TOWARDS PRACTICAL PHYSICAL-OPTICS RENDERING

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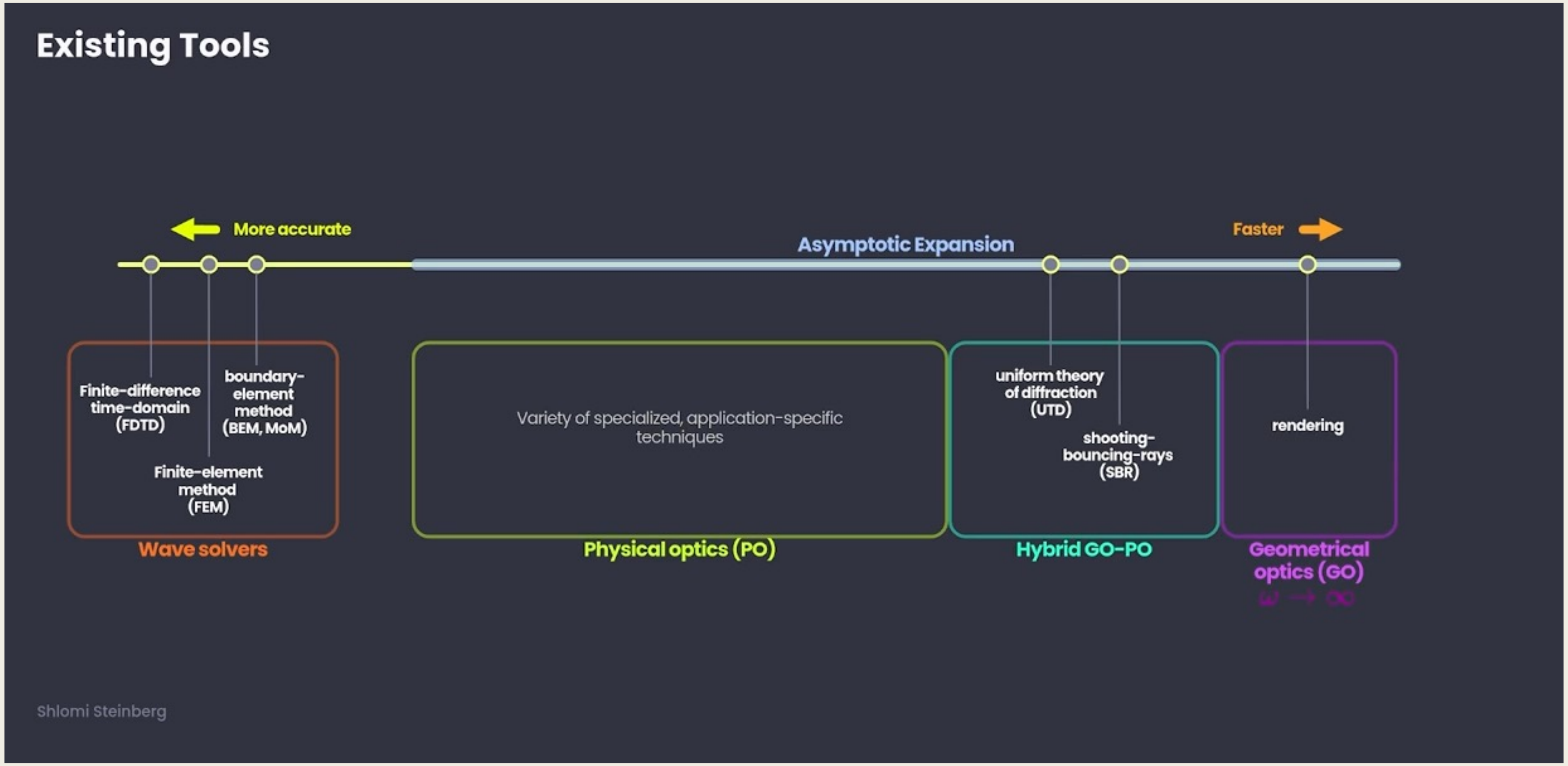
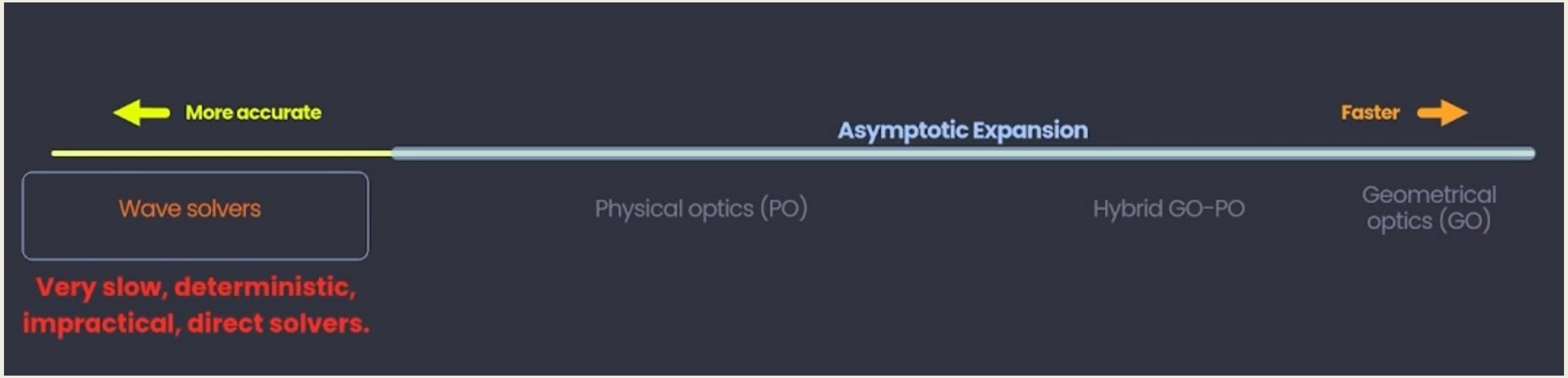
Important related work

- By same author
- Shlomi Steinberg and Ling-Qi Yan. 2021a. A Generic Framework for Physical Light Transport. ACM Transactions on Graphics 40, 4 (Aug 2021),
- Shlomi Steinberg and Ling-Qi Yan. 2021b. Physical Light-Matter Interaction in Hermite-Gauss Space. ACM Trans. Graph. 40, 6, Article 283 (dec 2021),

