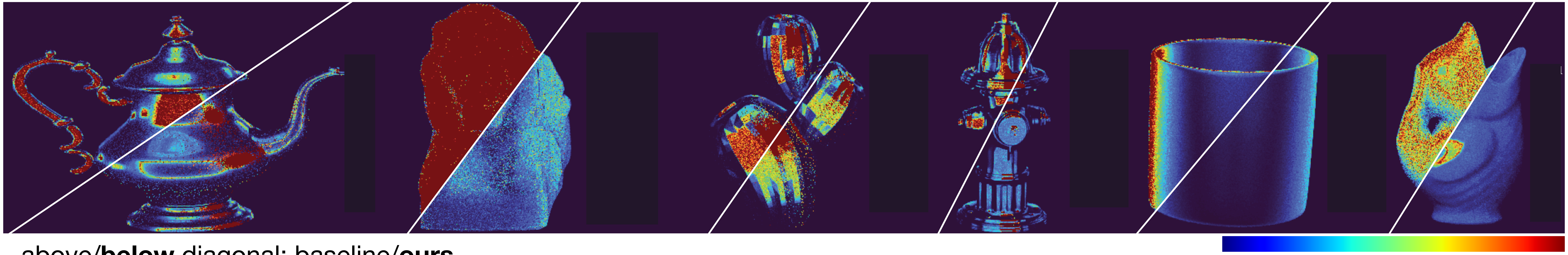
Importance Sampling BRDF Derivatives

Isotropic GGX *Hanrahan-Krueger* *Anisotropic GGX* *Anisotropic Beckmann* *Oren-Nayar* *Mixture Model*



above/**below** diagonal: baseline/**ours**

low variance high variance

Variance reduction in differentiable rendering by <u>correctly handling the derivative's sign</u>

Yash Belhe, Bing Xu, Sai Praveen Bangaru*, Ravi Ramamoorthi, Tzu-Mao Li — UCSD (*MIT)

Inverse rendering via derivatives of images

update

3D scene:
triangle positions
camera pose
materials
...

