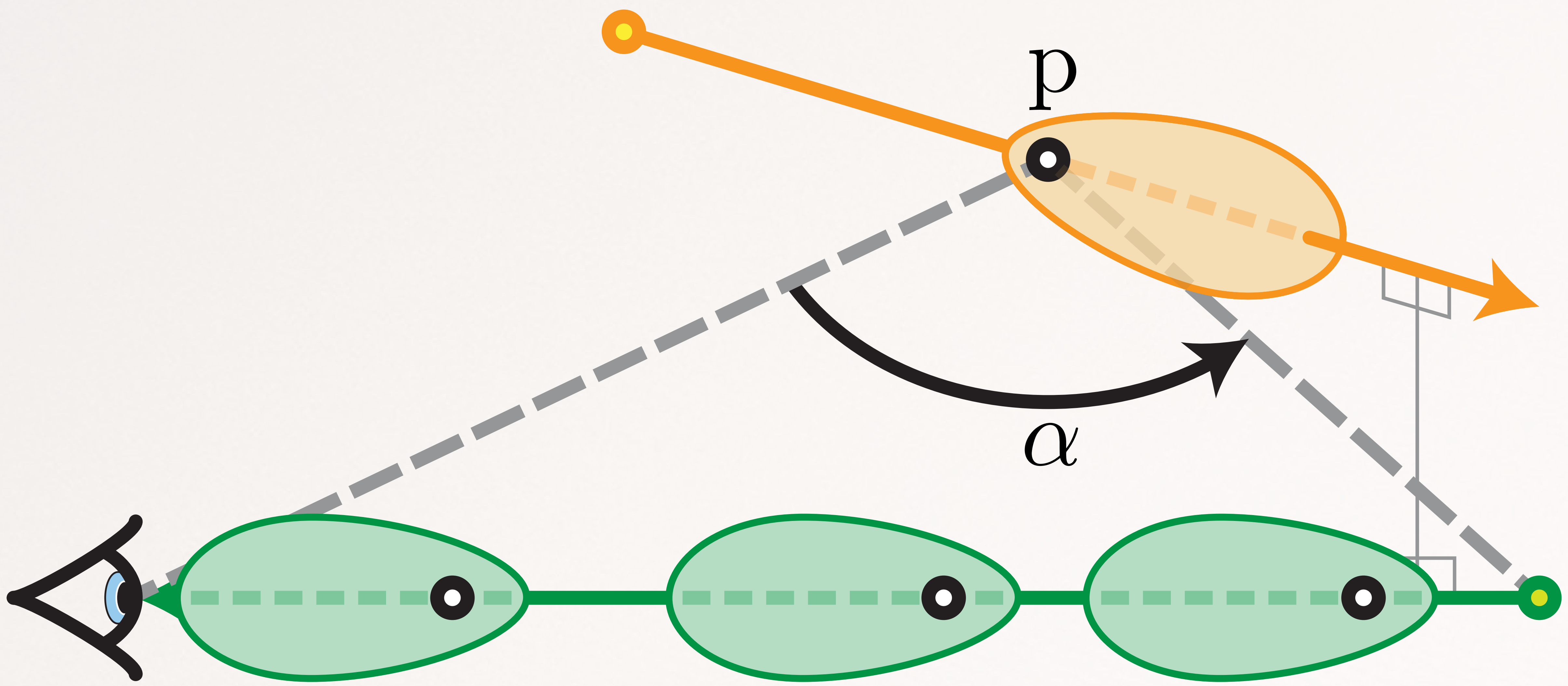


angular domain about p

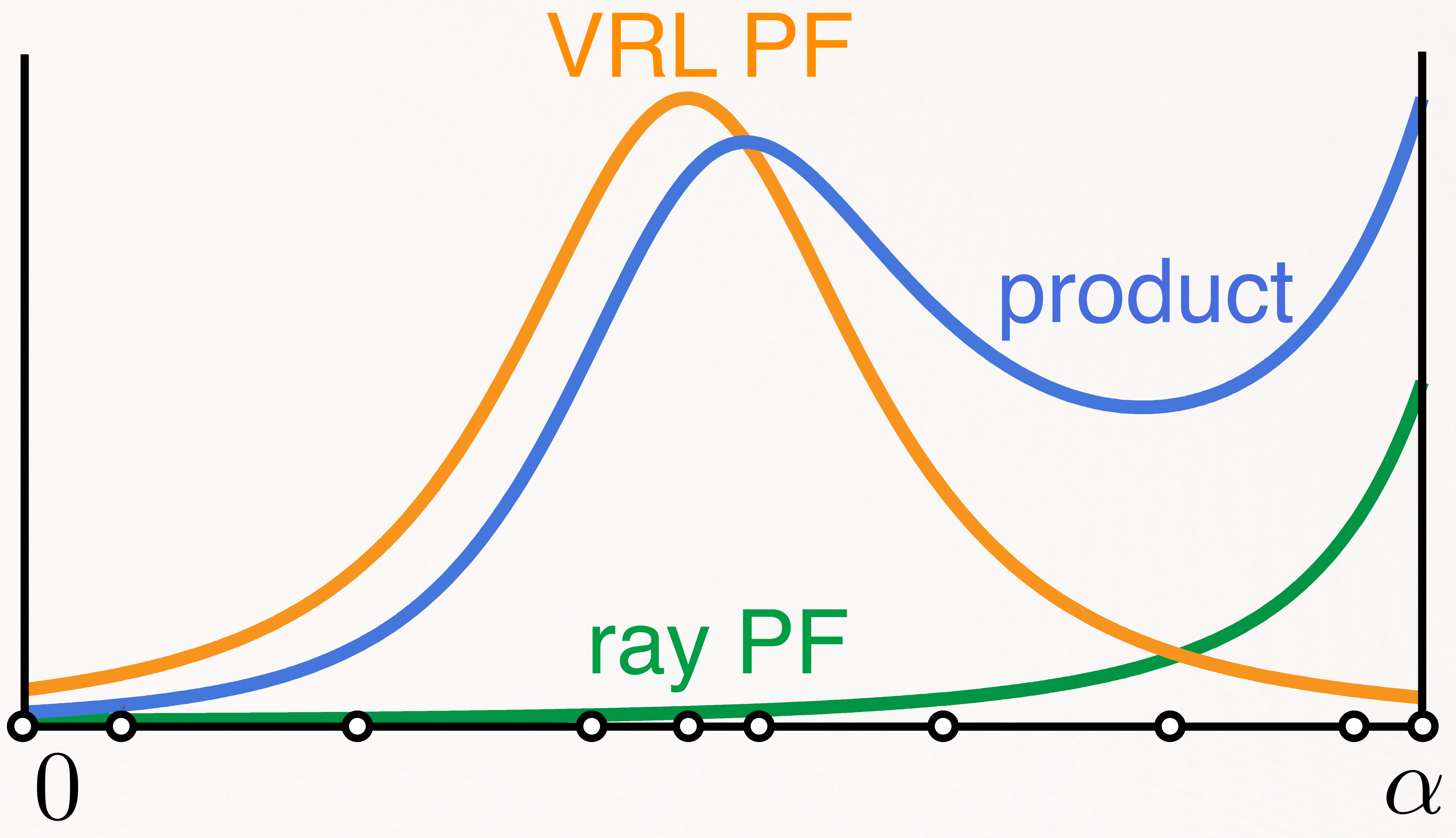
Anisotropic media

SIGGRAPH2012

- **Conditional PDF**
  - replace equi-angular sampling by **importance sampling the PF product**



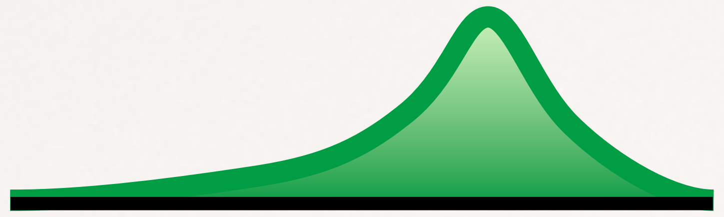
anisotropic

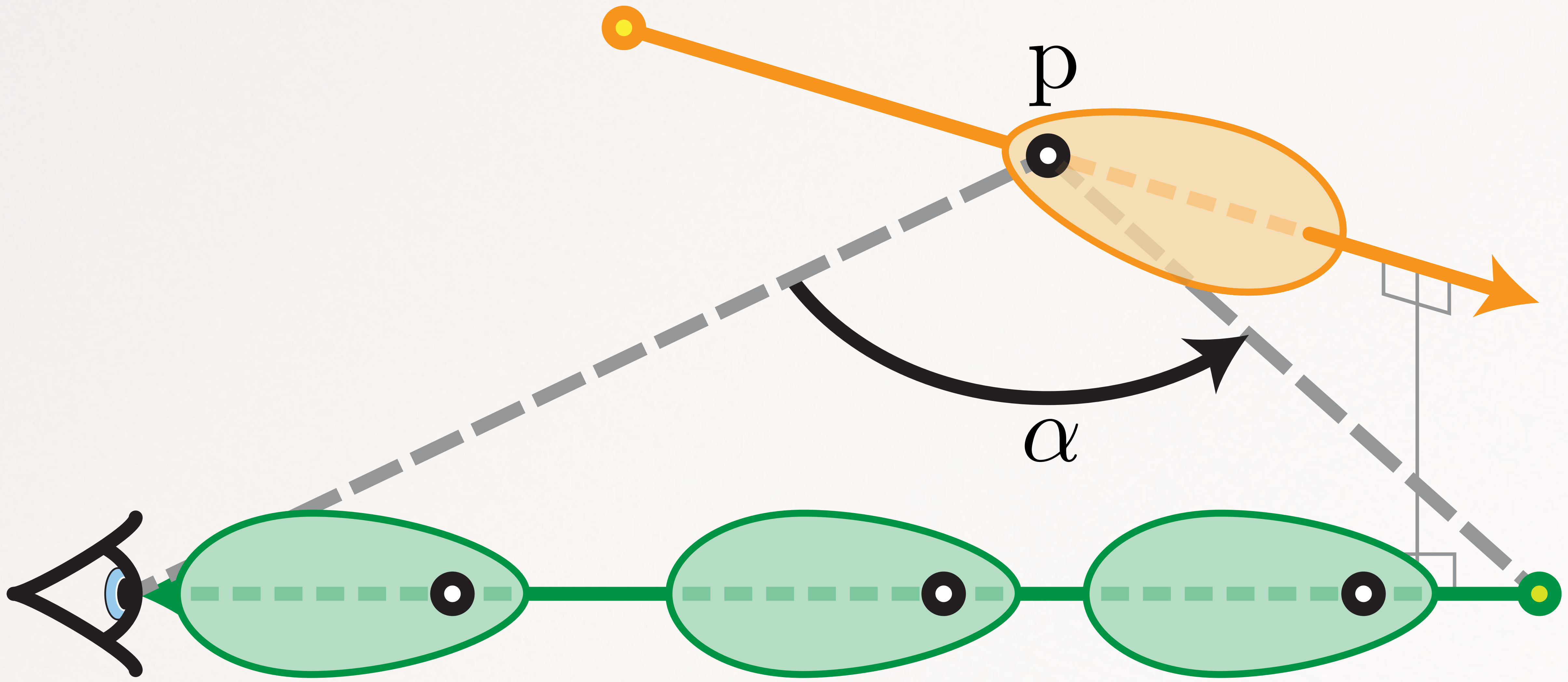


angular domain about p

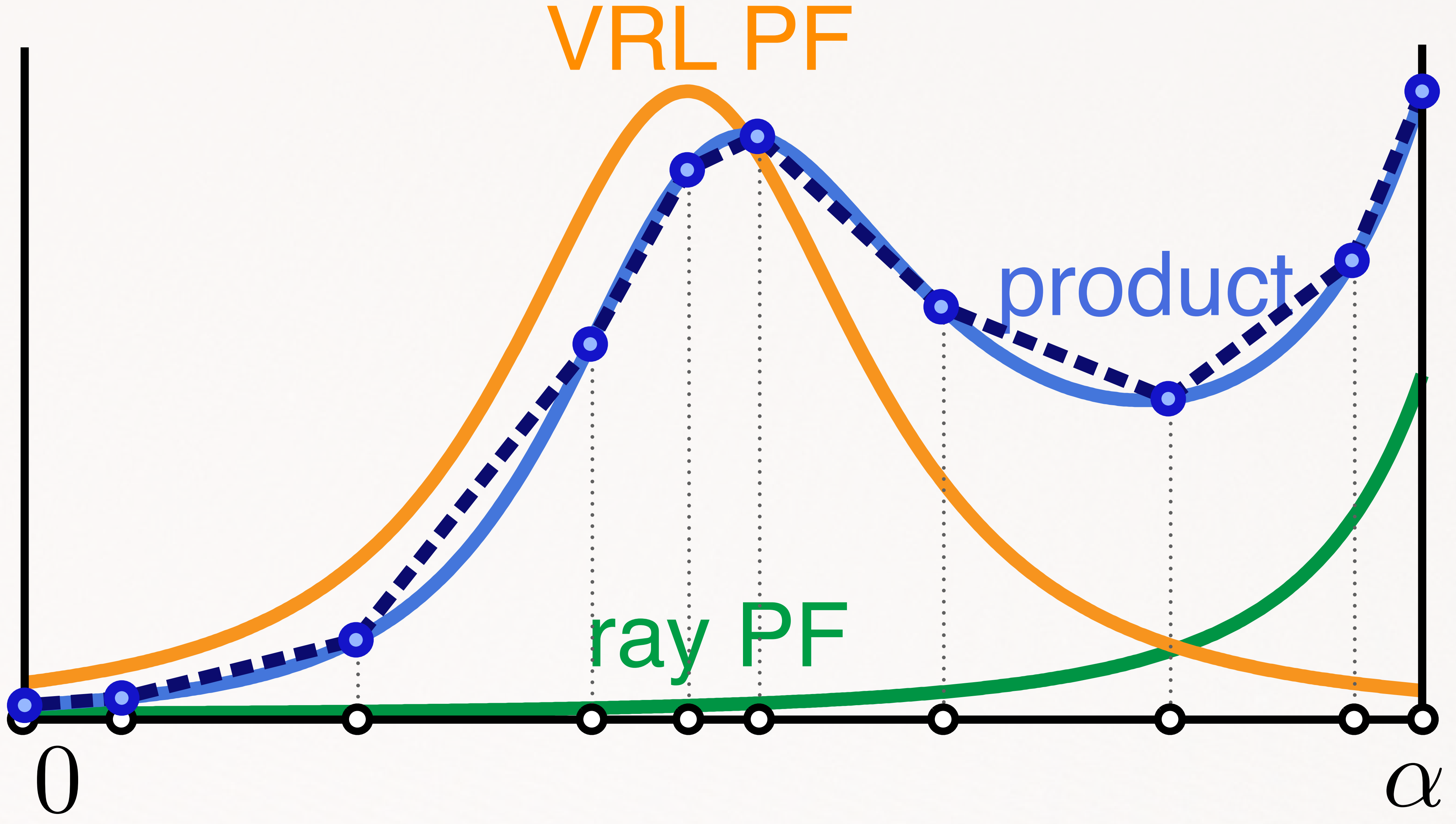
Anisotropic media

SIGGRAPH2012

- **Conditional PDF** 
  - replace equi-angular sampling by **importance sampling the PF product**