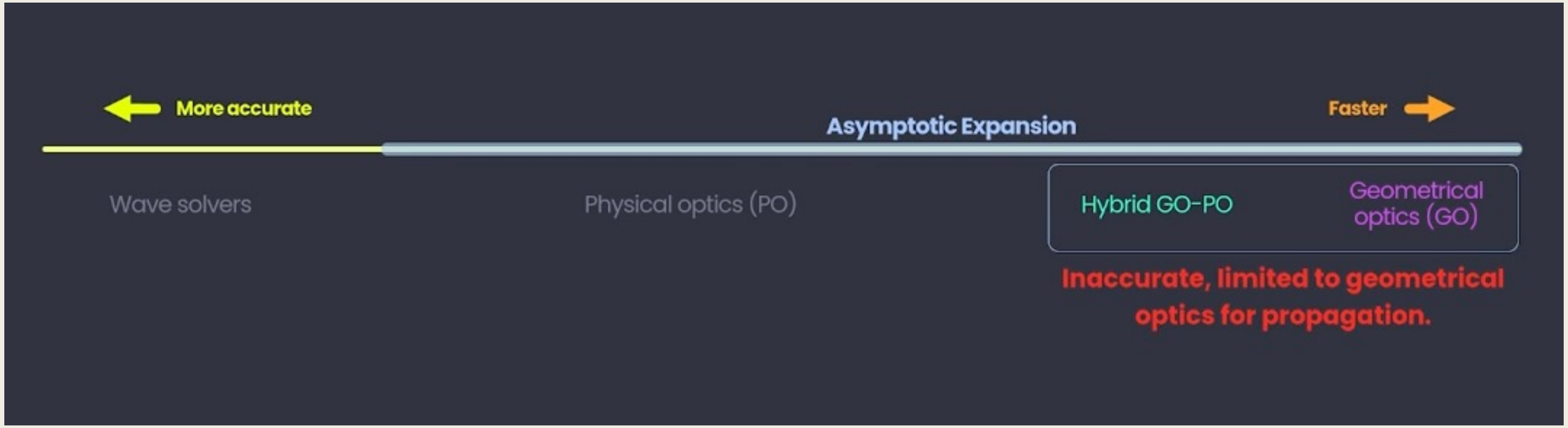
Motivation


Existing Tools
More accurate
Asymptotic Expansion
Faster
Finite-difference time-domain (FDTD)
boundary-element method (BEM, MoM)
Finite-element method (FEM)
Wave solvers
Variety of specialized, application-specific techniques
Physical optics (PO)
uniform theory of diffraction (UTD)
shooting-bouncing-rays (SBR)
Hybrid GO-PO
rendering
Geometrical optics (GO)
Shlomi Steinberg

Motivation


More accurate
Faster
Asymptotic Expansion
Wave solvers
Physical optics (PO)
Hybrid GO-PO
Geometrical optics (GO)
Very slow, deterministic, impractical, direct solvers.

Motivation



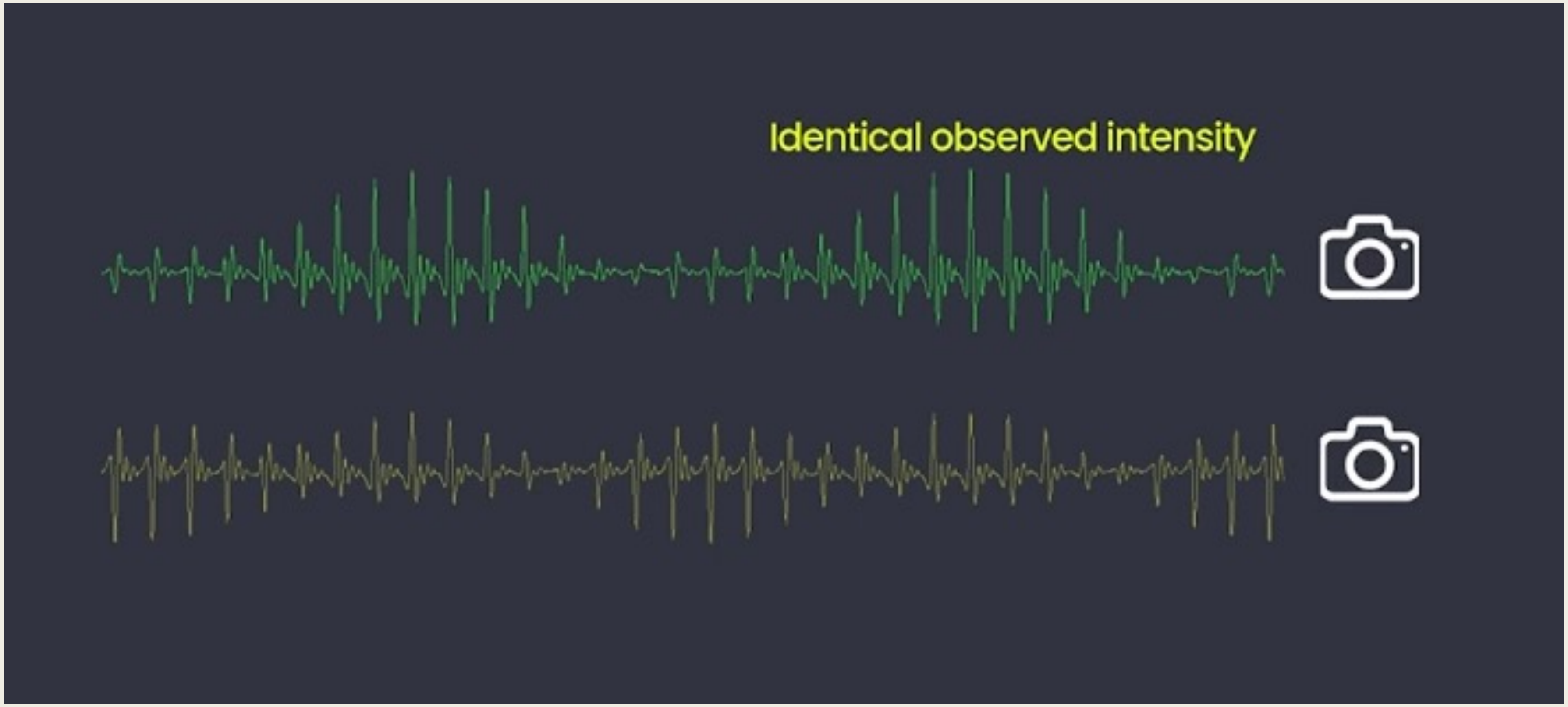
More accurate
Asymptotic Expansion
Faster
Wave solvers
Physical optics (PO)
Hybrid GO-PO
Geometrical optics (GO)
Inaccurate, limited to geometrical optics for propagation.