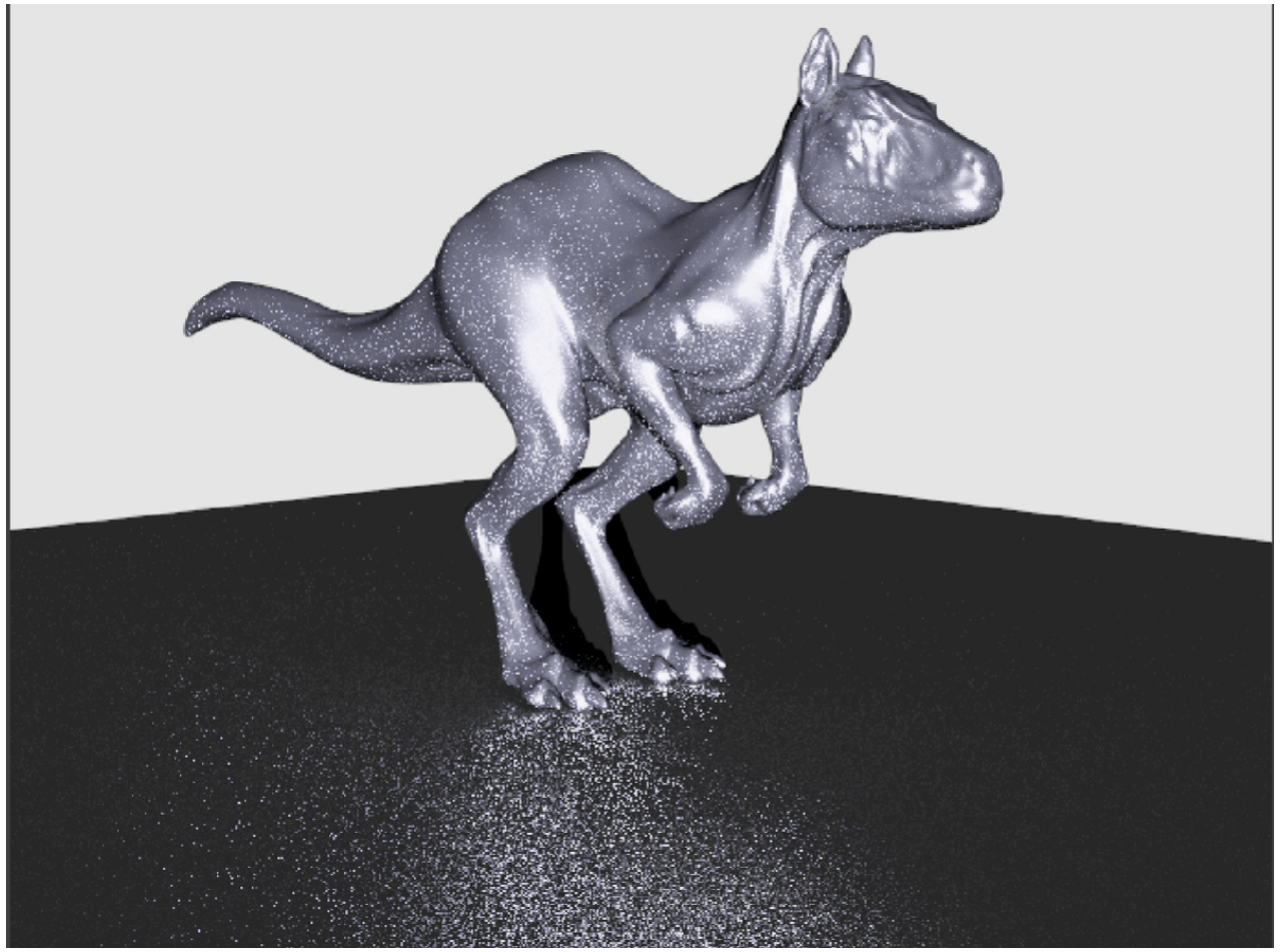
image

target

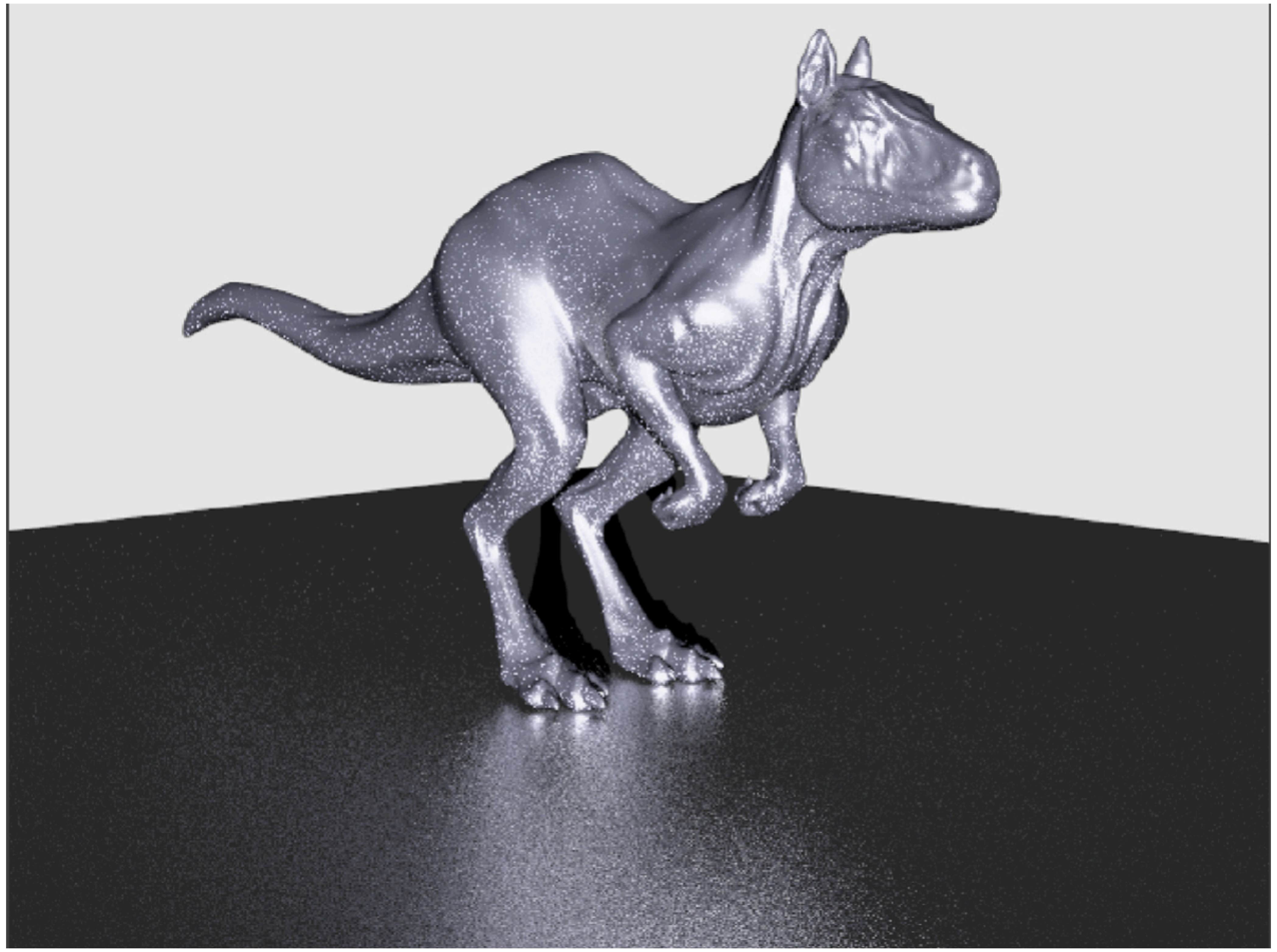
∇ loss

slide credit: Tzu-Mao Li

BRDF importance sampling is important in forward rendering



Uniform Sampling



BRDF Importance Sampling