anisotropic

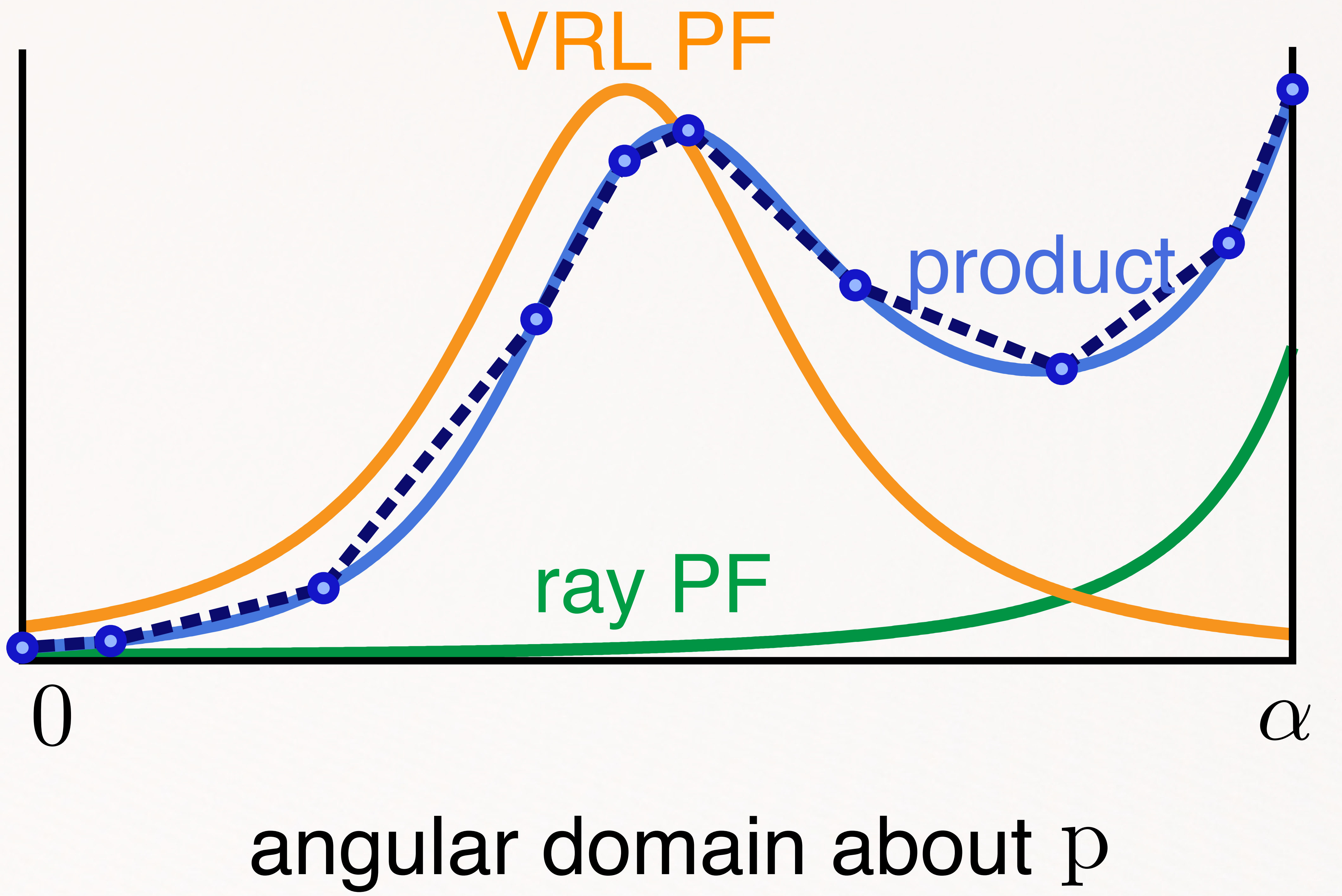


angular domain about p

Anisotropic media

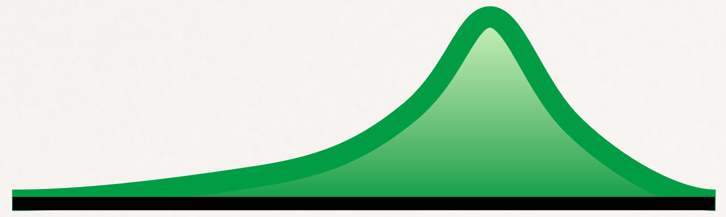
SIGGRAPH2012

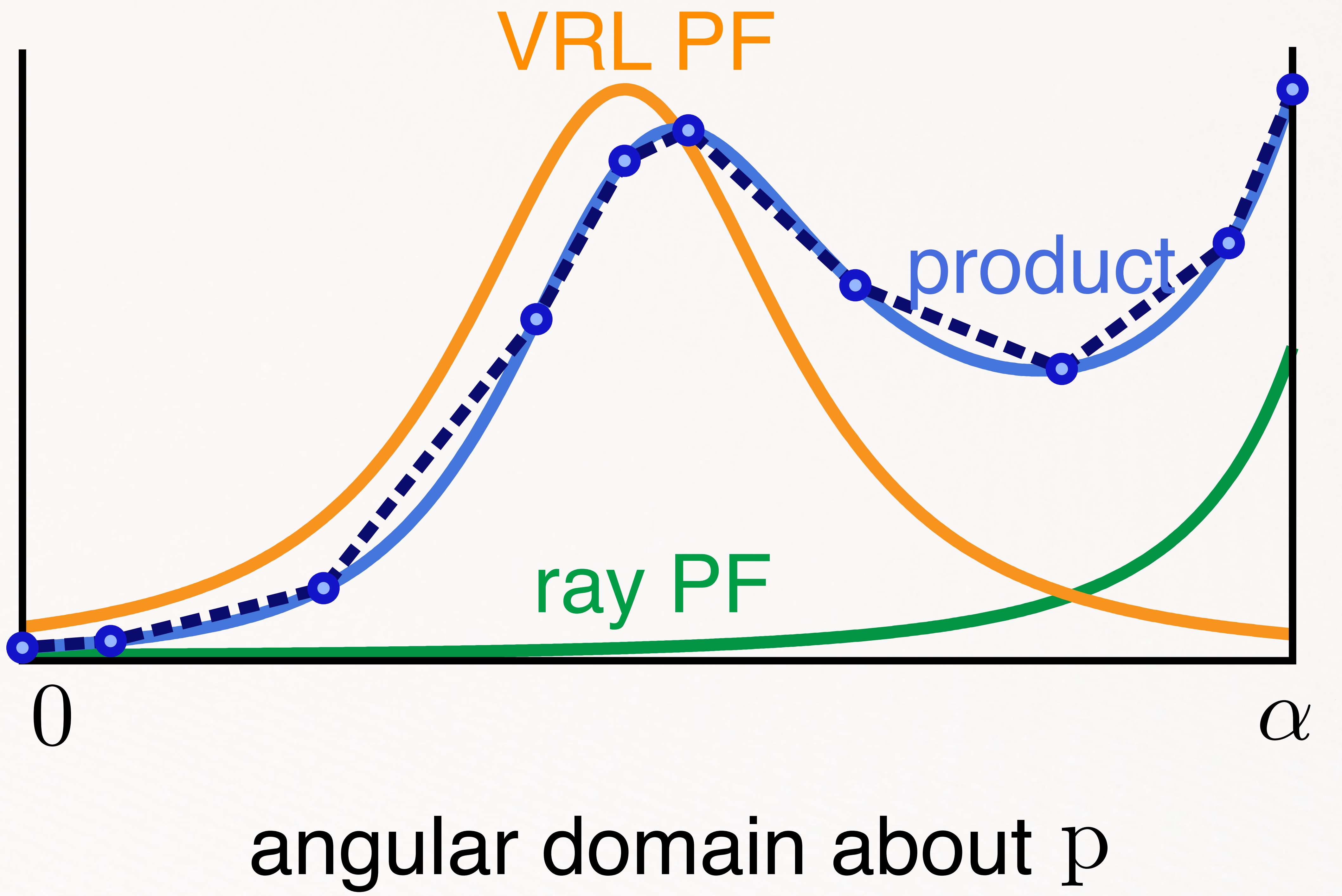
- **Conditional PDF**
  - replace equi-angular sampling by **importance sampling the PF product**
  - piece-wise **linear PDF**



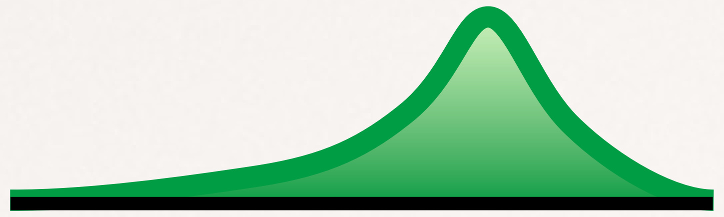
Anisotropic media

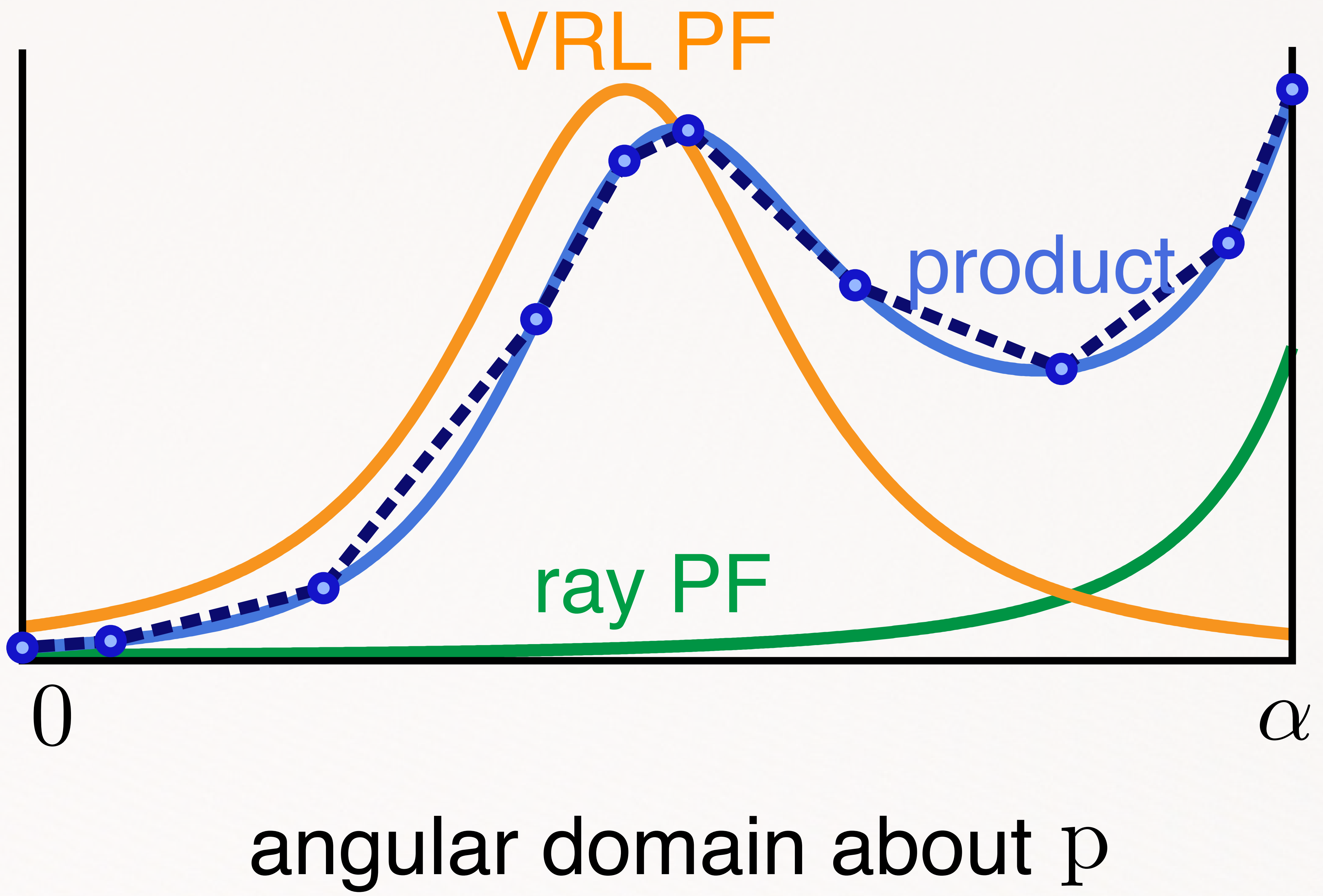
SIGGRAPH2012

- **Conditional PDF** 
  - replace equi-angular sampling by **importance sampling the PF product**
  - piece-wise **linear PDF**
  - piece-wise **quadratic CDF**



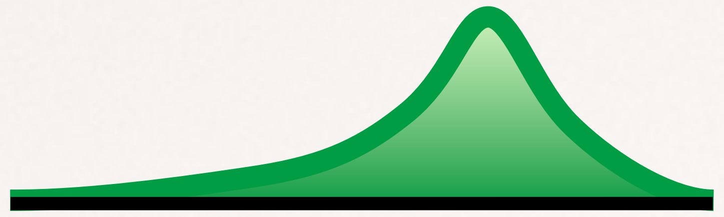
Anisotropic media

- **Conditional PDF** 
  - replace equi-angular sampling by **importance sampling the PF product**
  - piece-wise **linear PDF**
  - piece-wise **quadratic CDF**
  - 10 adaptively distributed vertices
    balance between speed and quality