Motivation

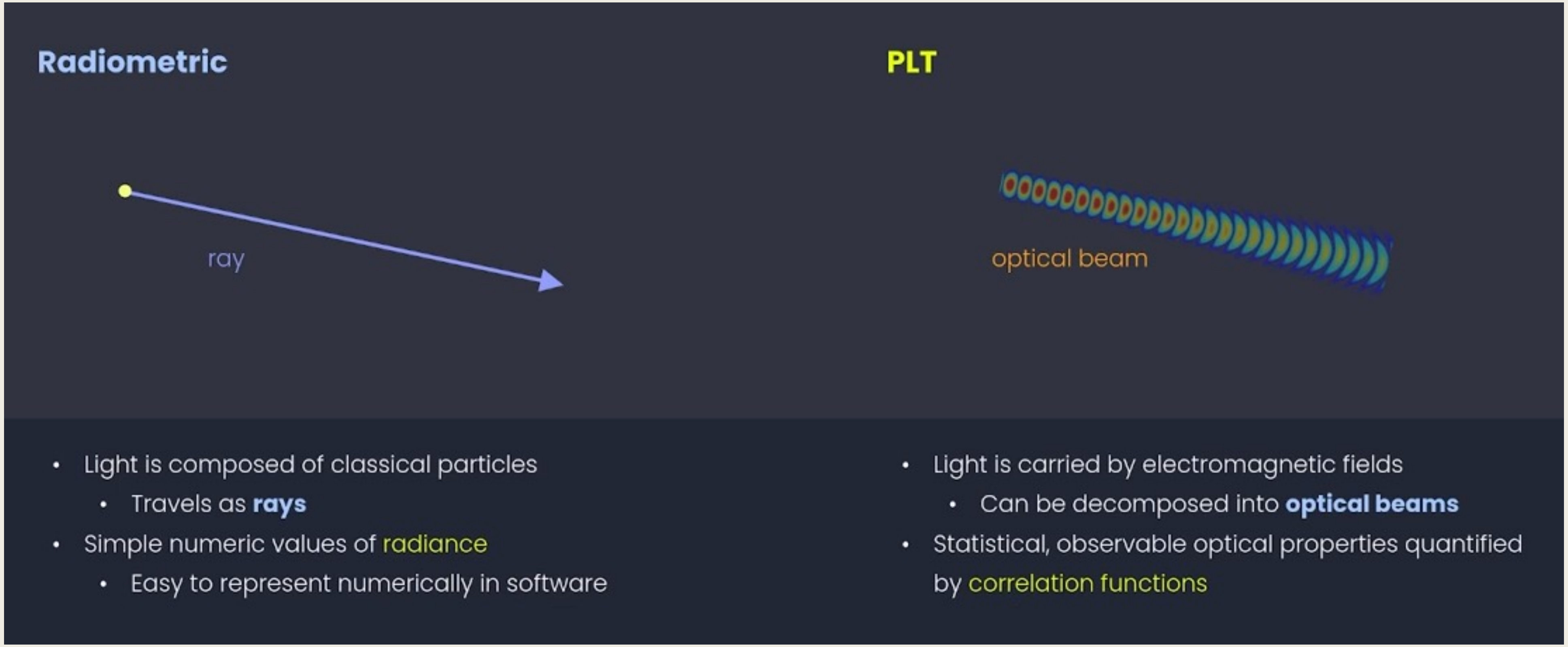
Background
Physical Light Transport - PLT

- Introduced in Shlomi Steinberg and Ling-Qi Yan. 2021a. A Generic Framework for Physical Light Transport. ACM Transactions on Graphics 40, 4 (Aug 2021),
- PLT based on Maxwell's electromagnetic theory

Light wave



Radiometric vs PLT

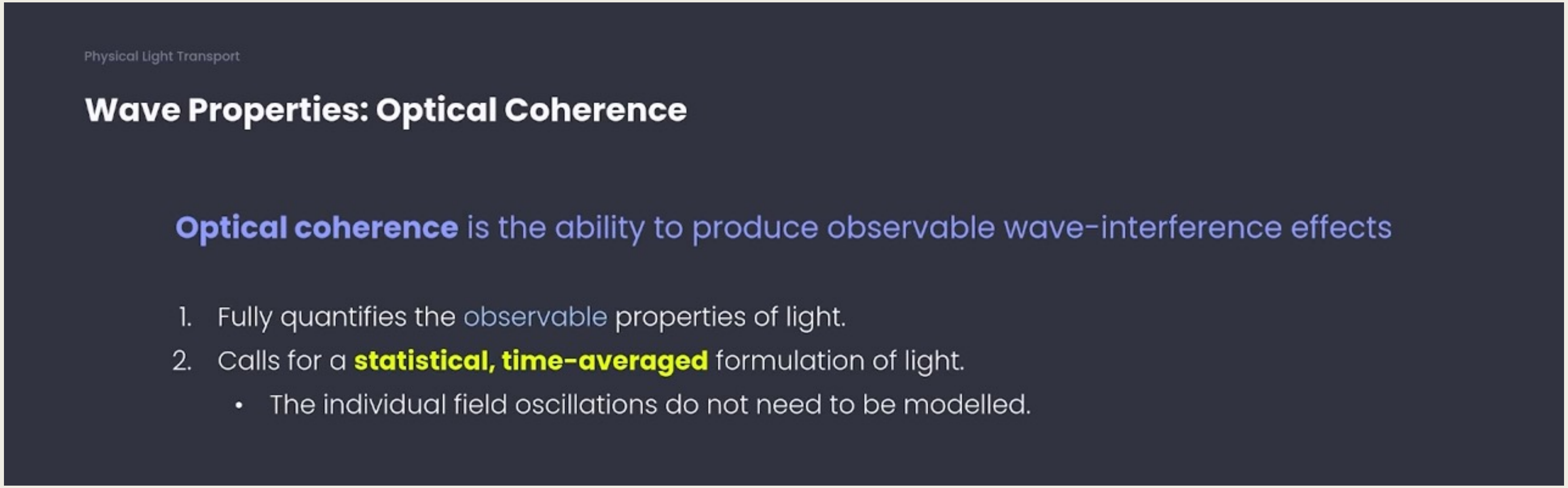


Global vs Local Treament

- A local treatment means that some form or formalism of wave optics is applied locally,
  - *We forget that light is composed of electromagnetic wave*
  - *We neglect and discard important wave properties of light on propagation*
  - *Accurate reproduction of wave effects requires information unavailable to hybrid methods.*

Global vs Local Treament

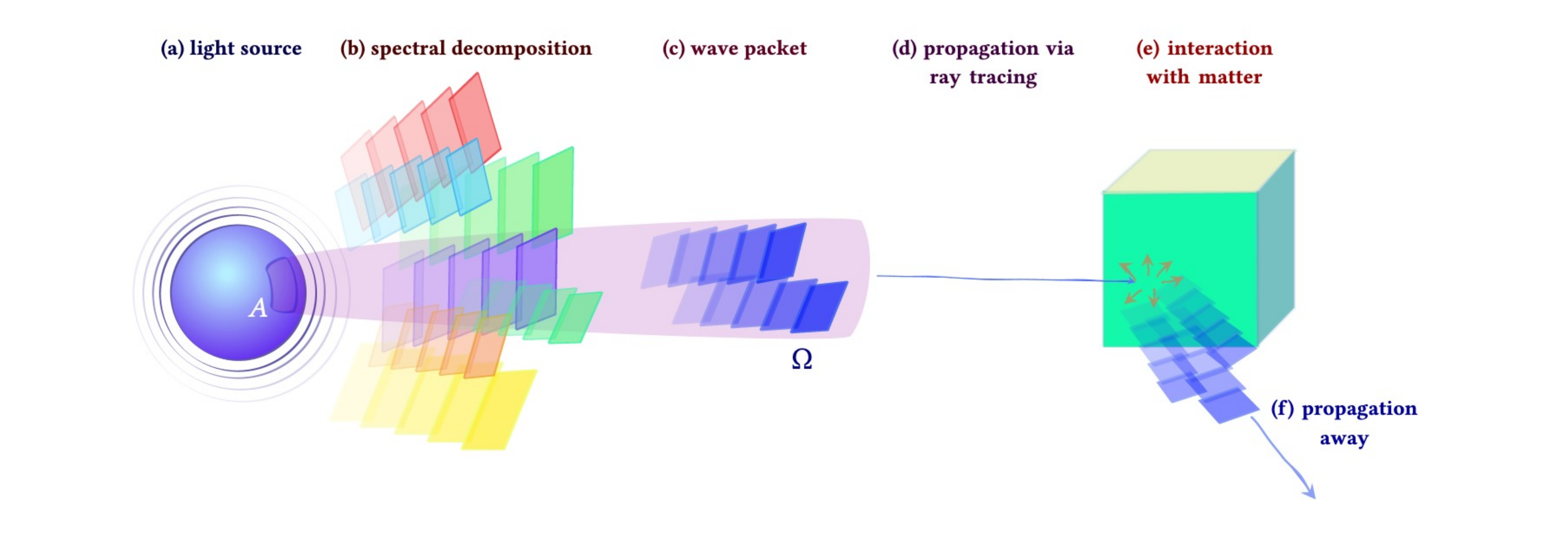
- The second-order statistical properties of light fully describe the observable properties of light
- Problem: PLT not practical to sample