image credit: PBRT - Pharr, Jakob and Humphreys

Goal: low-variance importance sampling of BRDF derivatives

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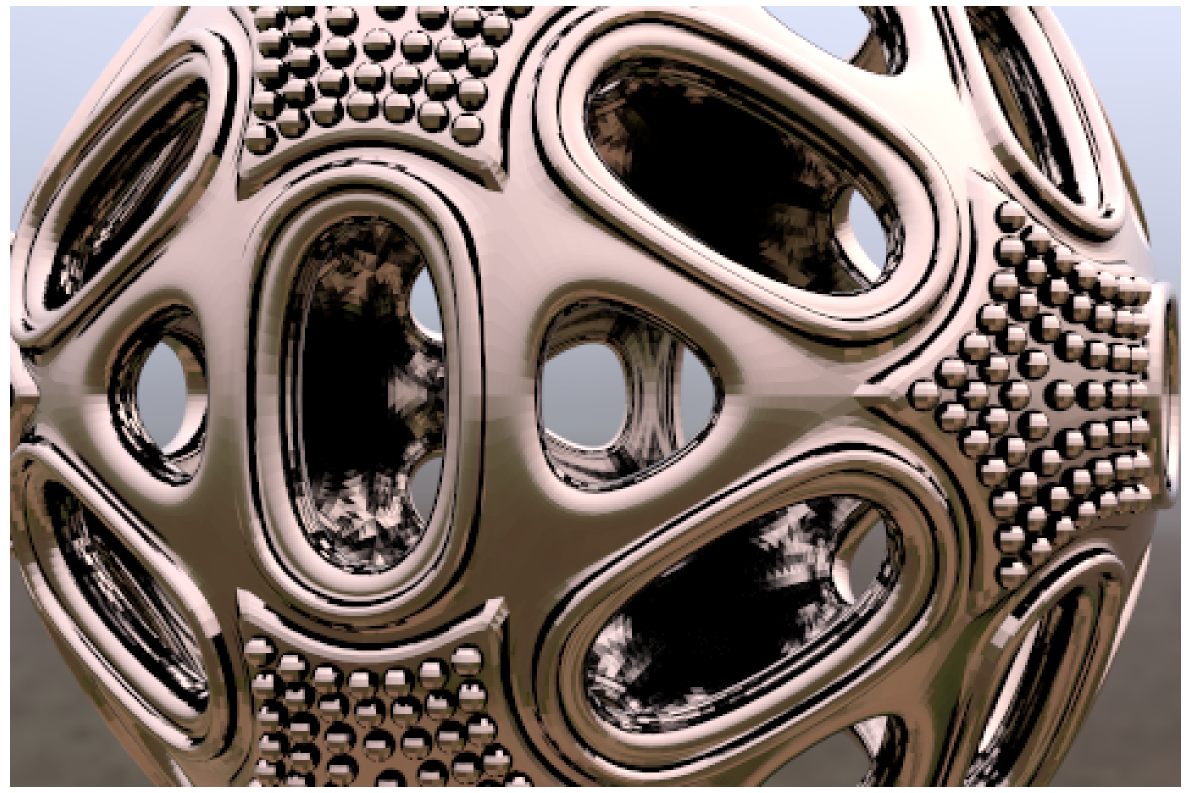
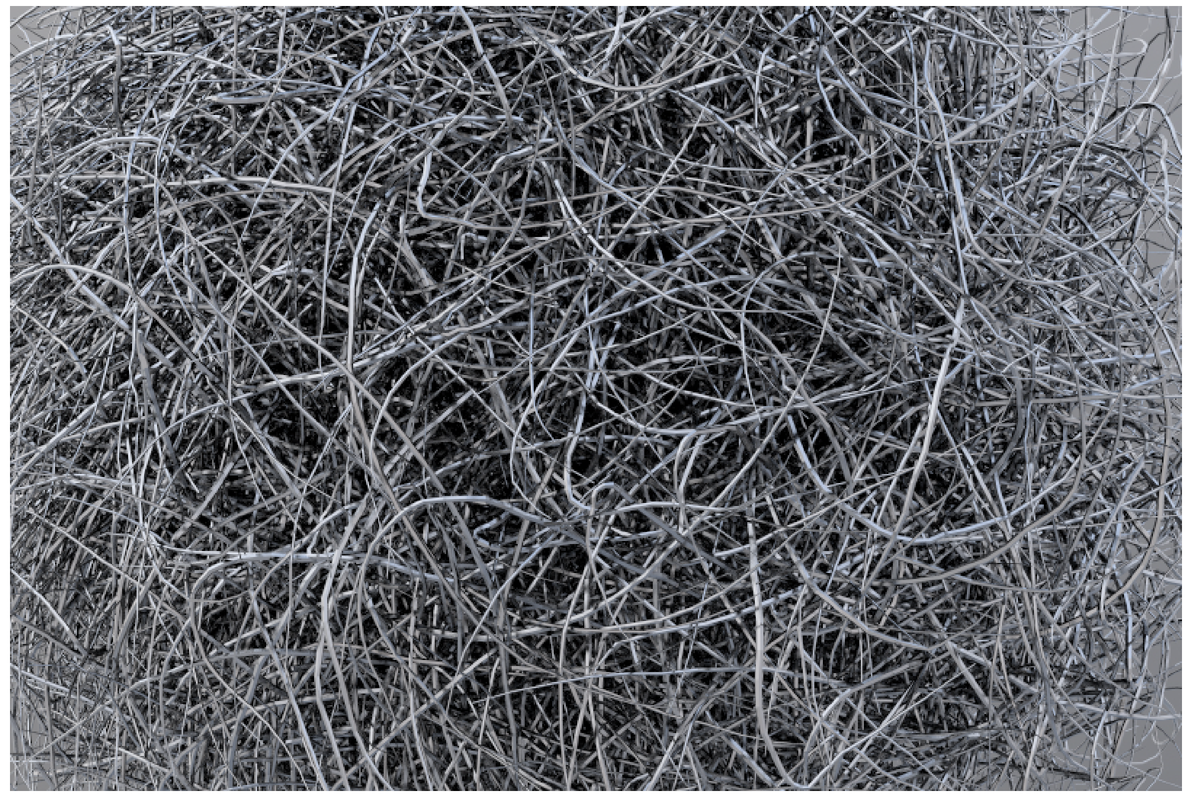
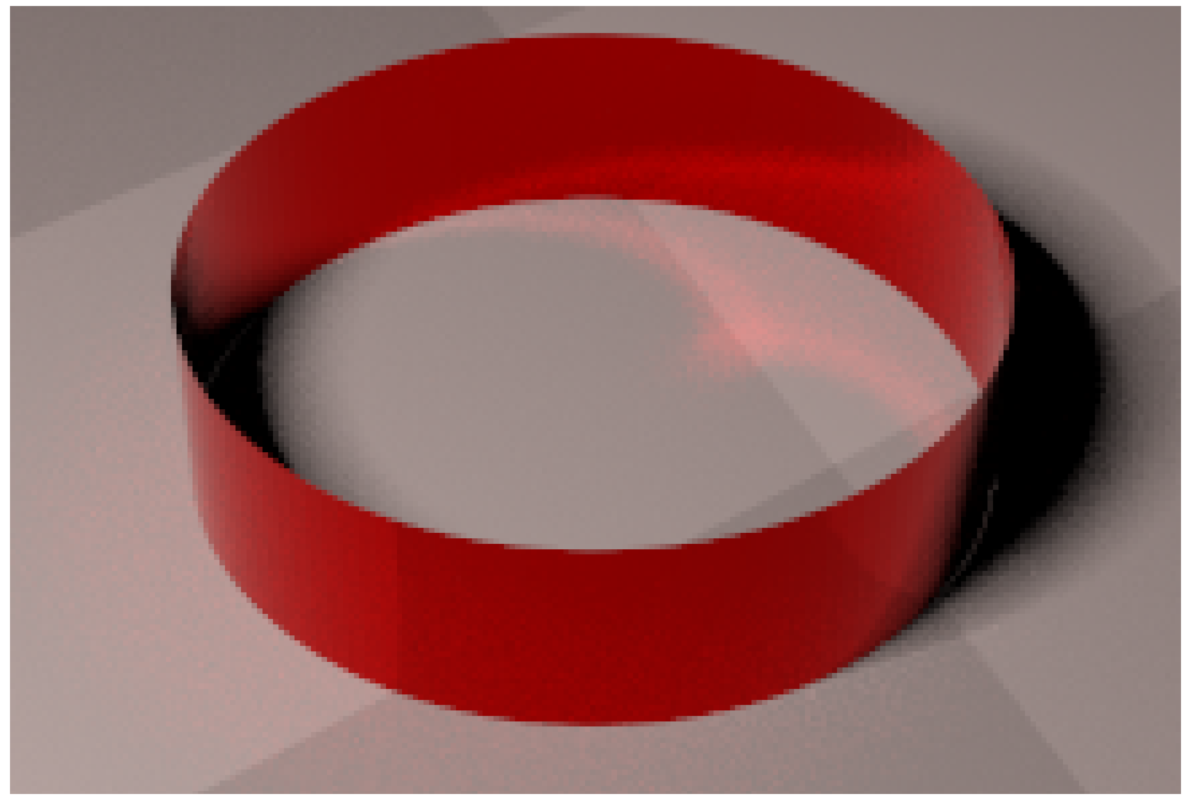