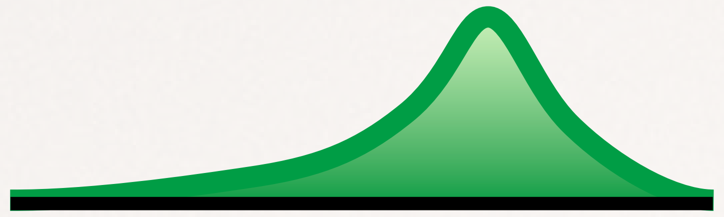


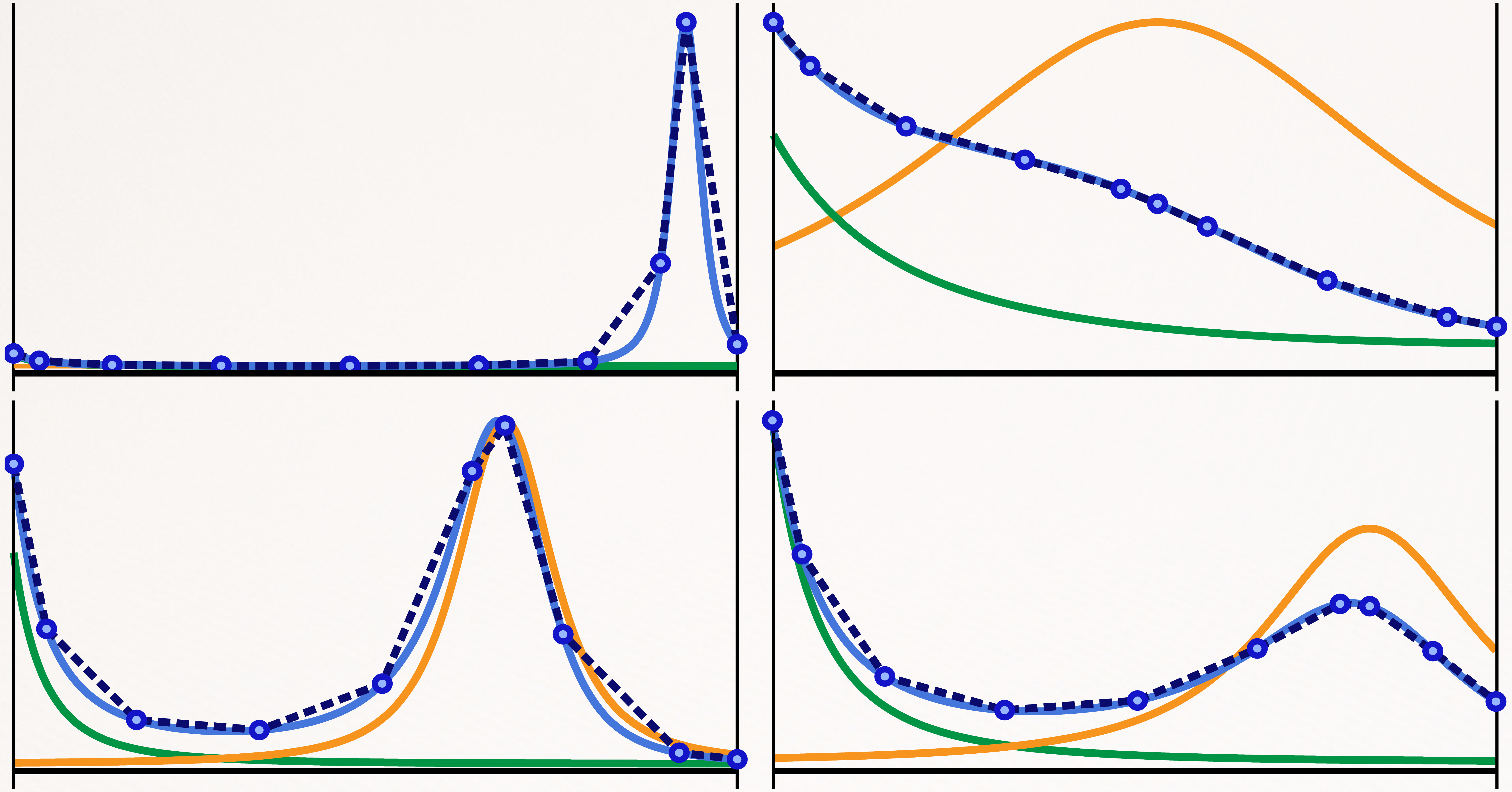
Anisotropic media

SIGGRAPH 2012

- **Conditional PDF** 
  - examples for Henyey-Greenstein PF with $g = 0.95$

Anisotropic media

- **Conditional PDF** 
  - examples for Henyey-Greenstein PF with g = 0.95

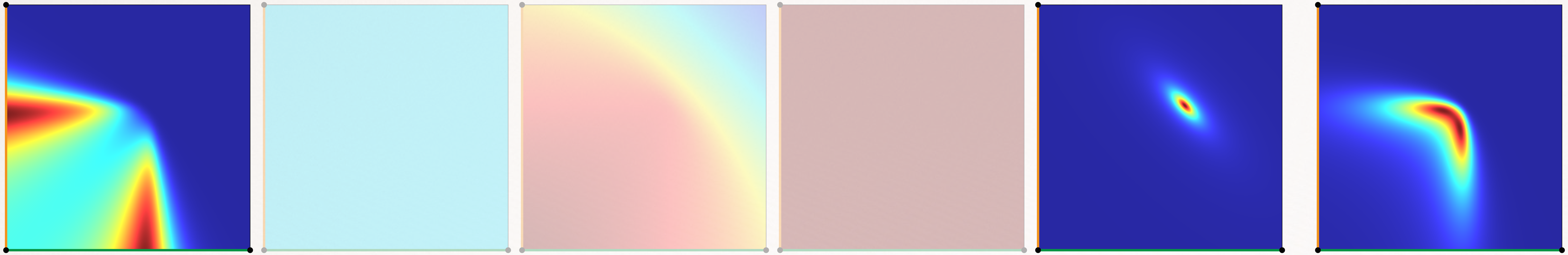


Importance sampling

SIGGRAPH2012

How to (importance) sample?

phase functions × scattering × transmittance × visibility × inverse squared distance = product of all terms

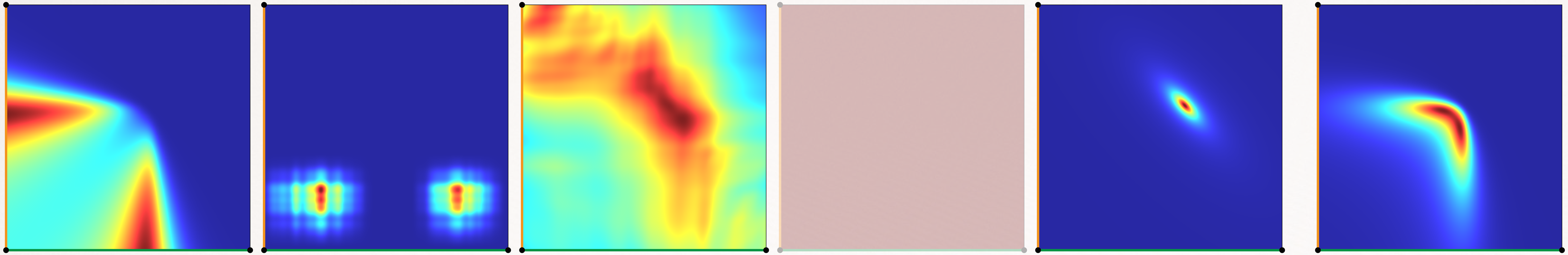


anisotropic homogeneous no occlusion

Importance sampling

SIGGRAPH2012

How to (importance) sample?

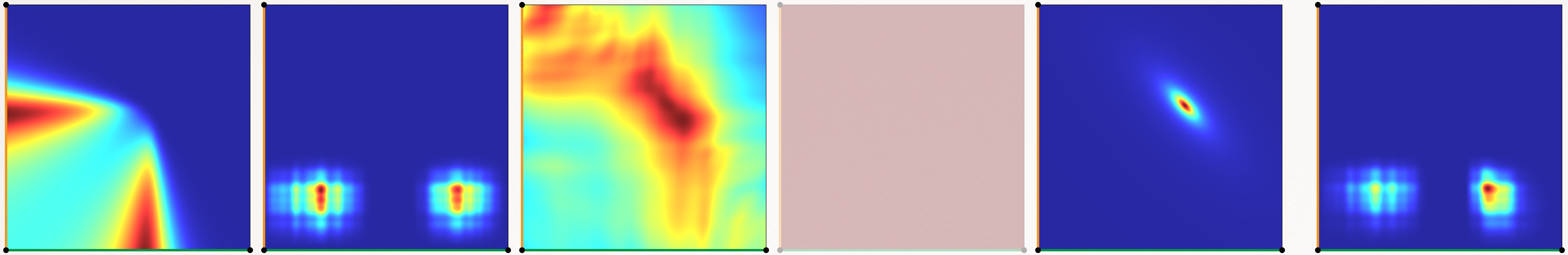


Importance sampling

SIGGRAPH2012

How to (importance) sample?

phase functions × scattering × transmittance × visibility × inverse squared distance = product of all terms