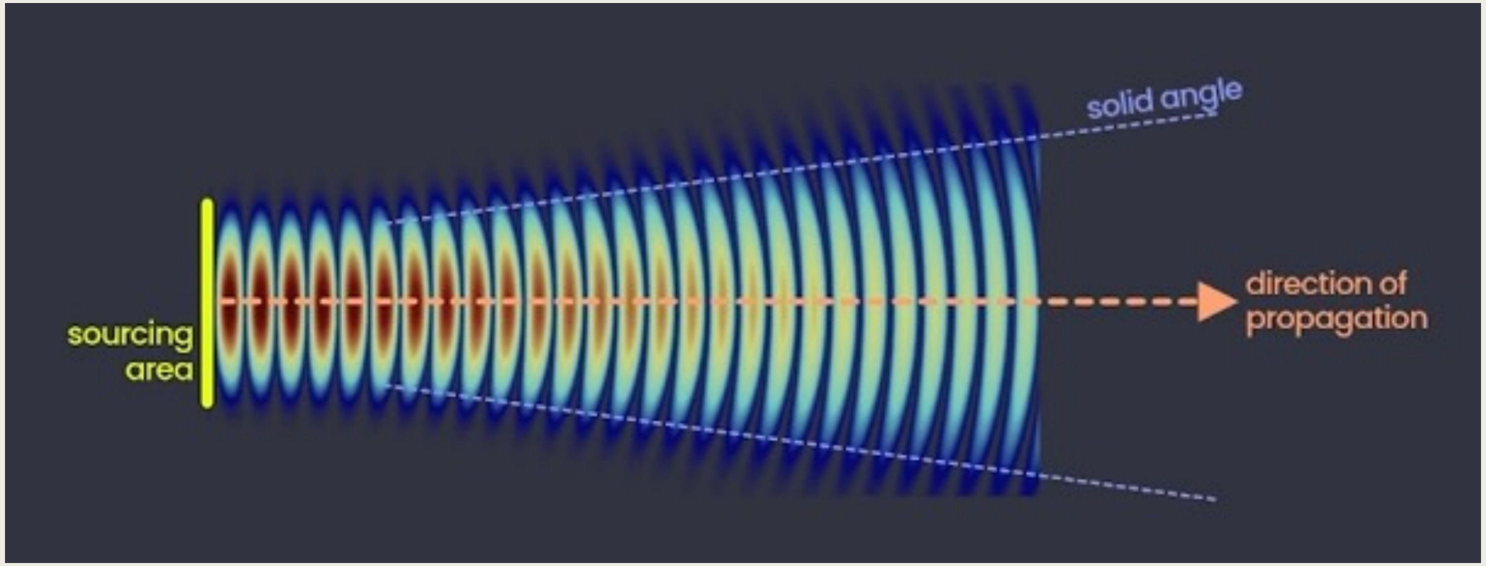
METHODOLOGY OF RENDERING WITH PLT

BEAM, PATH TRACING, wBSDF

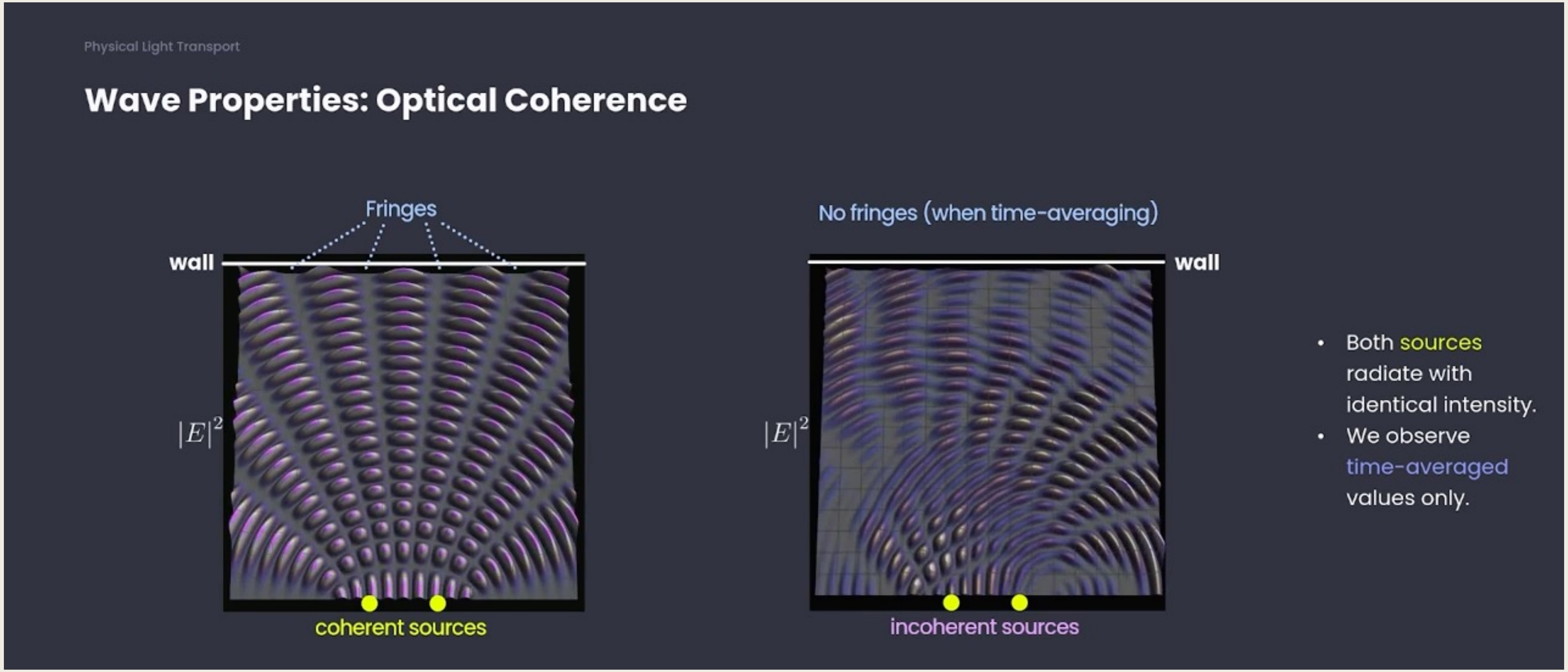
Methodology



Beam

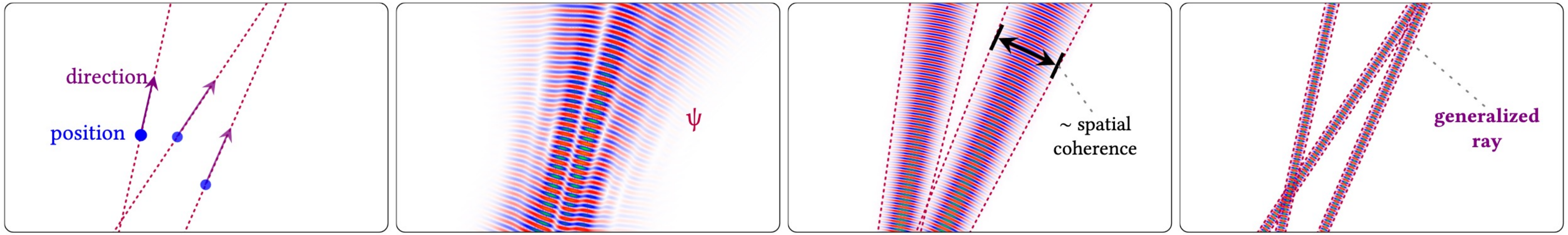


Beam



Physical Light Transport
Wave Properties: Optical Coherence
Fringes
wall
$|E|^2$
coherent sources
No fringes (when time-averaging)
wall
$|E|^2$
incoherent sources
• Both sources radiate with identical intensity.
• We observe time-averaged values only.

Beam



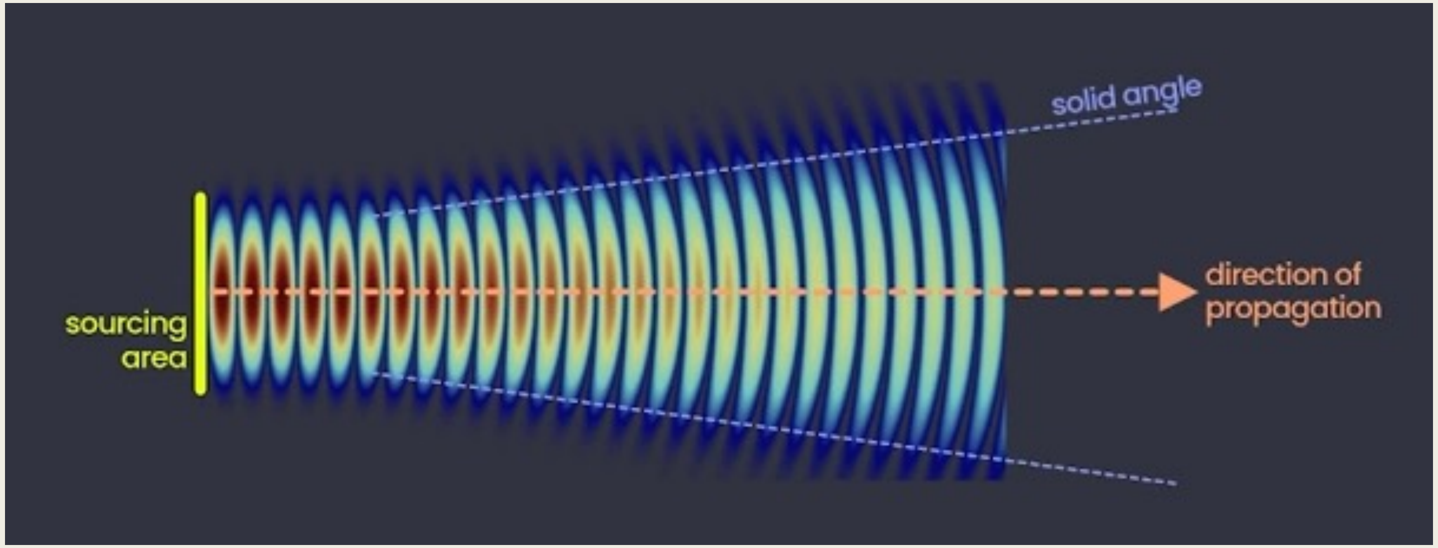
(a) ray optics (b) wave optics (c) PLT (d) generalized rays

Beam