Direct Illumination

Glossy Reflection



Complex Visibility

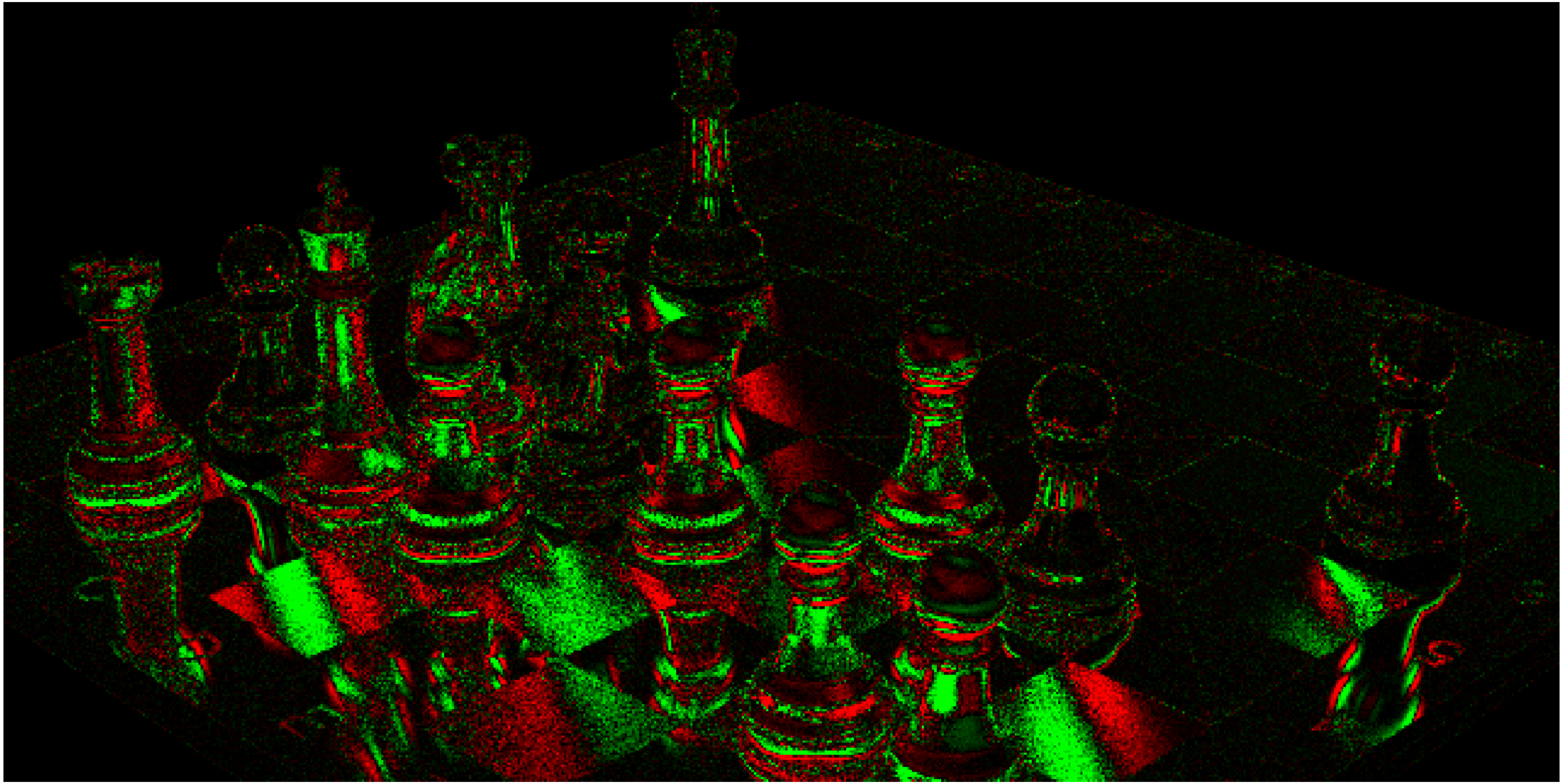


Caustics

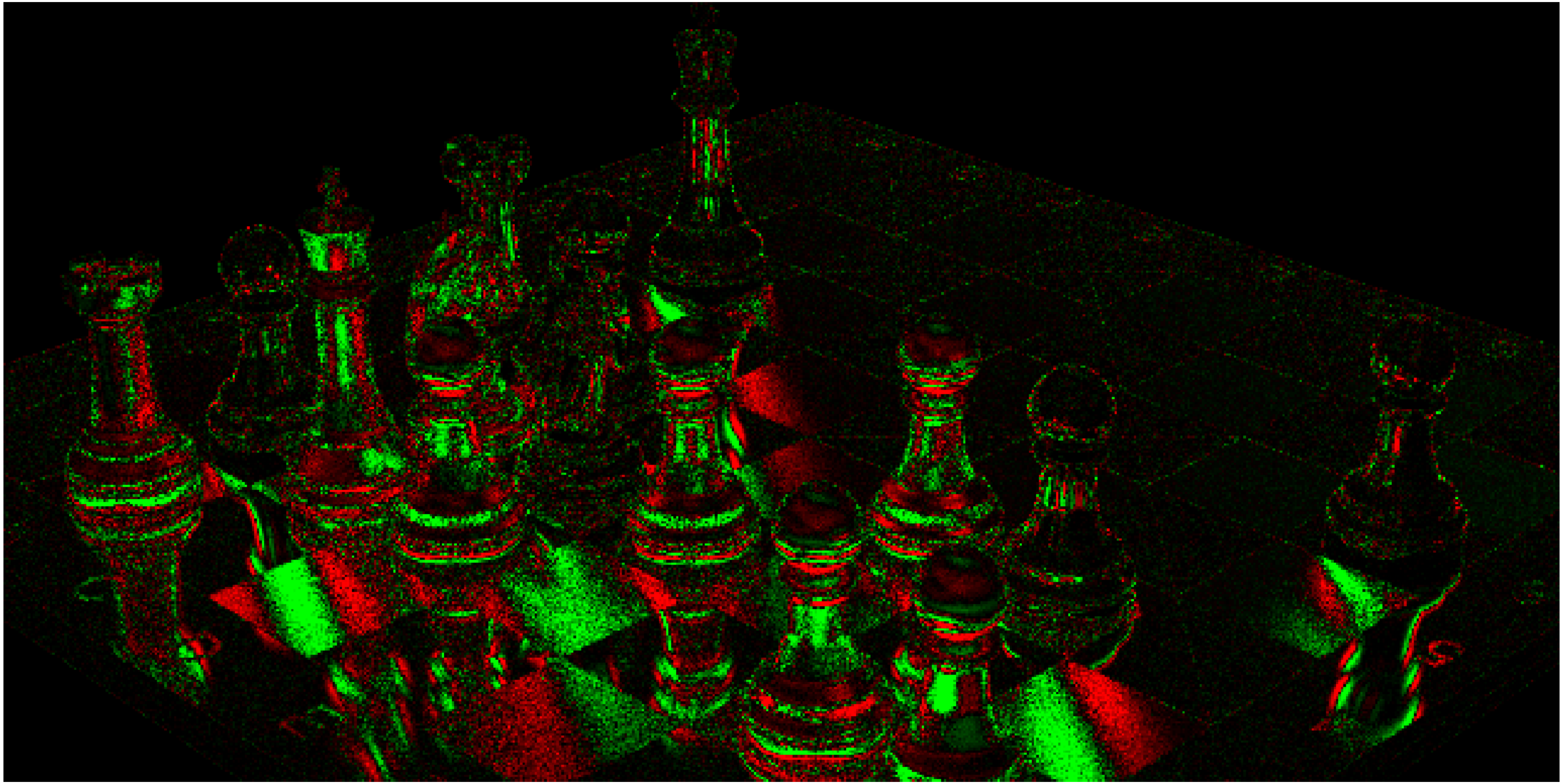
What do BRDF derivatives look like?