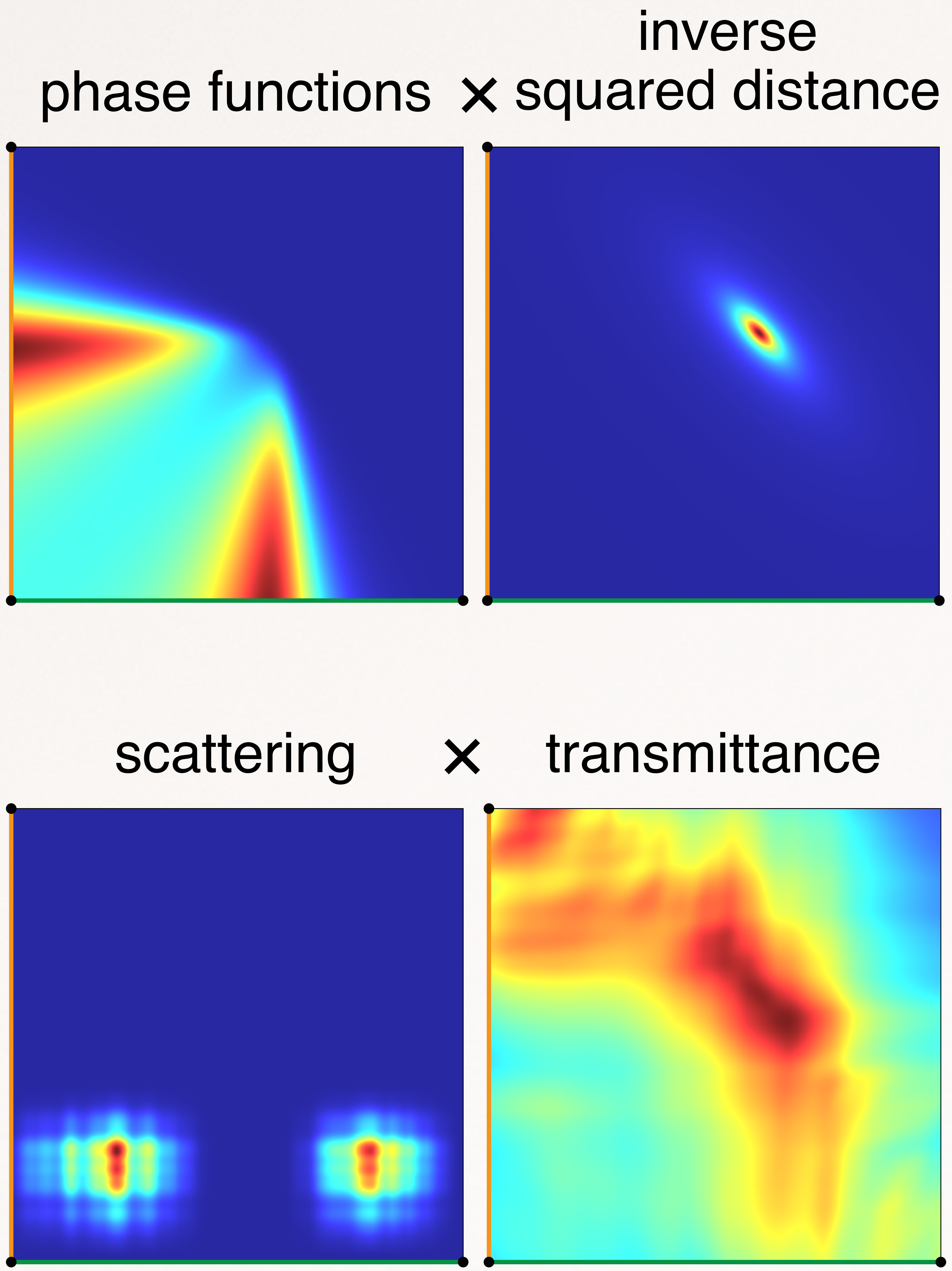


anisotropic heterogeneous no occlusion

Importance sampling

$$\frac{\textbf{anisotropy}}{\textbf{distance}^2}$$

heterogeneity



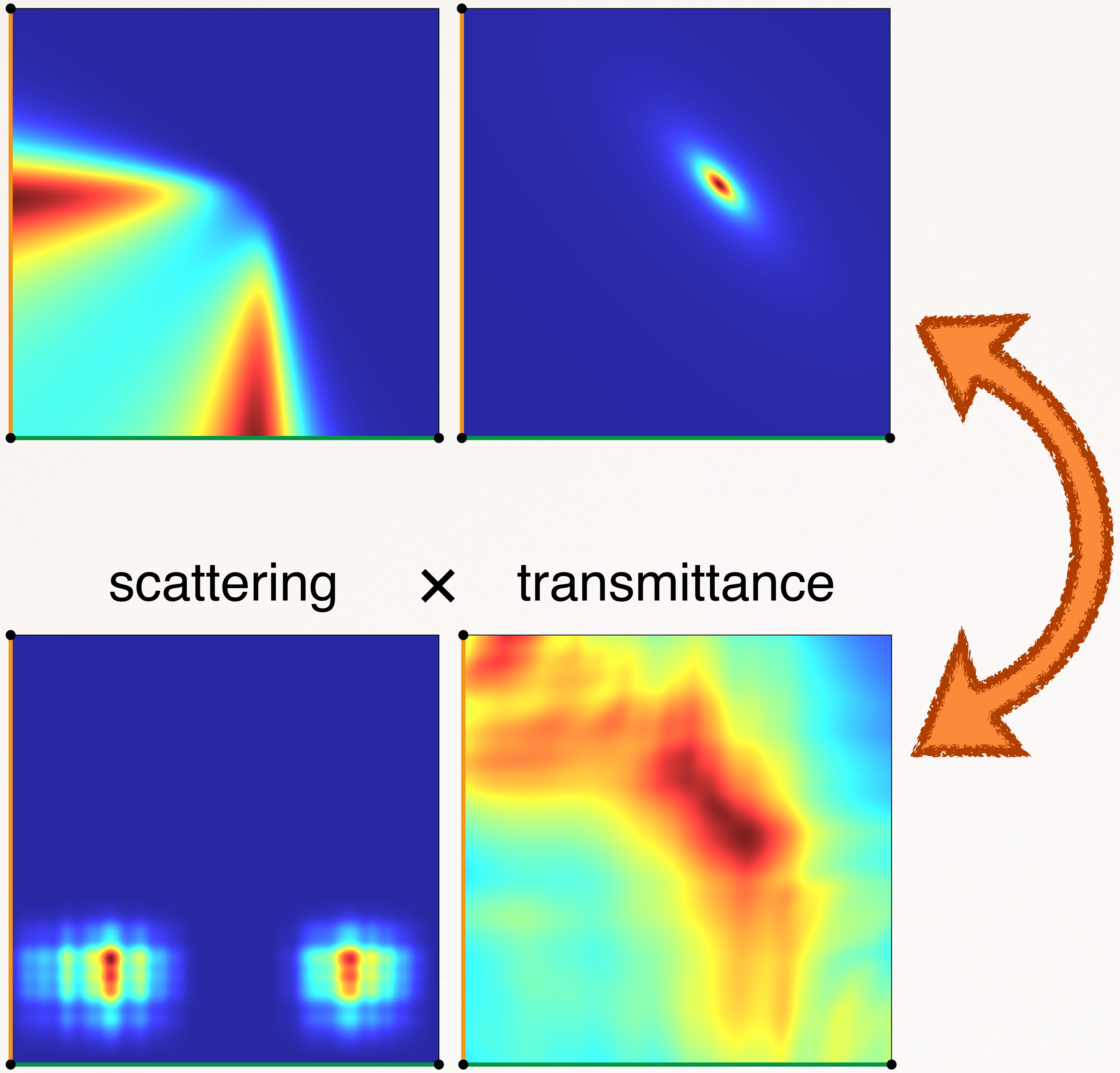
Importance sampling

$$\frac{\textbf{anisotropy}}{\textbf{distance}^2}$$

heterogeneity

phase functions × inverse squared distance

scattering × transmittance



Combine using MIS

Heterogeneity

SIGGRAPH2012

Heterogeneity

SIGGRAPH2012

$$\mathrm{pdf}(u,v) = \sigma_s(u)\,T(u)\;\sigma_s(v)\,T(v)\;T(u,v)$$

Heterogeneity

SIGGRAPH2012

$$\mathrm{pdf}(u, v) = \sigma_s(u)\, T(u)\ \sigma_s(v)\, T(v)\ T(u, v)$$

Heterogeneity

SIGGRAPH2012

$$\text{pdf}(u,v) = \underbrace{\sigma_s(u)\,T(u)}_{\text{along camera ray}}\;\underbrace{\sigma_s(v)\,T(v)}_{\text{along VRL}}\;T(u,v)$$

Separable!

Heterogeneity

SIGGRAPH2012

$$\text{pdf}(u,v) = \underbrace{\sigma_s(u)\,T(u)}_{\text{along camera ray}}\;\underbrace{\sigma_s(v)\,T(v)}_{\text{along VRL}}\;T(u,v)$$

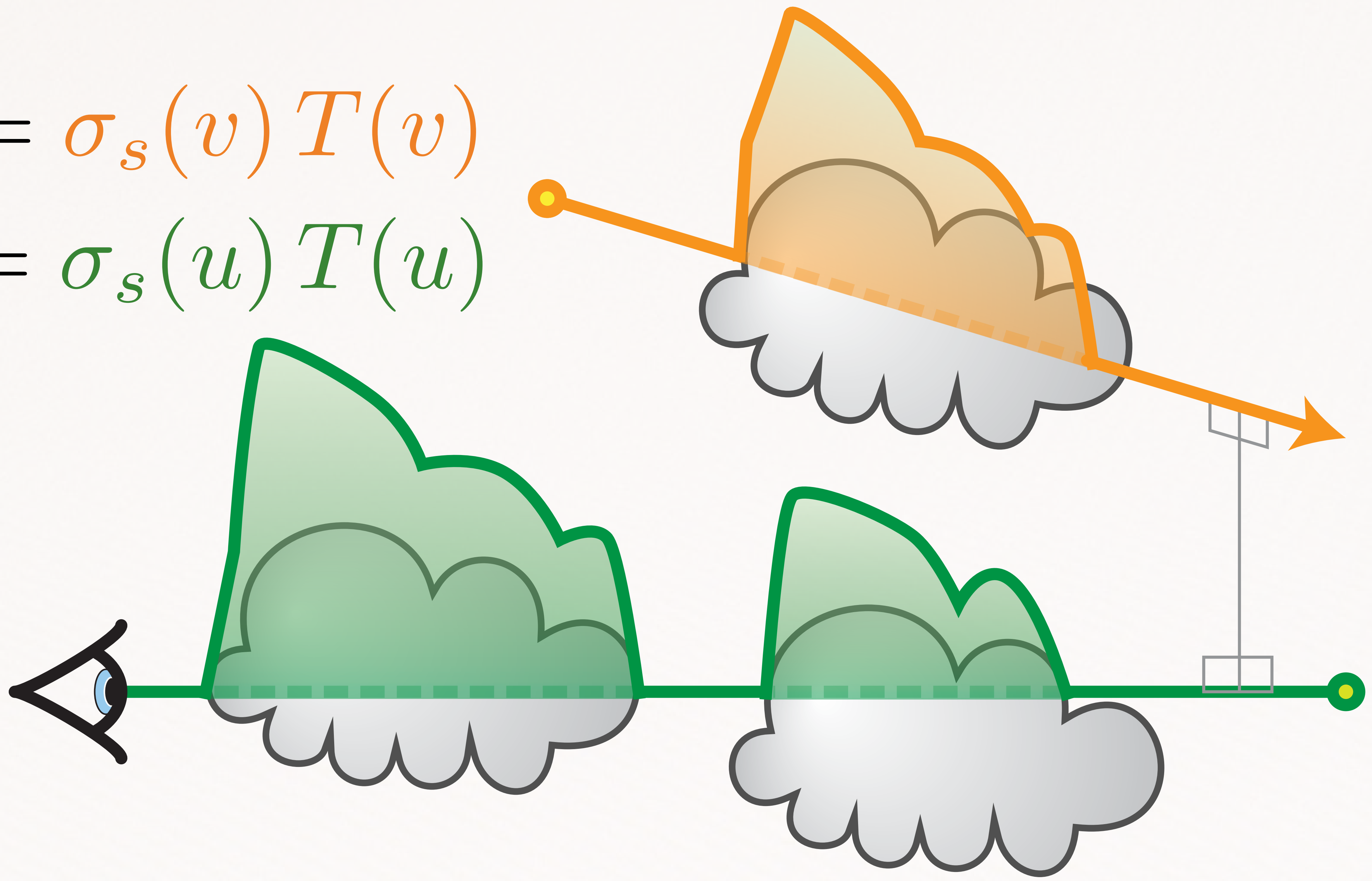
along camera ray

along VRL

Separable!

$$\text{pdf}(v) = \sigma_s(v)\,T(v)$$

$$\text{pdf}(u) = \sigma_s(u)\,T(u)$$

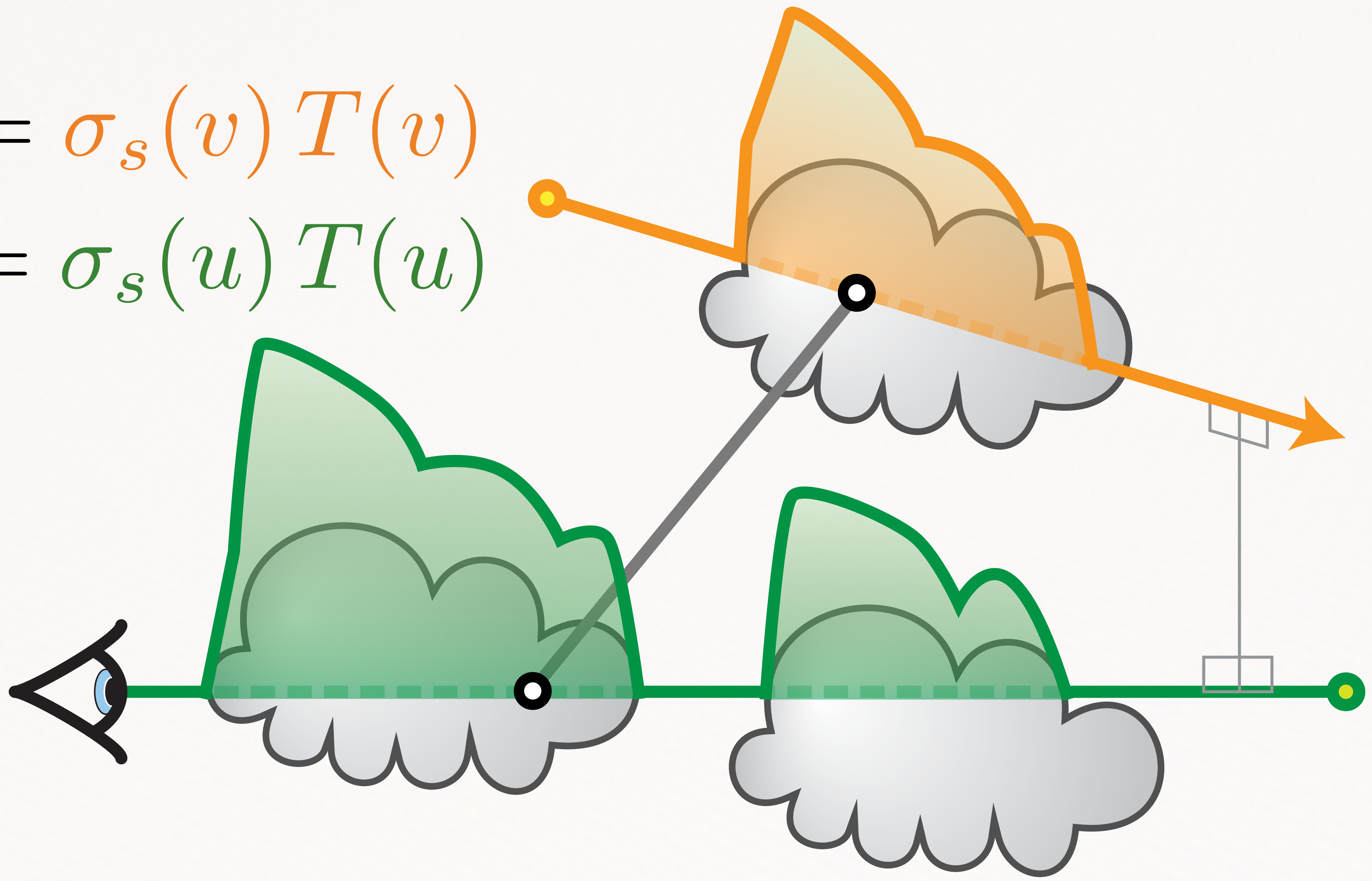


Heterogeneity

$$\mathrm{pdf}(u, v) = \underbrace{\sigma_s(u)\, T(u)}_{\text{along camera ray}}\ \underbrace{\sigma_s(v)\, T(v)}_{\text{along VRL}}\ T(u, v)$$

Separable!

$$\mathrm{pdf}(v) = \sigma_s(v)\, T(v)$$
$$\mathrm{pdf}(u) = \sigma_s(u)\, T(u)$$