$$\Phi \triangleq \oint_{\Delta S} \mathrm{d}^2\hat{\boldsymbol{k}} \left|\vec{\boldsymbol{\psi}}\left(k\hat{\boldsymbol{k}}\right)\right|^2 .$$

Path Tracing

- Beams should be
  - *wide enough to capture all the beam's statistics; but*
  - *narrow enough to be easy to trace.*



Path Tracing

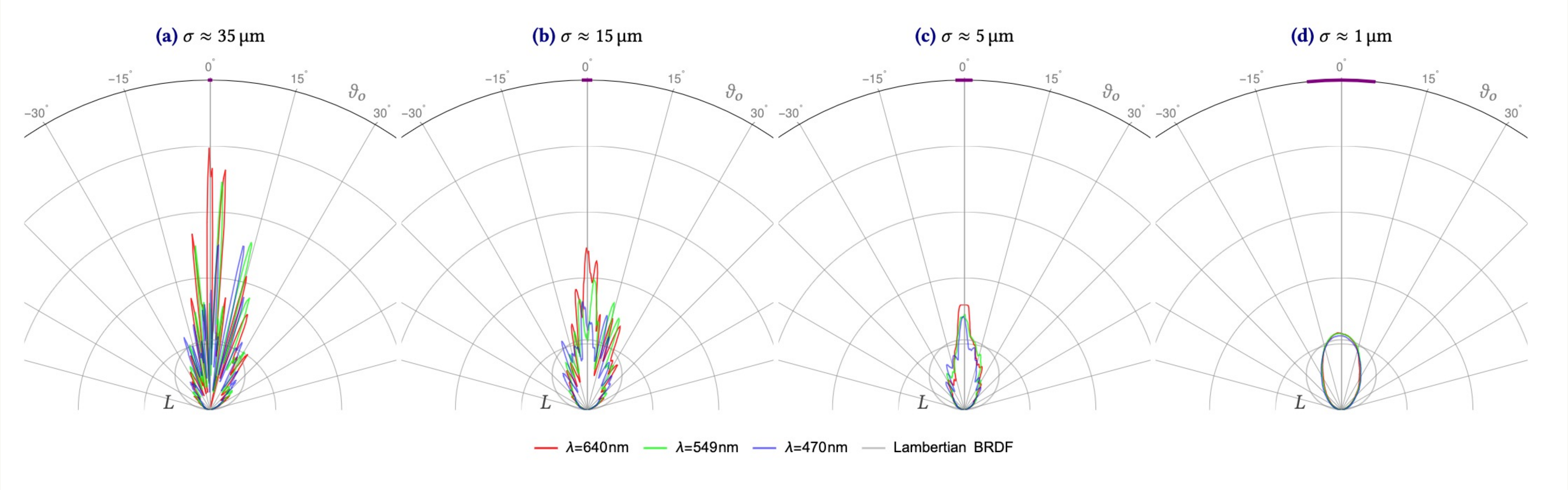
$$\overleftrightarrow{\boldsymbol{\mathcal{L}}}^{[\mu_o]} = \int_{\mathfrak{S}^2_+} \mathrm{d}^2\hat{\mathbf{s}}\ \boldsymbol{\mathcal{W}}\left\{\overleftrightarrow{\boldsymbol{\mathcal{L}}}^{[\mu_i]}\right\} \hat{\mathbf{s}} \cdot \hat{\boldsymbol{n}}\,,$$