500 samples per pixel

BRDF derivatives can take both positive and negative values

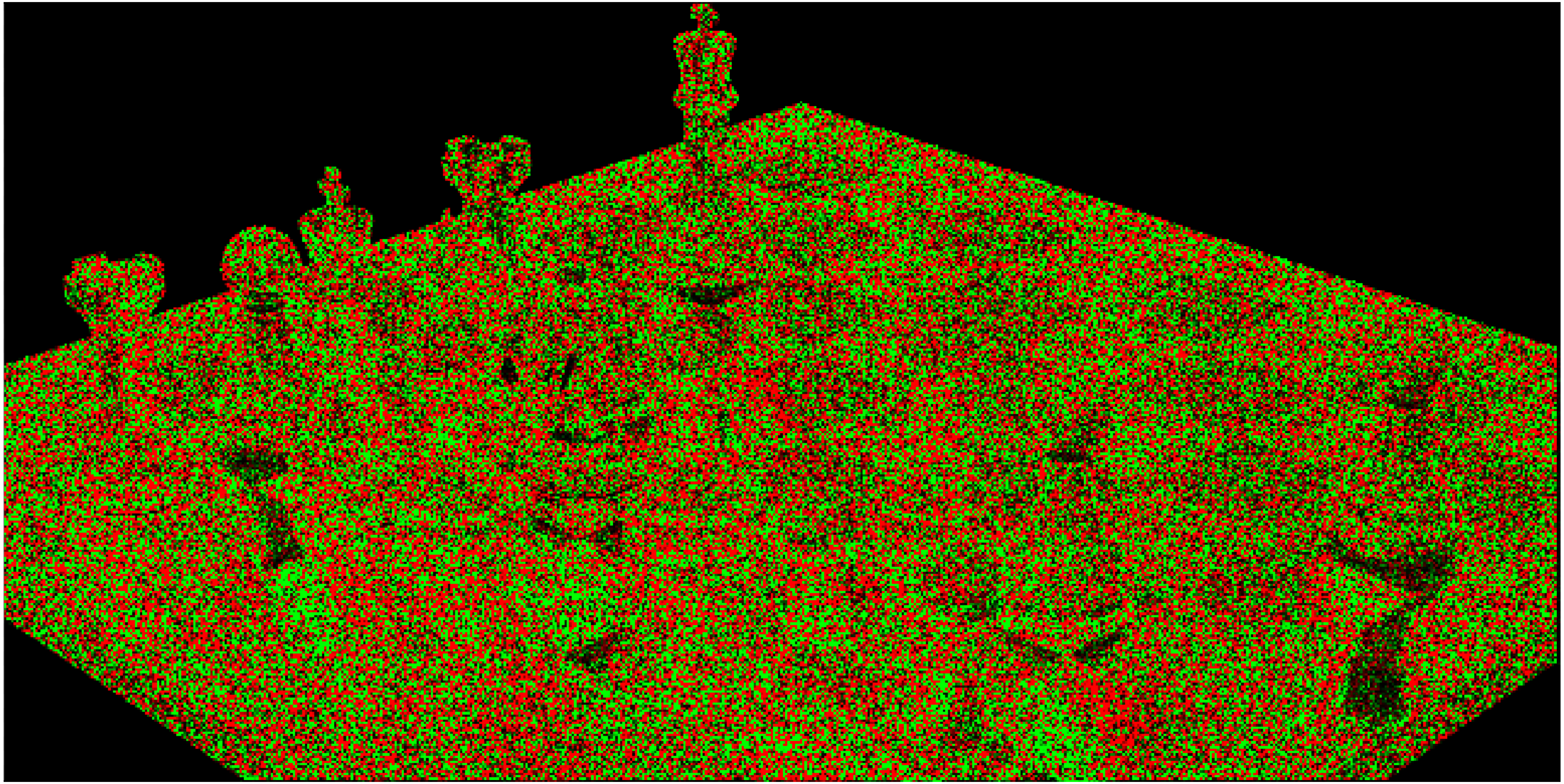


BRDF derivatives can take both positive and negative values



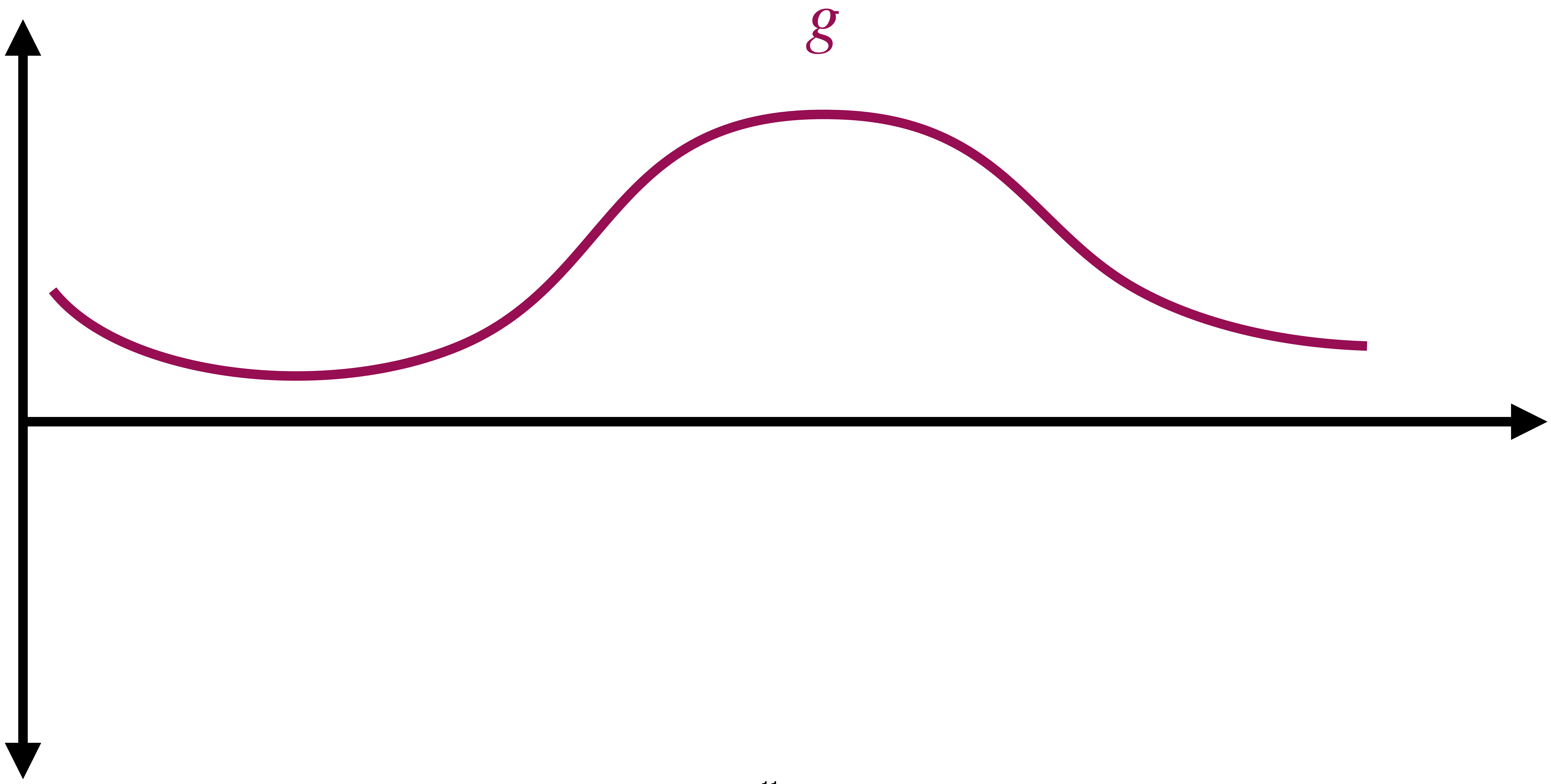
10,000 samples per pixel

BRDF derivatives can be very noisy



100 samples per pixel

Importance sampling PDF (p) $\propto$ BRDF (g)