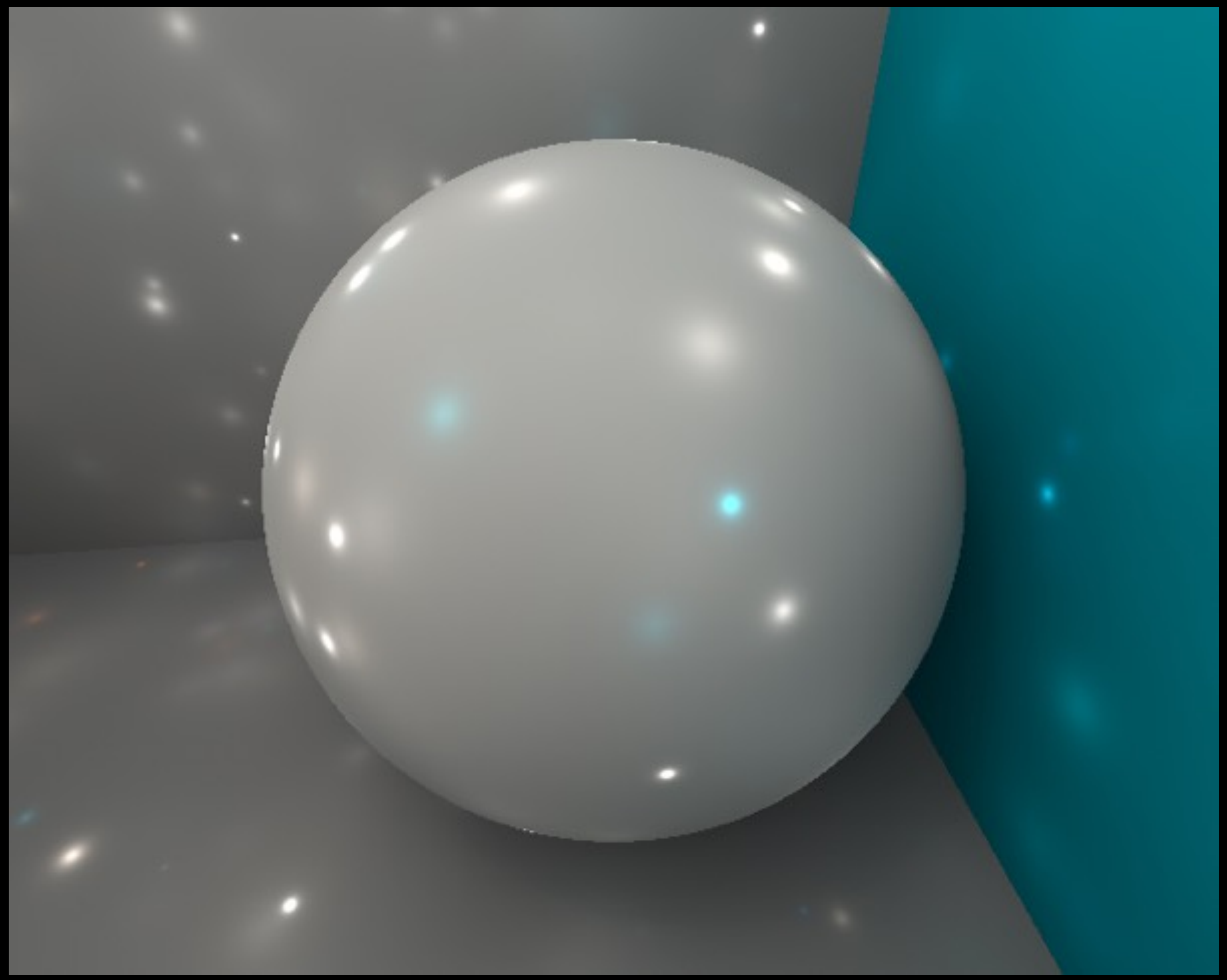


Analysis and Results

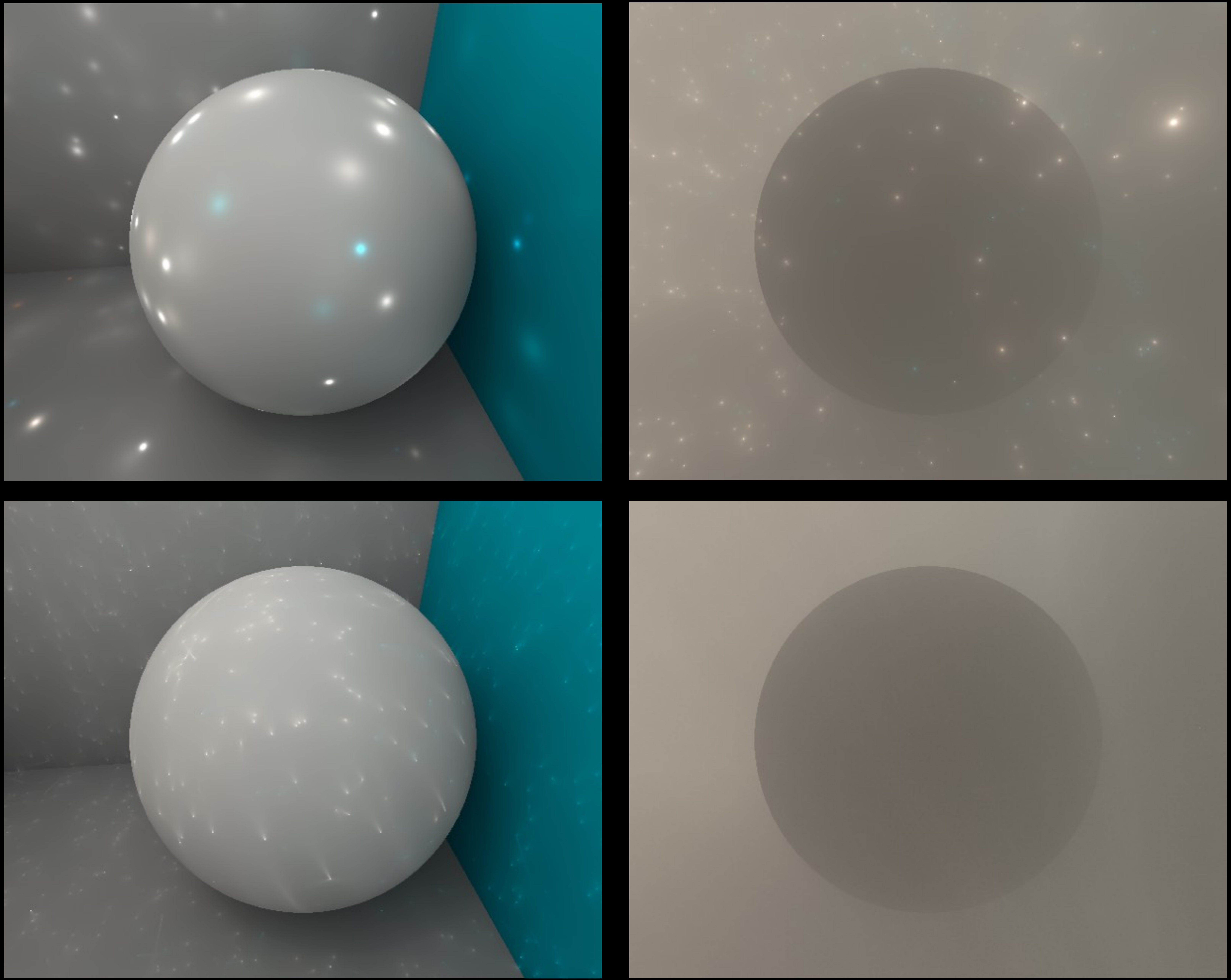
Analysis and Results

1. Analysis of singularities
   - **VRLs** vs. **VPLs**

2. Example renders
   - **VRLs** vs. **VPLs** vs. **Progressive Photon Beams**

	Media-to-Surface	**Media-to-Media**
Virtual **Point** Lights		

	Media-to-Surface	**Media-to-Media**
Virtual **Point** Lights		
Virtual **Ray** Lights (our method)		

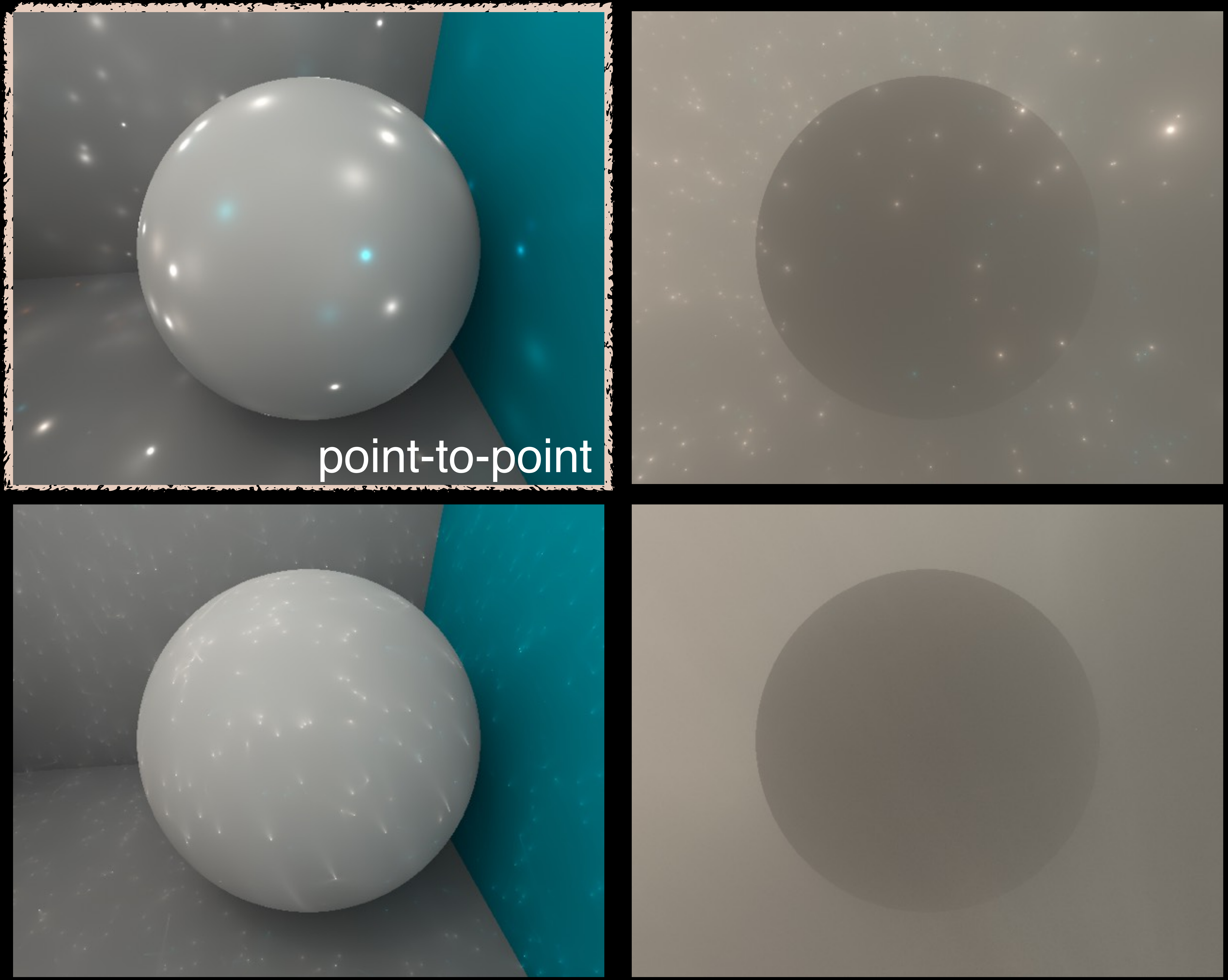


equal time comparison

Media-to-Surface | **Media-to-Media**

Virtual **Point** Lights

Virtual **Ray** Lights (our method)



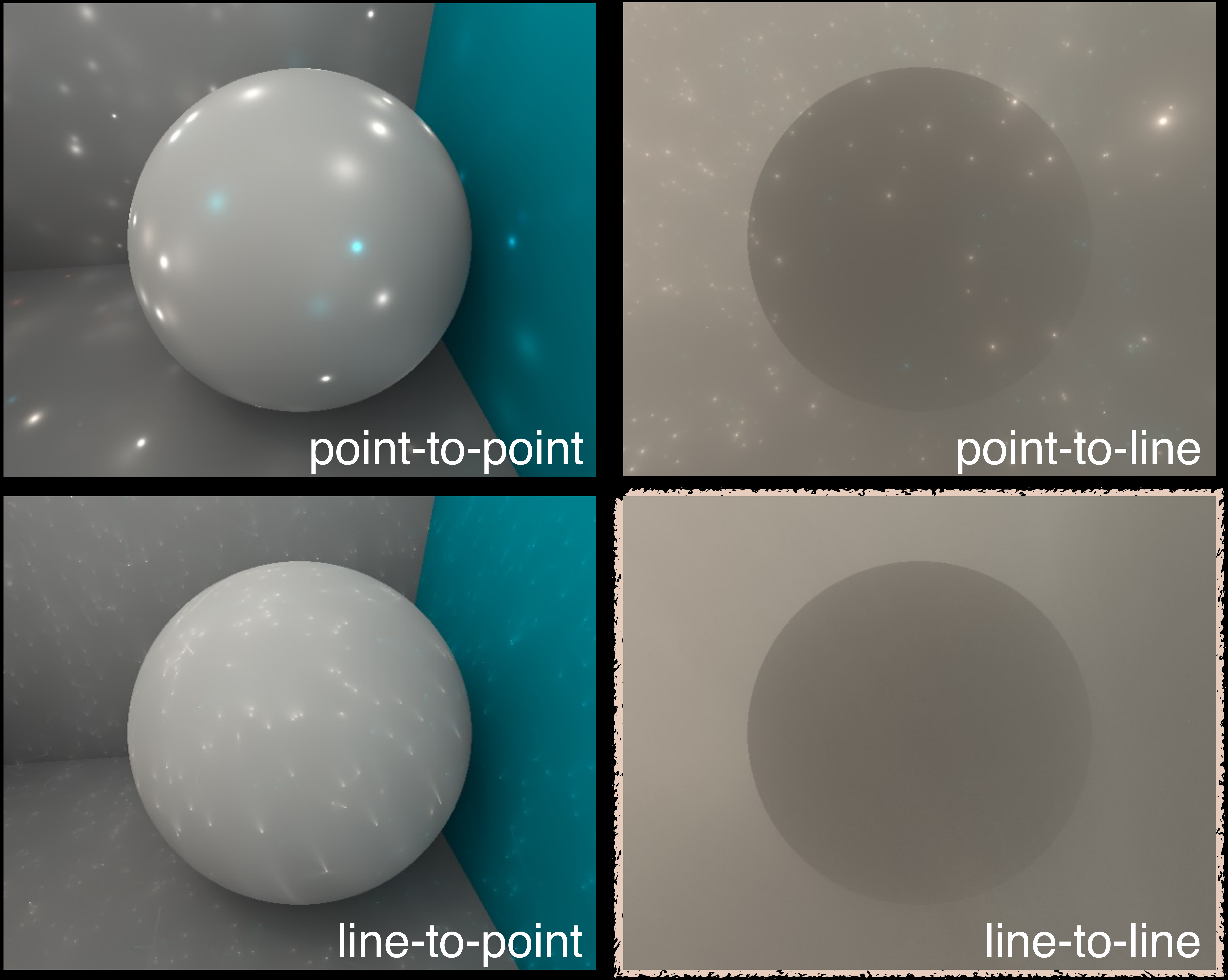
equal time comparison

Media-to-Surface
Media-to-Media
Virtual **Point** Lights
Virtual **Ray** Lights (our method)
point-to-point
point-to-line
line-to-point
equal time comparison