- d distance
- $\mathcal{L}$ Generalized radiance
- $\boldsymbol{\mathcal{W}}$ Wave BSDF
- ŝ direction of the propagation
- n normal to the interface

Wave BSDF(wBSDF)

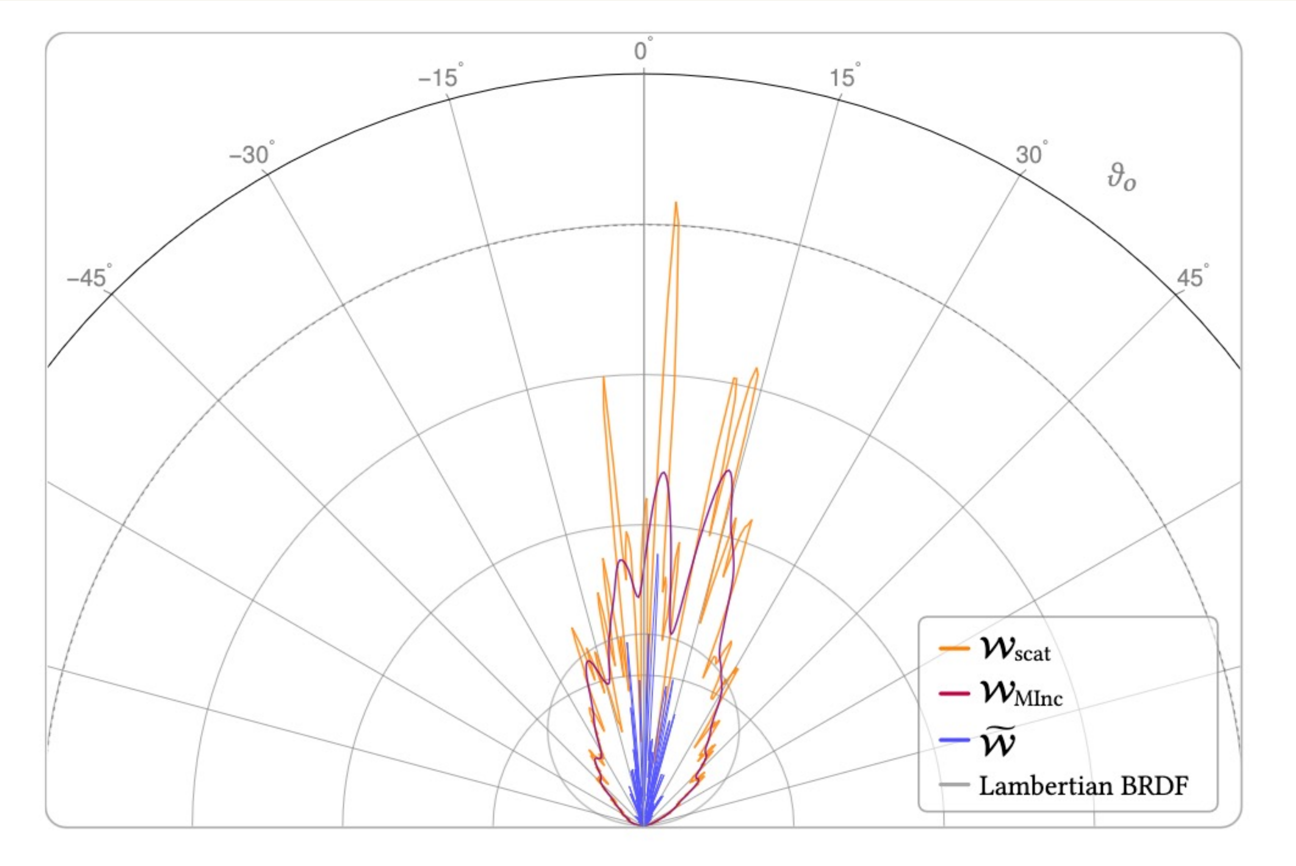
$$\mathcal{W}_{\text{scat}}\left\{\overleftrightarrow{\boldsymbol{\mathcal{S}}}^{[\mu_i]}\right\} \triangleq \cos\vartheta_o \boldsymbol{M}^{[\mu_i]\rightarrow[\mu_o]} \times \left[S_x^{(\text{i})}\mathcal{D}\left\{\boldsymbol{\Xi}_x^{(\text{i})}\right\}\vec{\mathbf{S}}_{\text{LHP}} + S_y^{(\text{i})}\mathcal{D}\left\{\boldsymbol{\Xi}_y^{(\text{i})}\right\}\vec{\mathbf{S}}_{\text{LVP}} + \sqrt{S_x^{(\text{i})}S_y^{(\text{i})}}\mathcal{D}\left\{\boldsymbol{\Xi}_{1/2}^{(\text{i})}\right\}\vec{\mathbf{S}}_{\text{c}}\left(\chi^{(\text{i})},\varsigma^{(\text{i})}\right)\right],$$

Wave BSDF(wBSDF)