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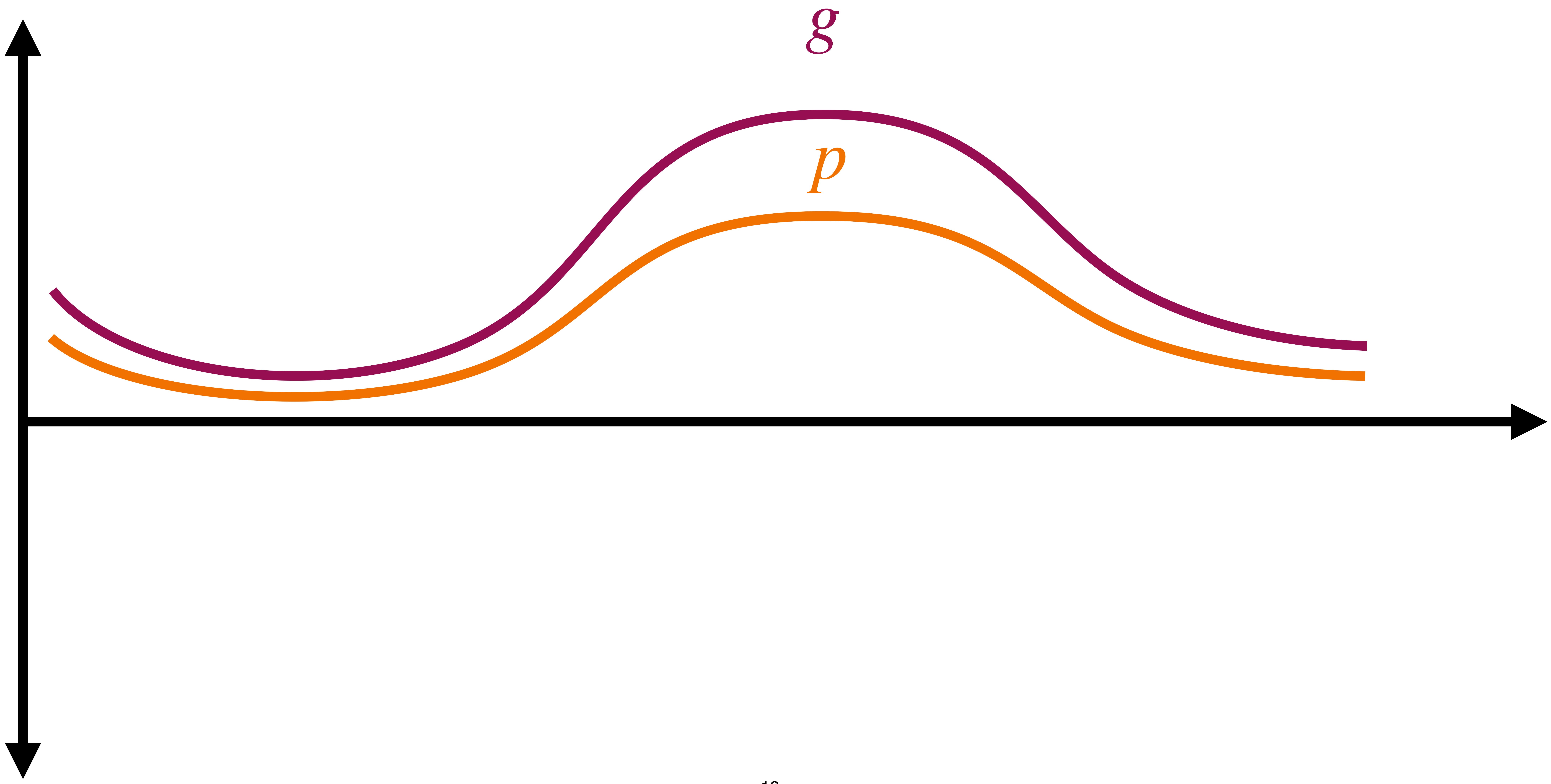
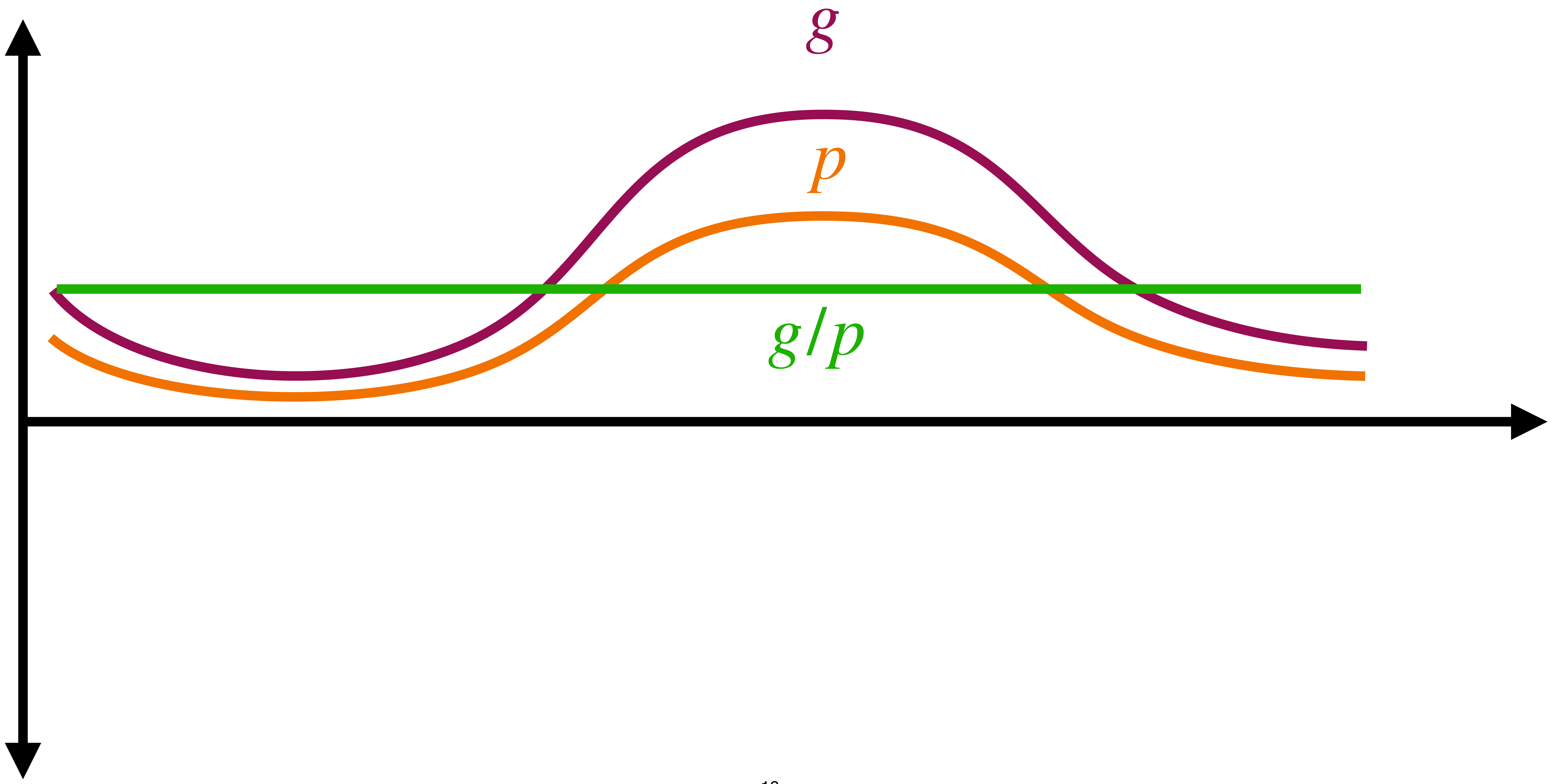
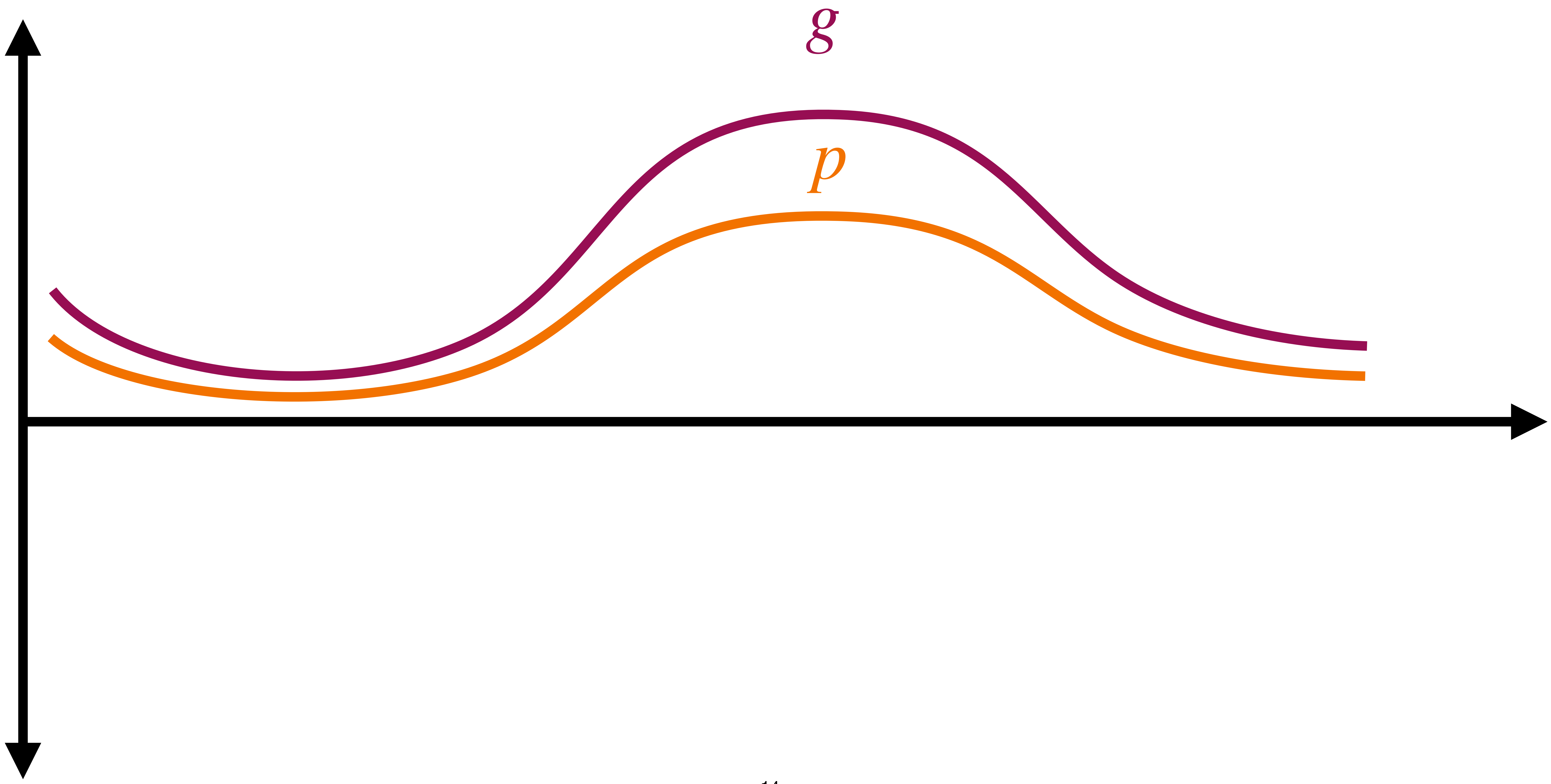