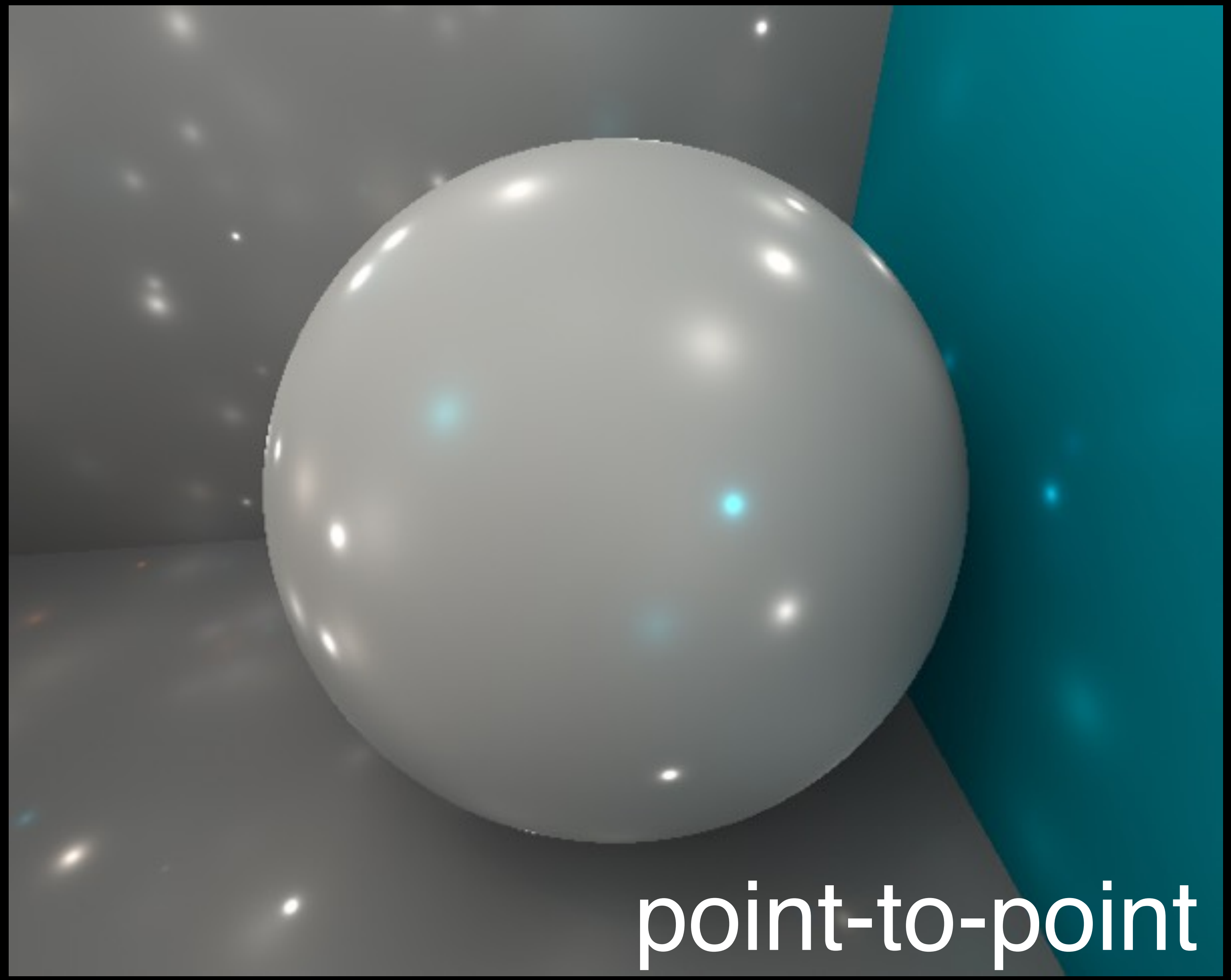
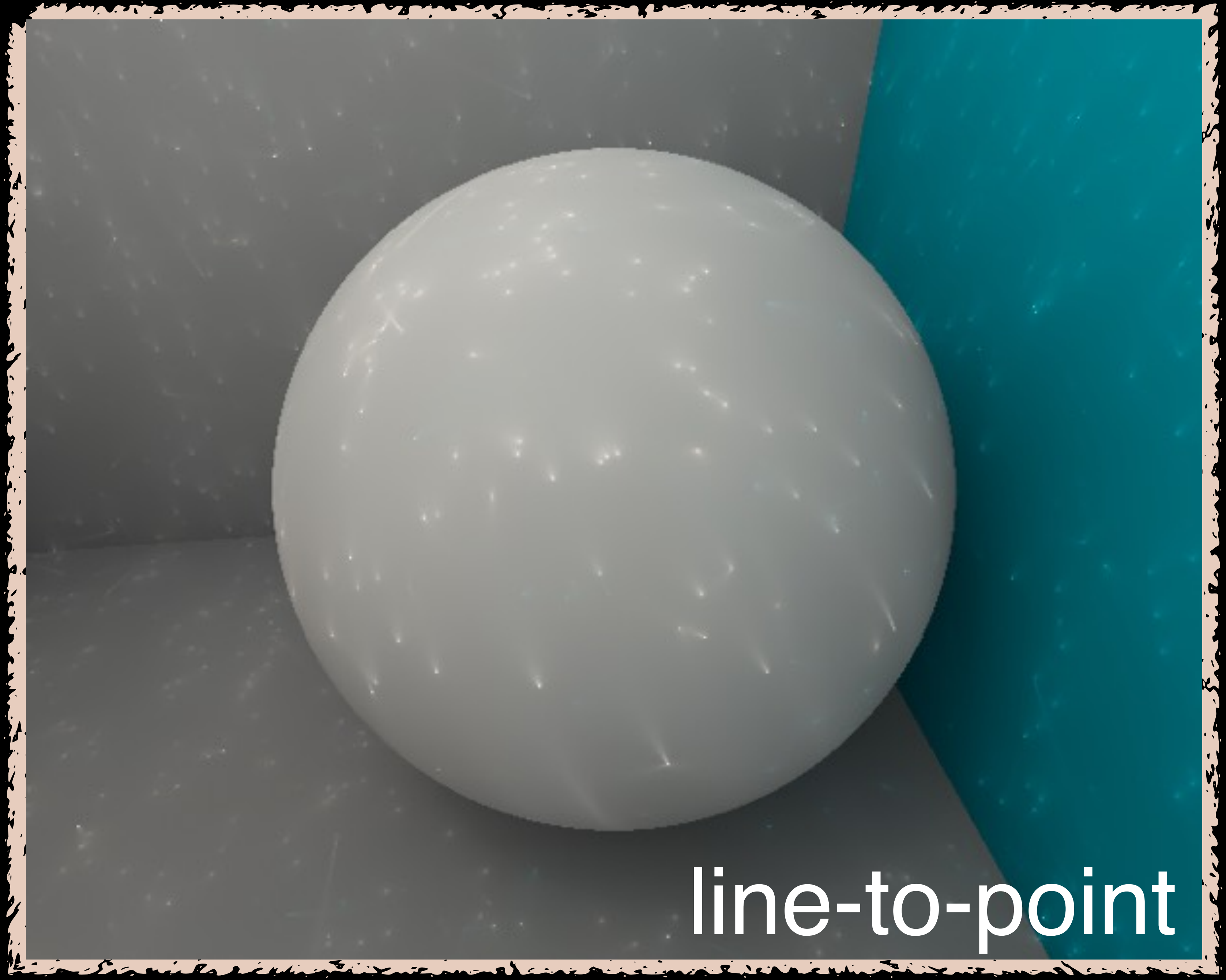
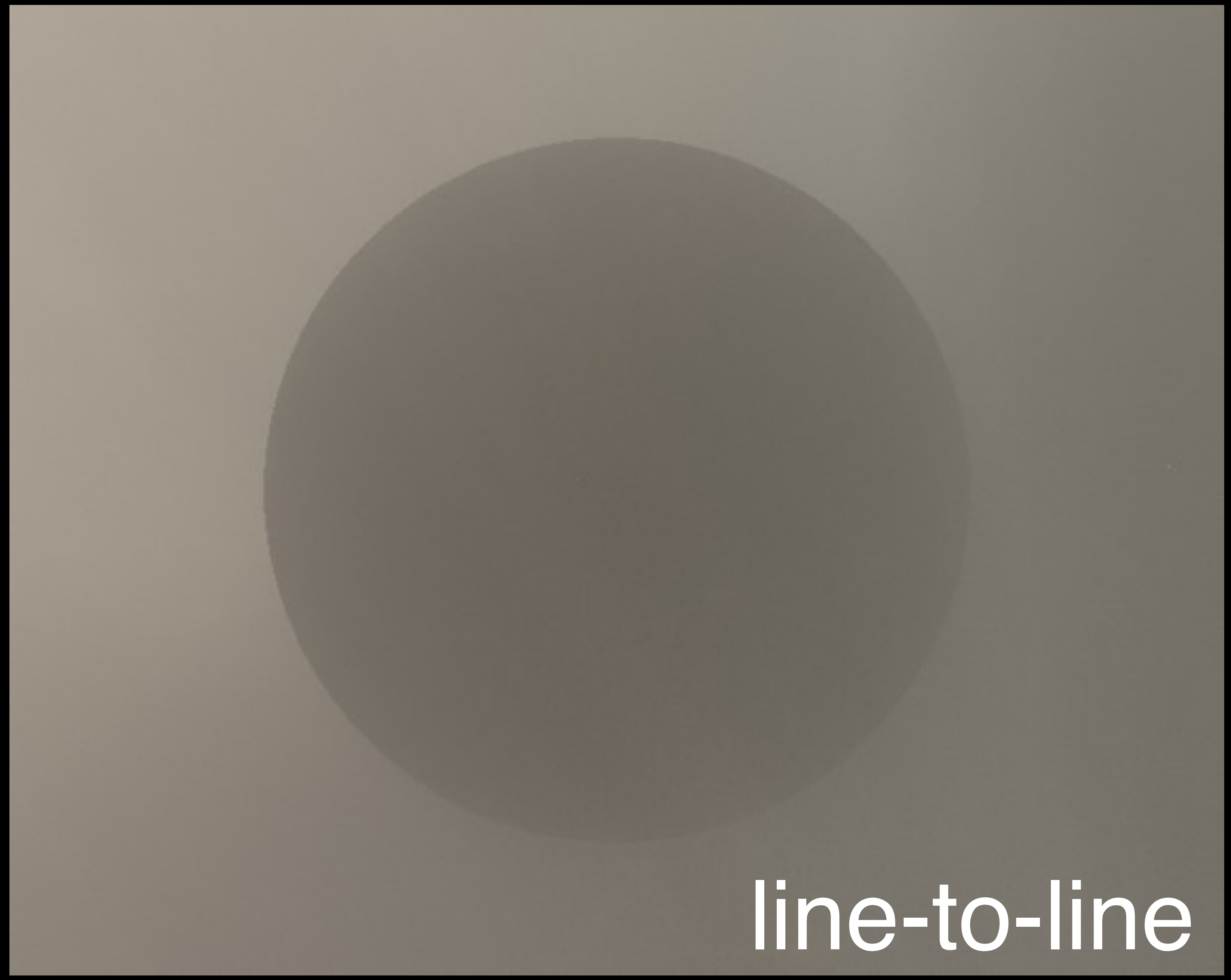
Media-to-Surface | Media-to-Media

Virtual **Point** Lights

Virtual **Ray** Lights (our method)



equal time comparison

	Media-to-Surface	**Media-to-Media**	
Virtual **Point** Lights			equal time comparison
Virtual **Ray** Lights (our method)			

Fruit Juice

homogeneous

anisotropic (HG g = 0.55)