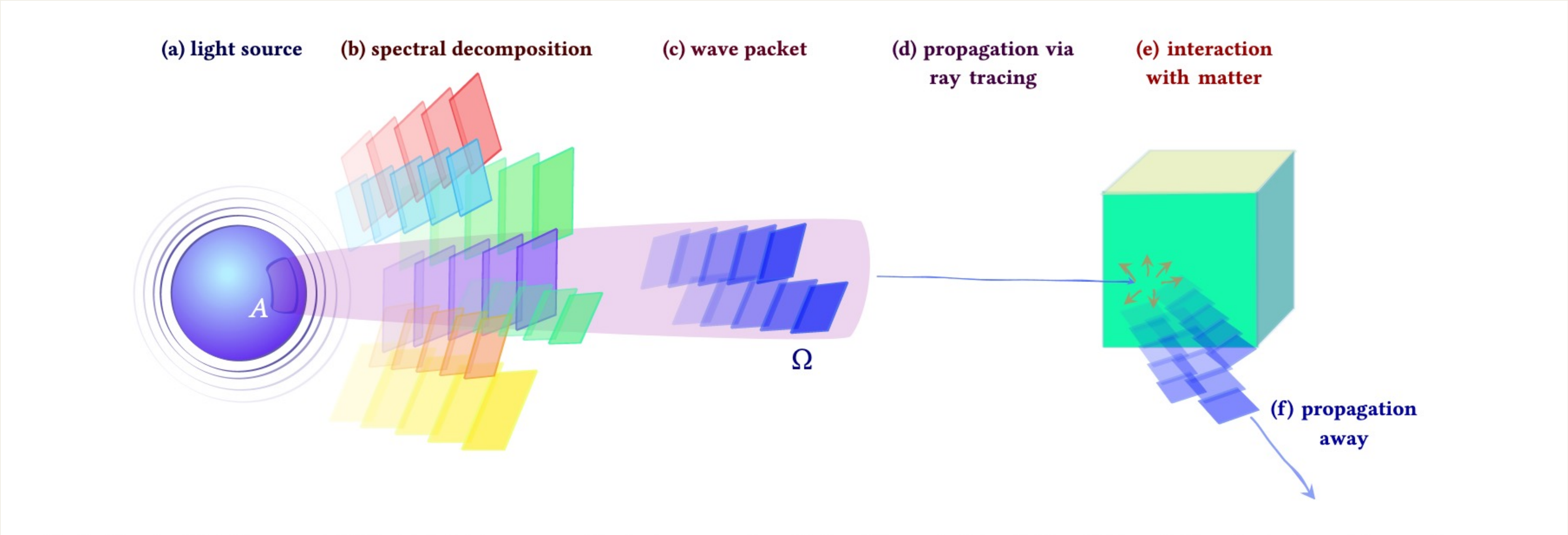


Wave BSDF(wBSDF)