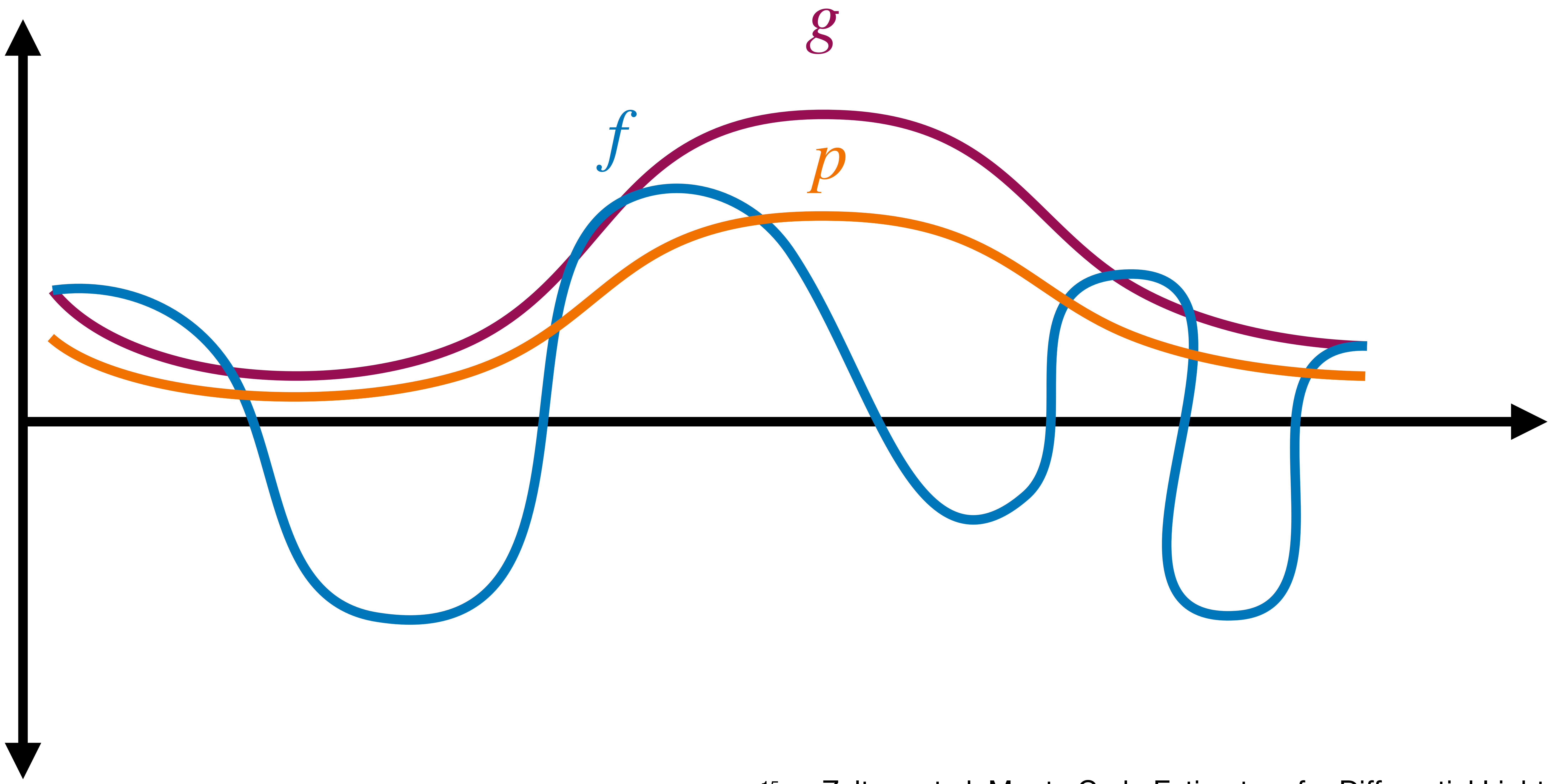
Importance sampling PDF (p) $\propto$ BRDF (g)