512x512

Surface illumination
Photon Mapping

Single scattering
Photon Beams

Multiple scattering

Multiple scattering

Multiple Scattering

Virtual Ray Lights

Progressive Photon Beams

Virtual Point Lights

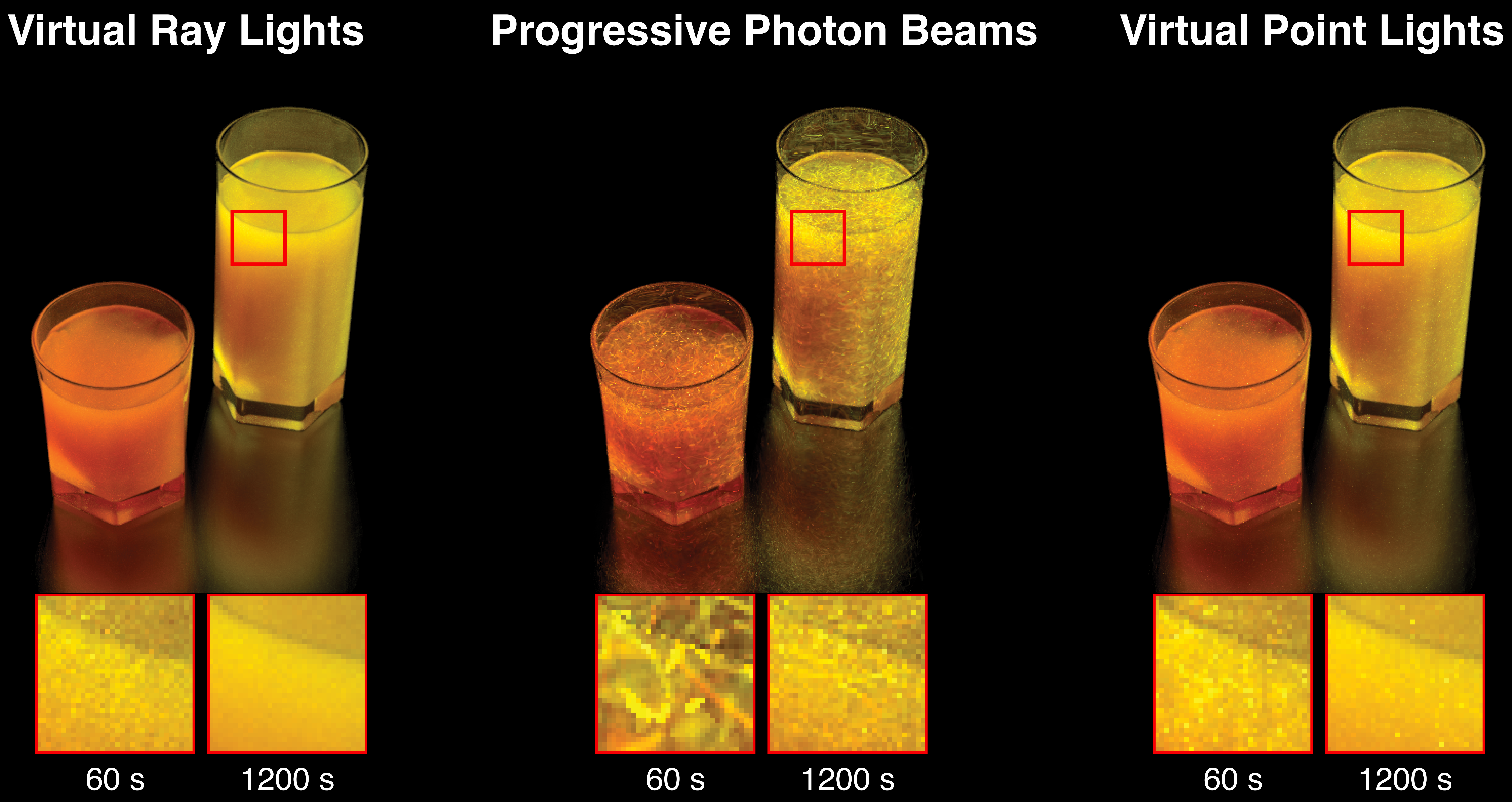
Multiple Scattering

Virtual Ray Lights | Progressive Photon Beams | Virtual Point Lights

4K VRLs | 1K beams | 4K VPLs

6 seconds

Multiple Scattering



Smoky Room

heterogeneous

1280x720

Media-to-Media

Virtual Ray Lights | Progressive Photon Beams | Virtual Point Lights

Media-to-Media

Virtual Ray Lights

6K VRLs

Progressive Photon Beams

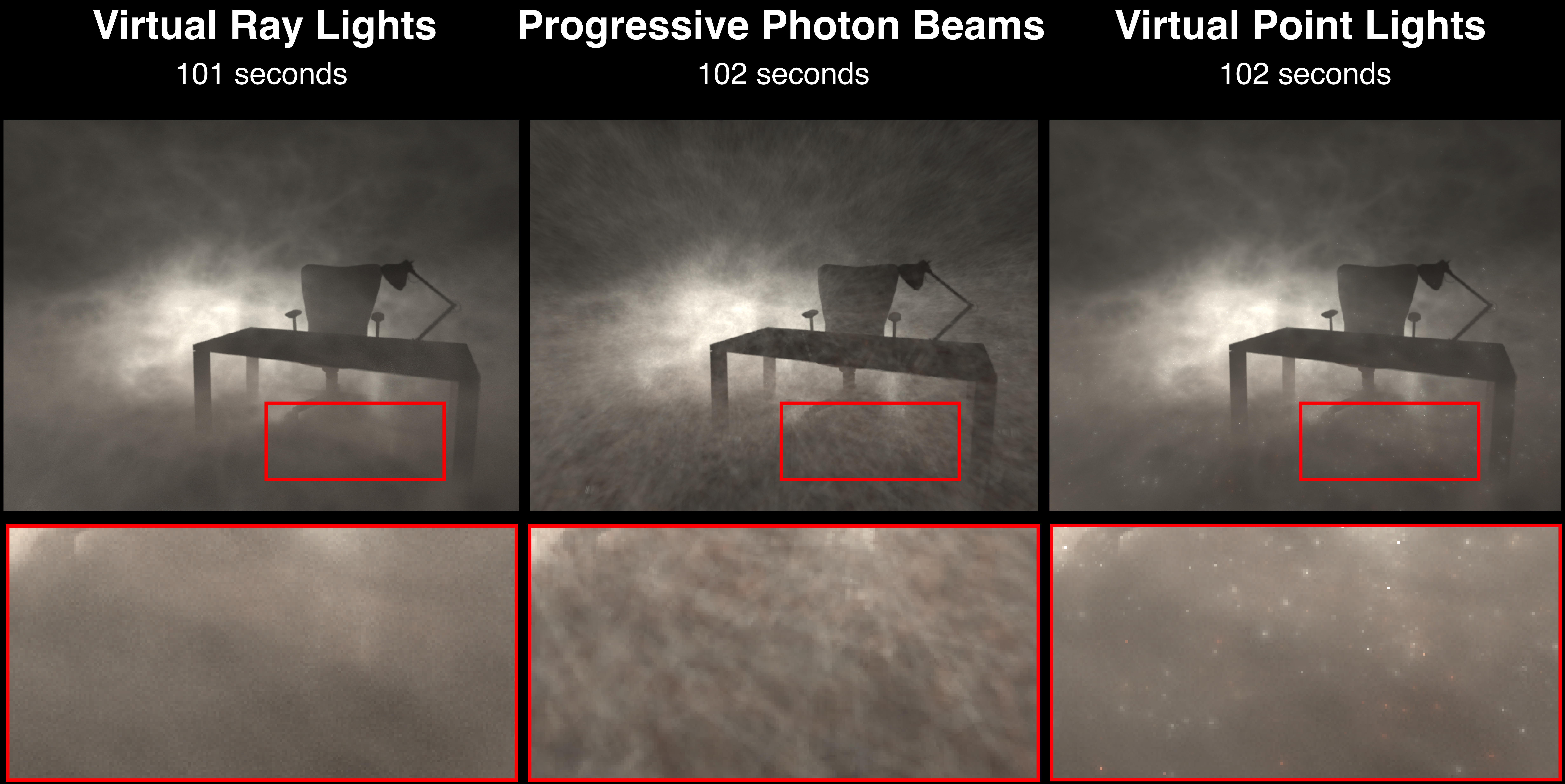
142K beams

Virtual Point Lights

8K VPLs

5 seconds

Media-to-Media



Media-to-Surface

Virtual Ray Lights

600 seconds

Virtual Point Lights

600 seconds

Temporal coherence
VPLs vs. VRLs

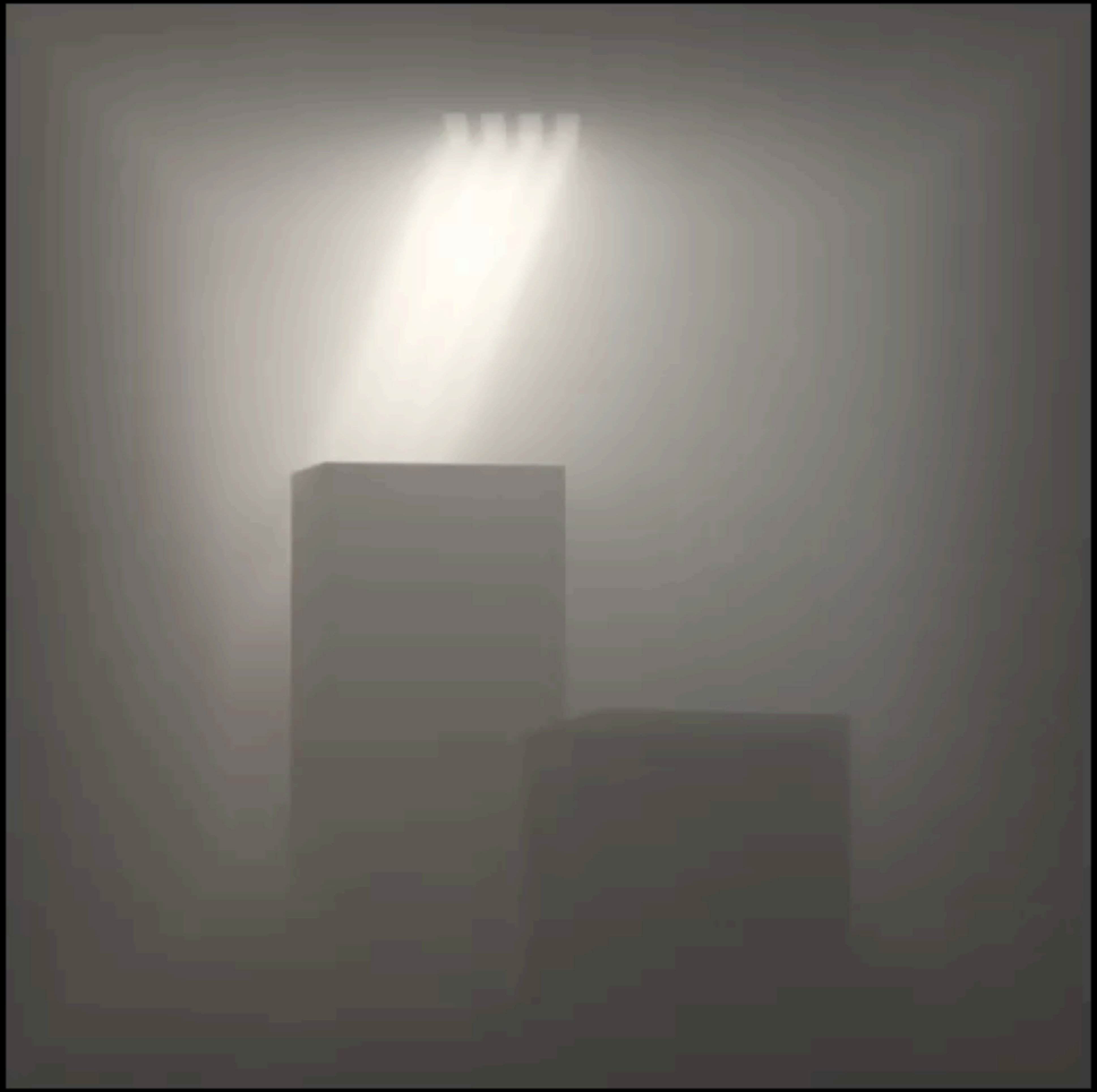
Media-to-Media

Virtual Ray Lights

Virtual Point Lights