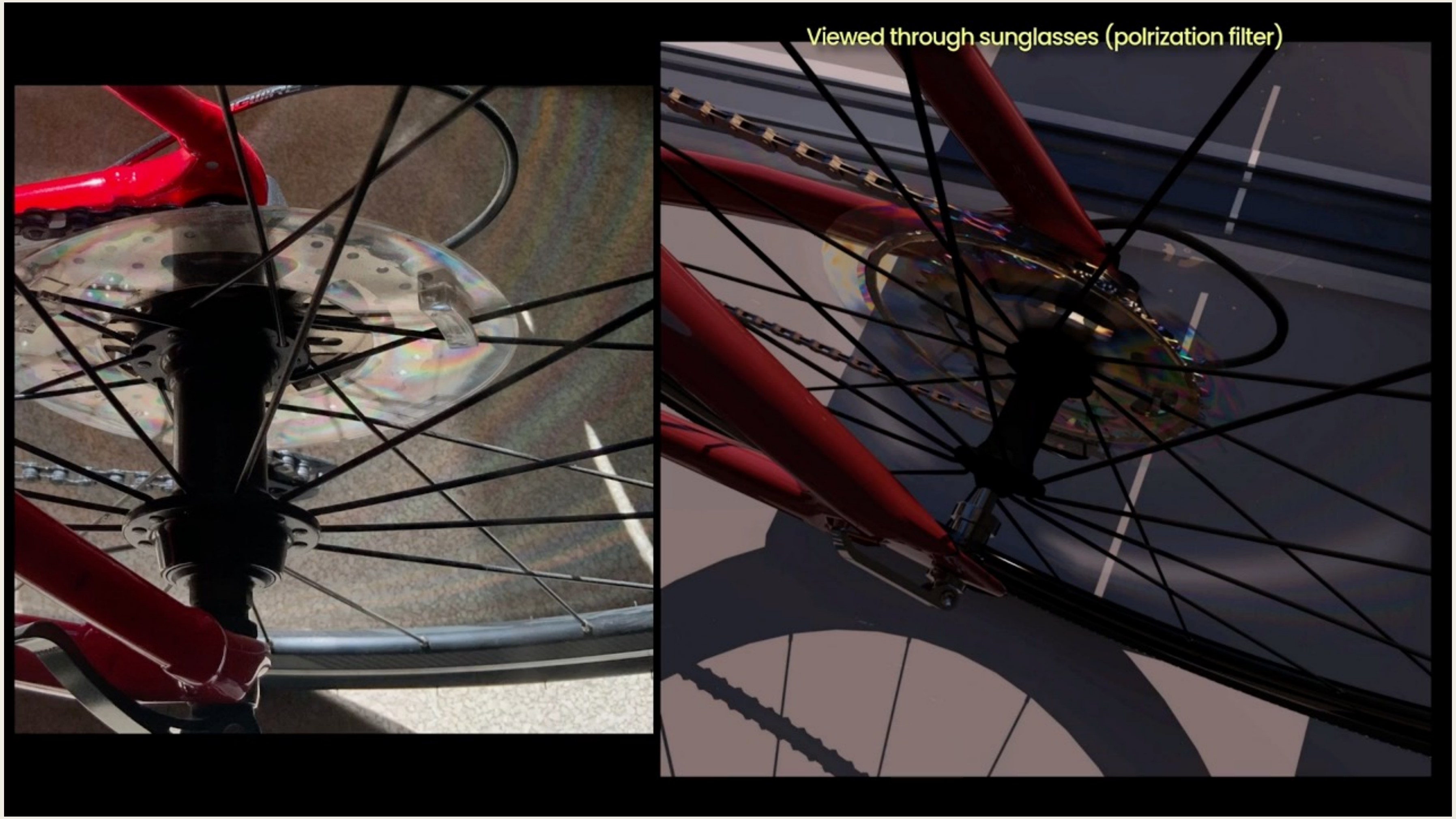
- Importance sampling



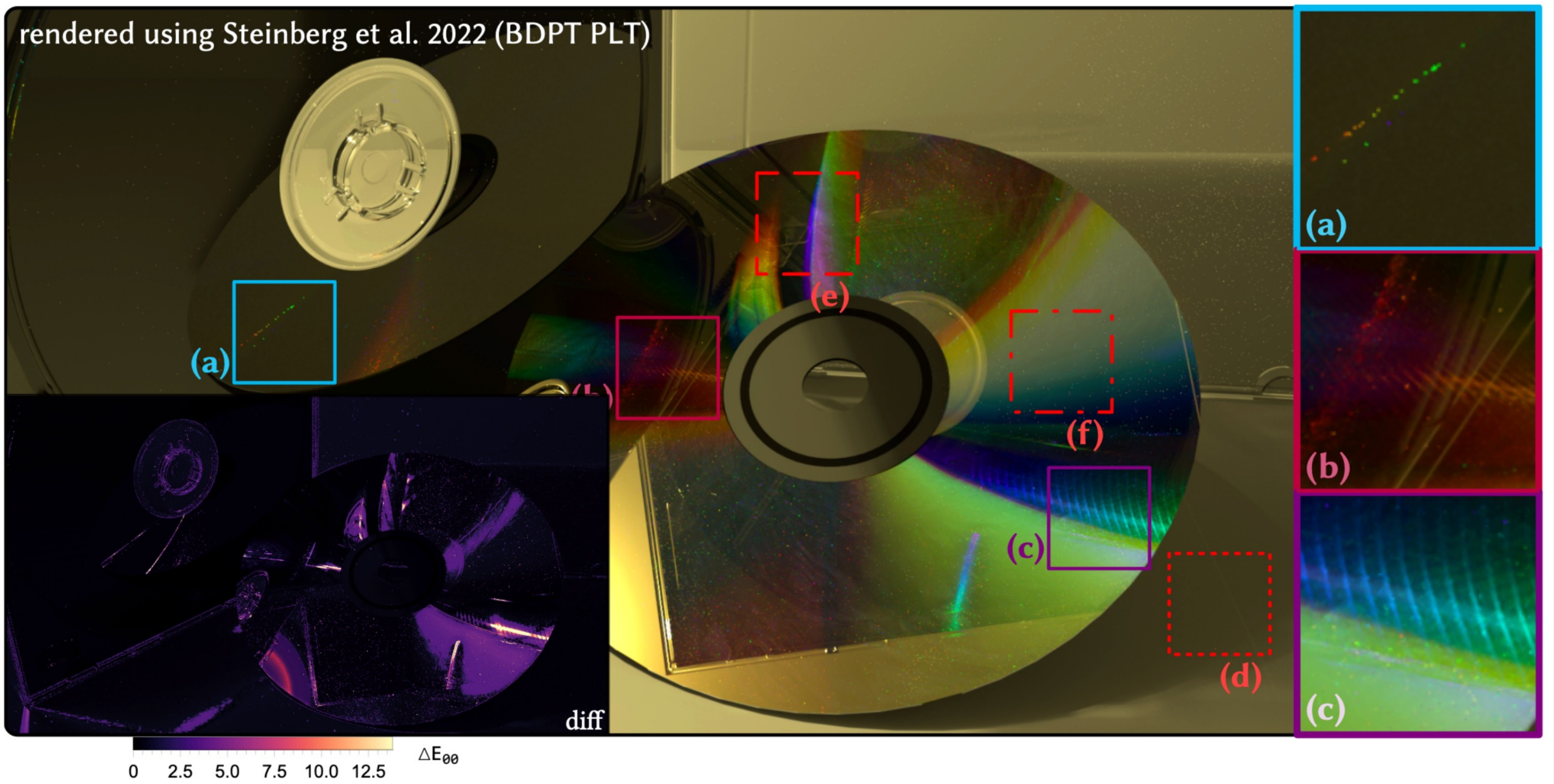
Summary


(a) light source
(b) spectral decomposition
(c) wave packet
(d) propagation via
ray tracing
(e) interaction
with matter
A
Ω
(f) propagation
away

Results



Weakness



rendered using Steinberg et al. 2022 (BDPT PLT)
(a)
(e)
(f)
(c)
(d)
(a)
(b)
(c)
diff
0
2.5
5.0
7.5
10.0
12.5
ΔE00

Results

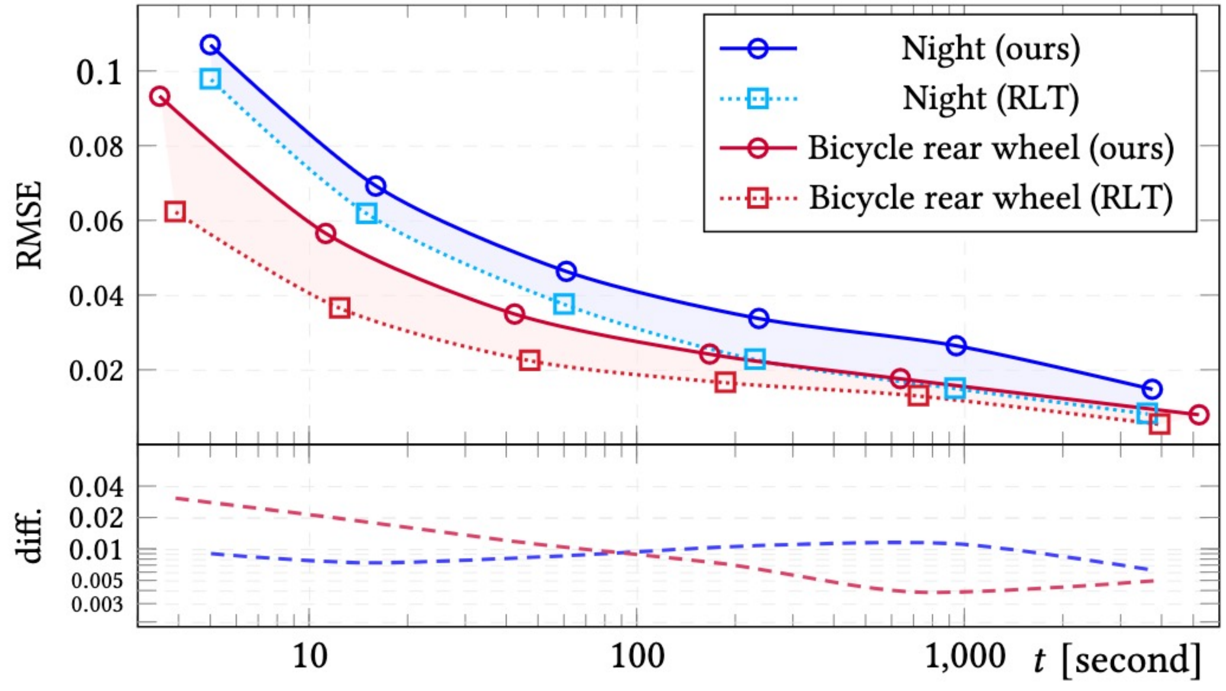


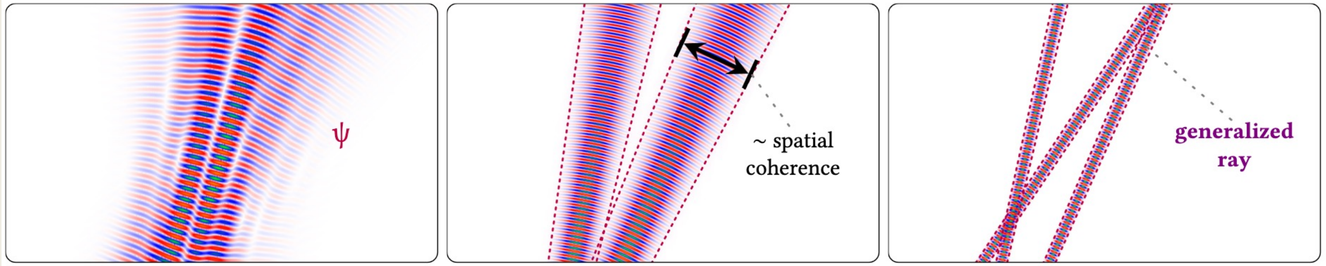
Fig. 14. Convergence performance of our framework compared against the scalar, radiometric renderer. (top) RMSE values as functions of rendering time for the (blue) "night" and (red) "bicycle rear wheel" scenes from Fig. 13, both when rendered under (dotted) RLT and our (solid) PLT method; and (bottom) the differences between the methods (log-log plot).

Quiz

- Q1: For Path tracing how should beams be?
  - *wide enough to capture all the beam's statistics; but narrow enough to be easy to trace.*

  Or

  - *narrow enough to capture all the beam's statistics; but wide enough to be easy to trace.*
- Q2: For sophisticated sampling techniques what kind of „ray/wave optics“ do we use?



(b) wave optics (c) PLT (d) generalized rays