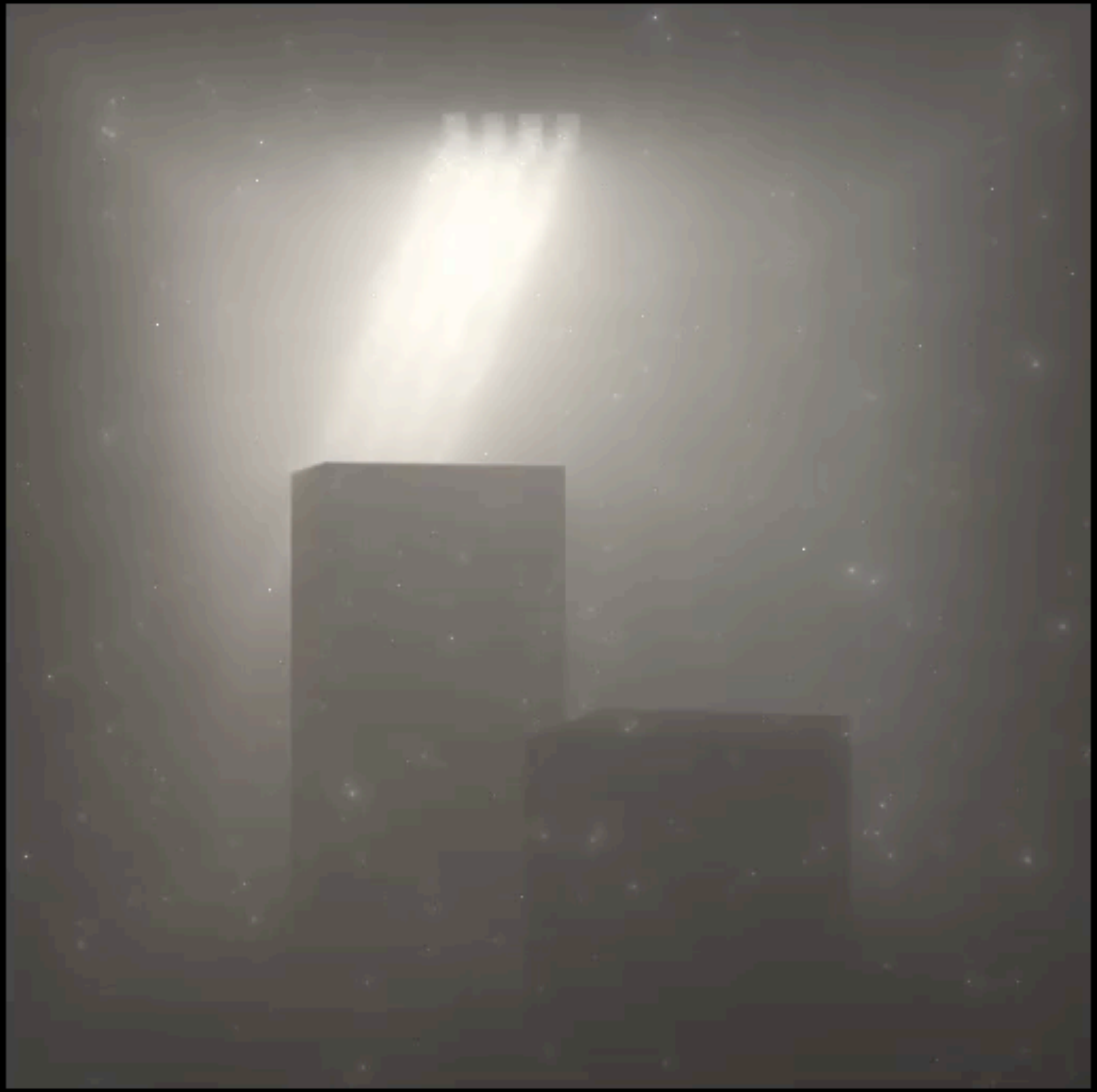
Media-to-Media

Virtual Ray Lights



1 minute/frame

Virtual Point Lights



1 minute/frame

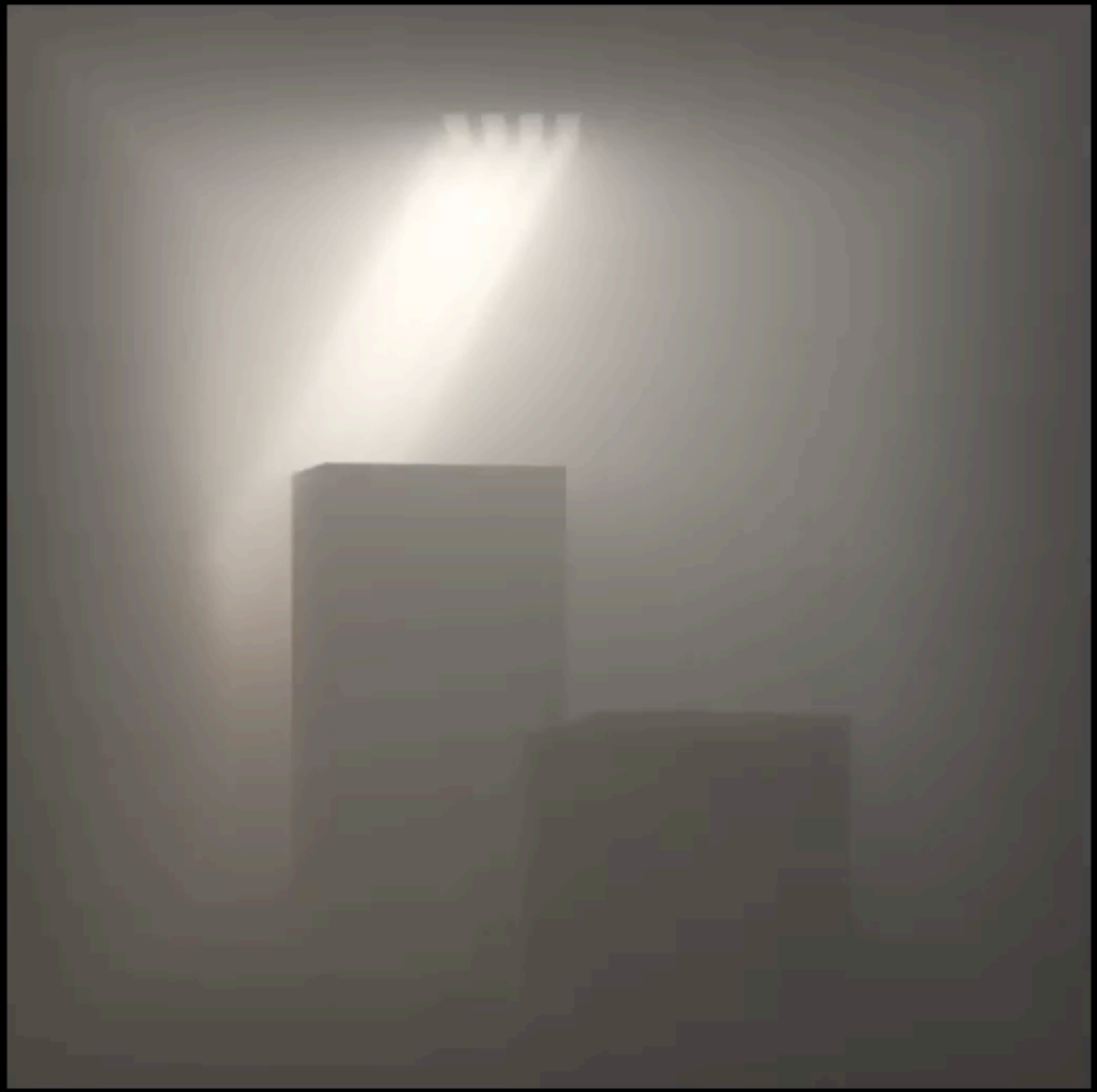
Media-to-Media

Virtual Ray Lights

Virtual Point Lights

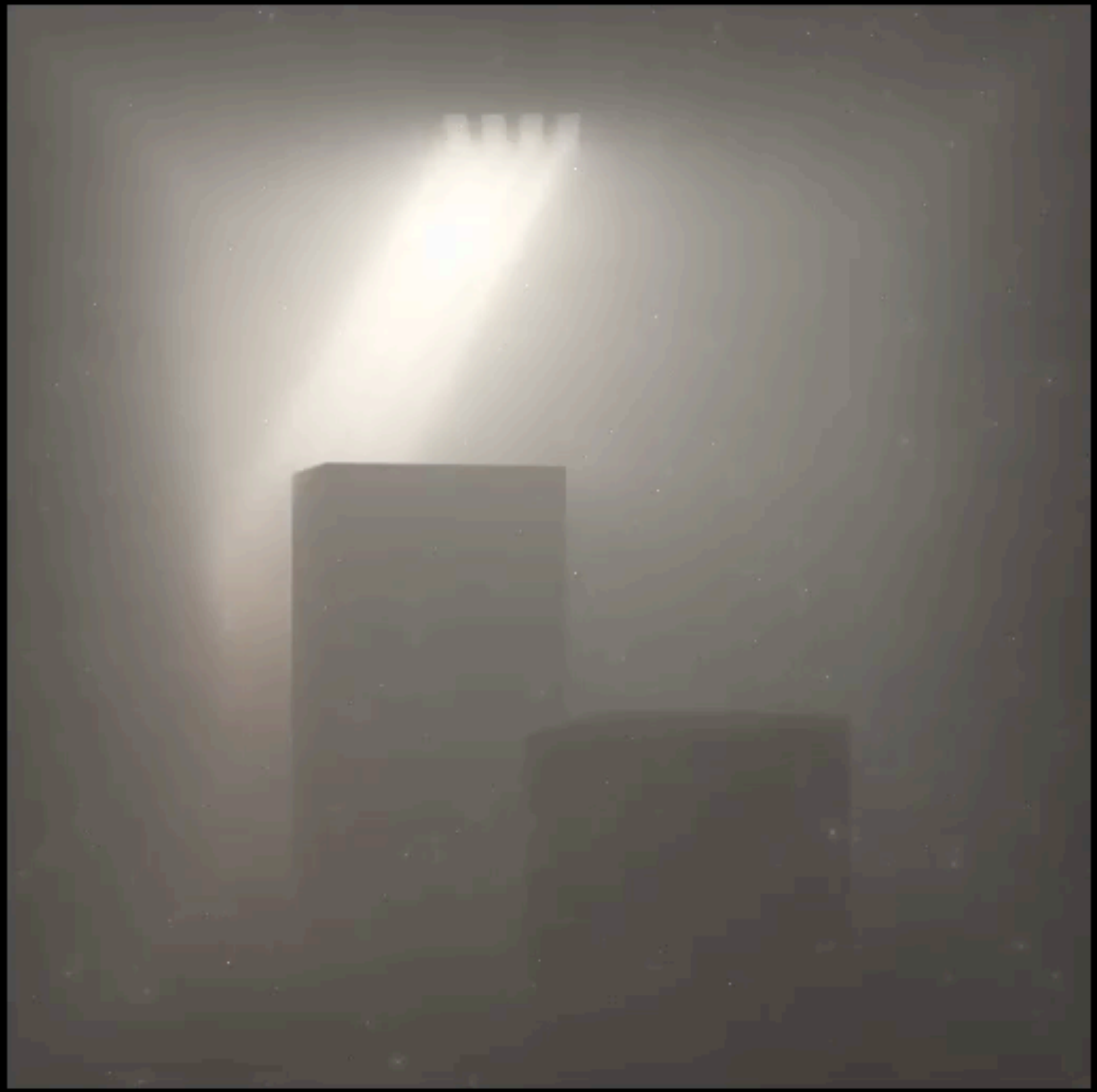
Media-to-Media

Virtual Ray Lights



1 minute/frame

Virtual Point Lights



3 minutes/frame

Conclusion

SIGGRAPH2012

Conclusion

SIGGRAPH2012

- **Virtual Ray Lights**
  - turn **segments** of a light path into light sources
  - importance sampling
  - easily integrates into existing PM frameworks, GPU friendly!

Future work

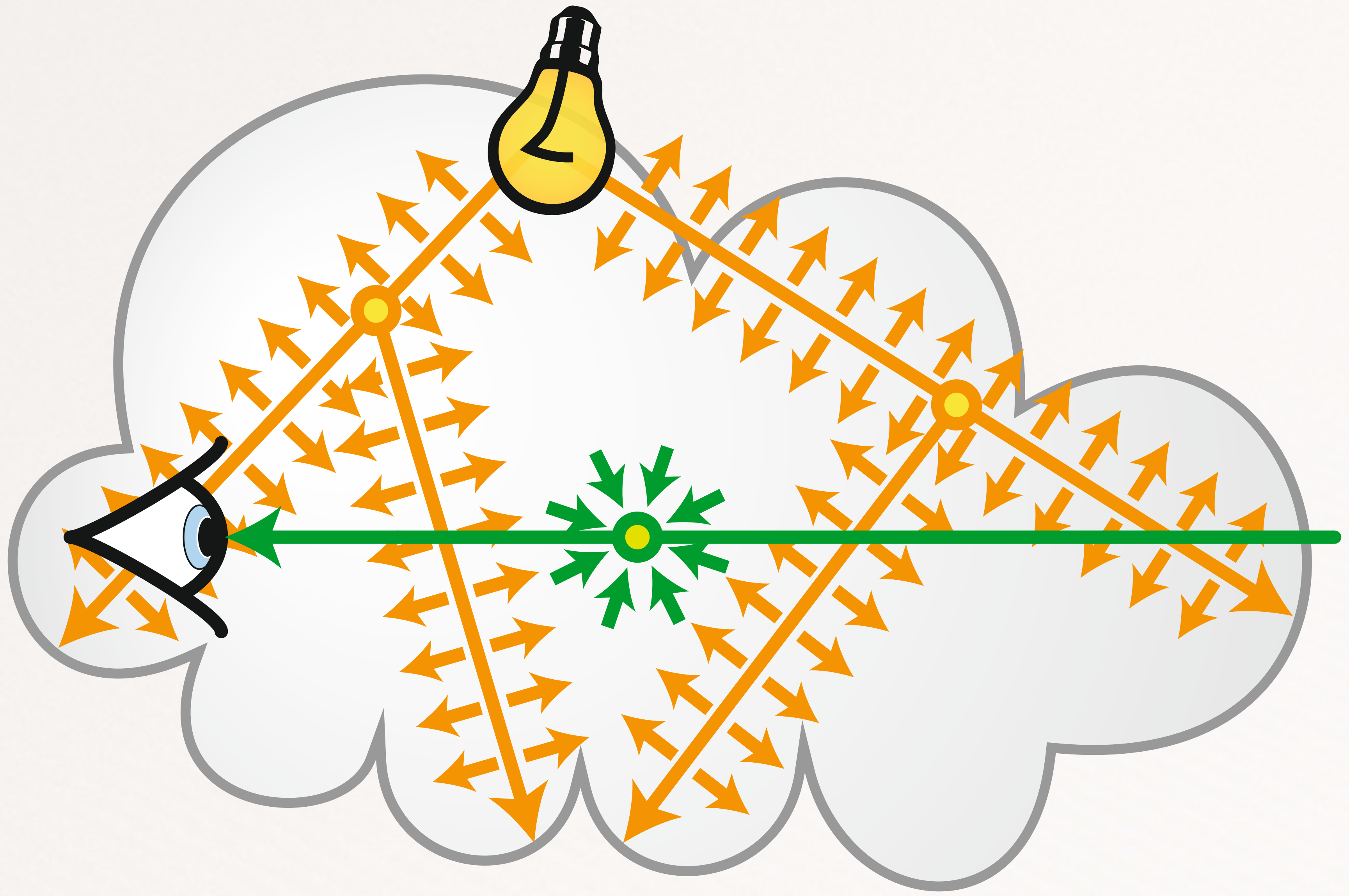
SIGGRAPH2012

Future work

SIGGRAPH2012

ams

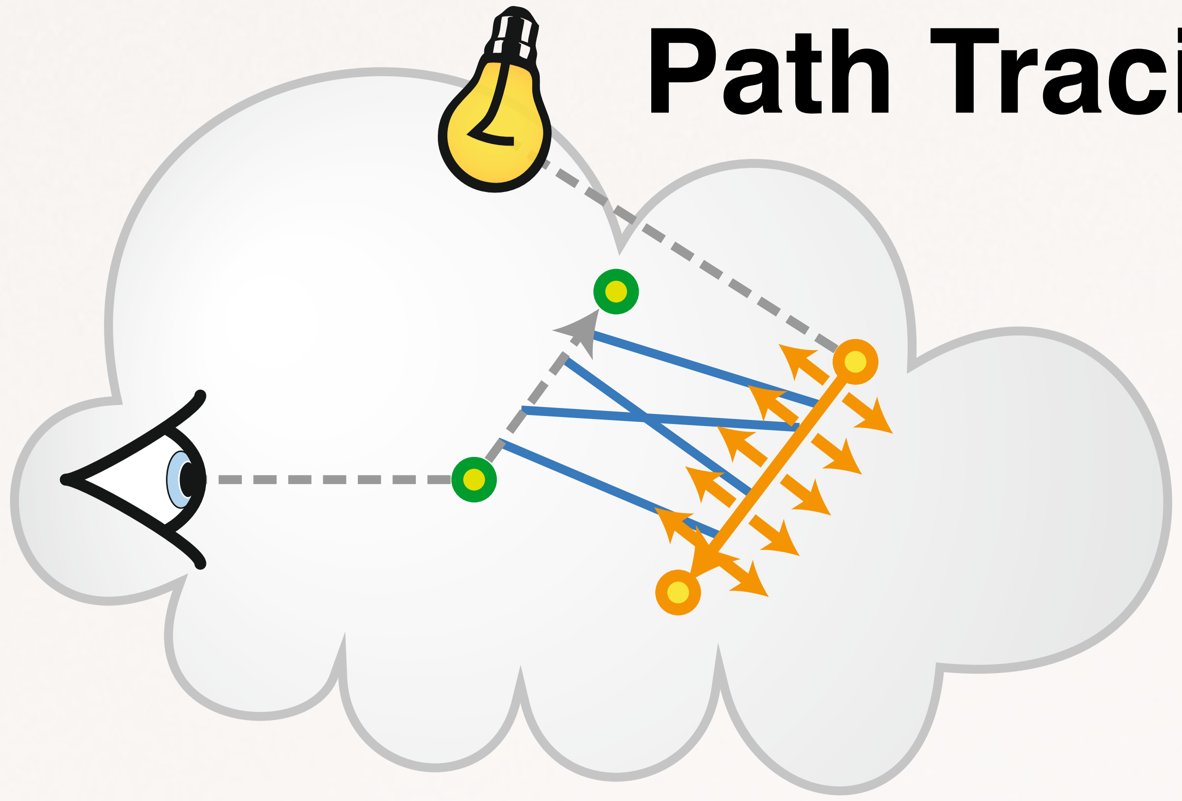
Virtual Ray Lights



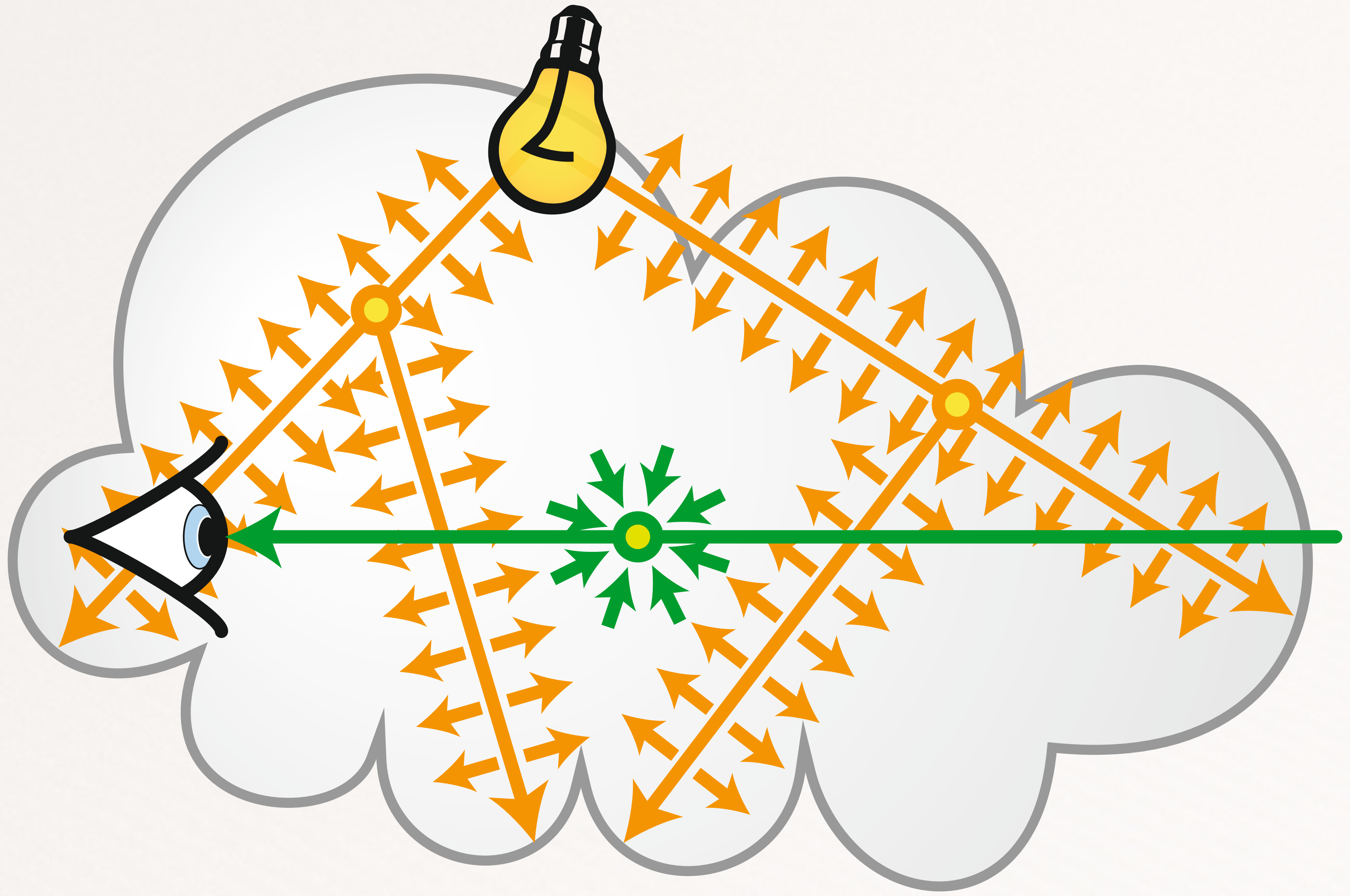
Future work

ams

Bidirectional Volumetric
Path Tracing



Virtual Ray Lights



Future work

SIGGRAPH2012

Future work

SIGGRAPH2012

Let’s have a break...

Thank you!