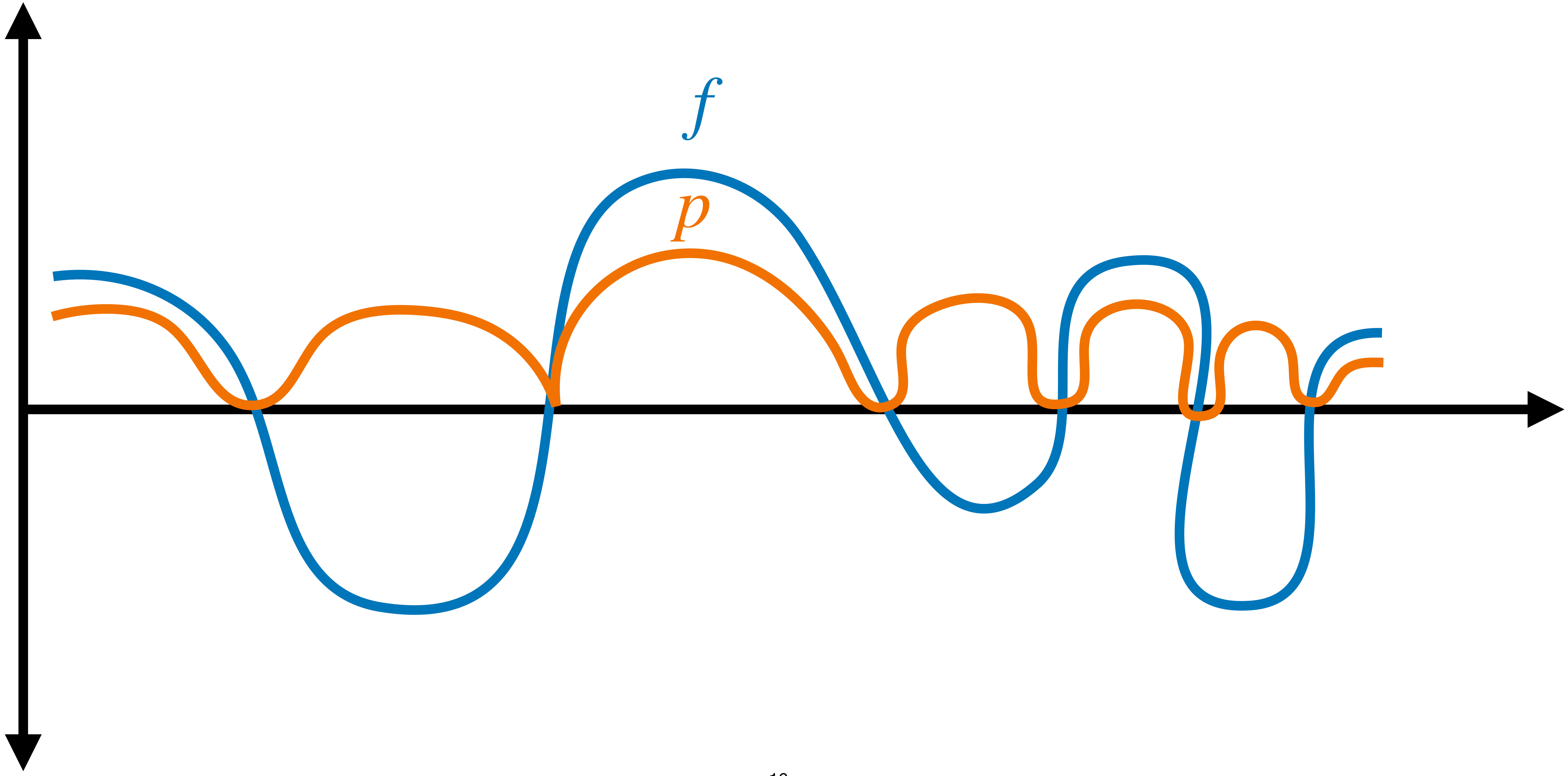
Same PDF to importance sample BRDF derivative?



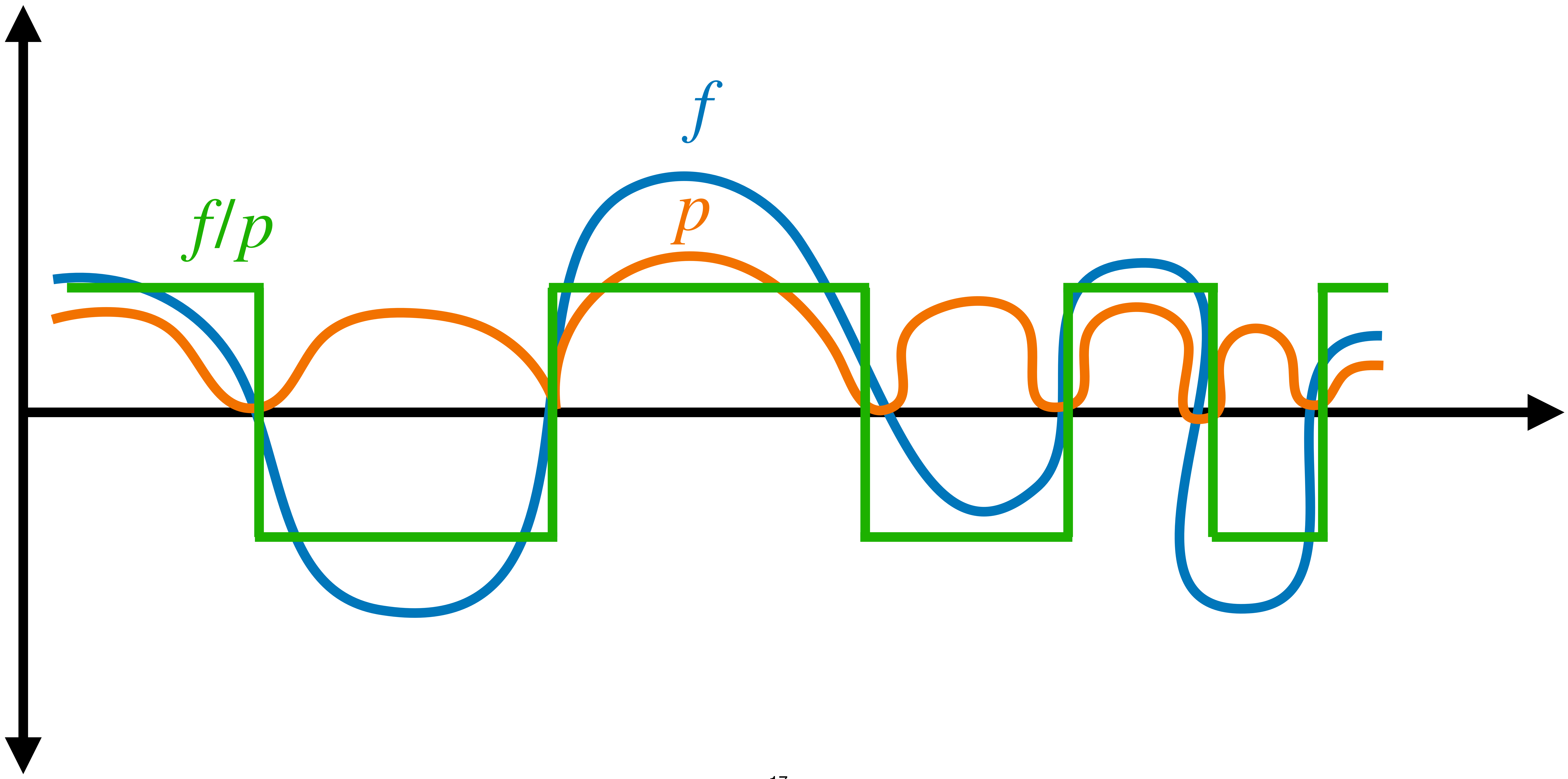
BRDF g is very different from its derivative f



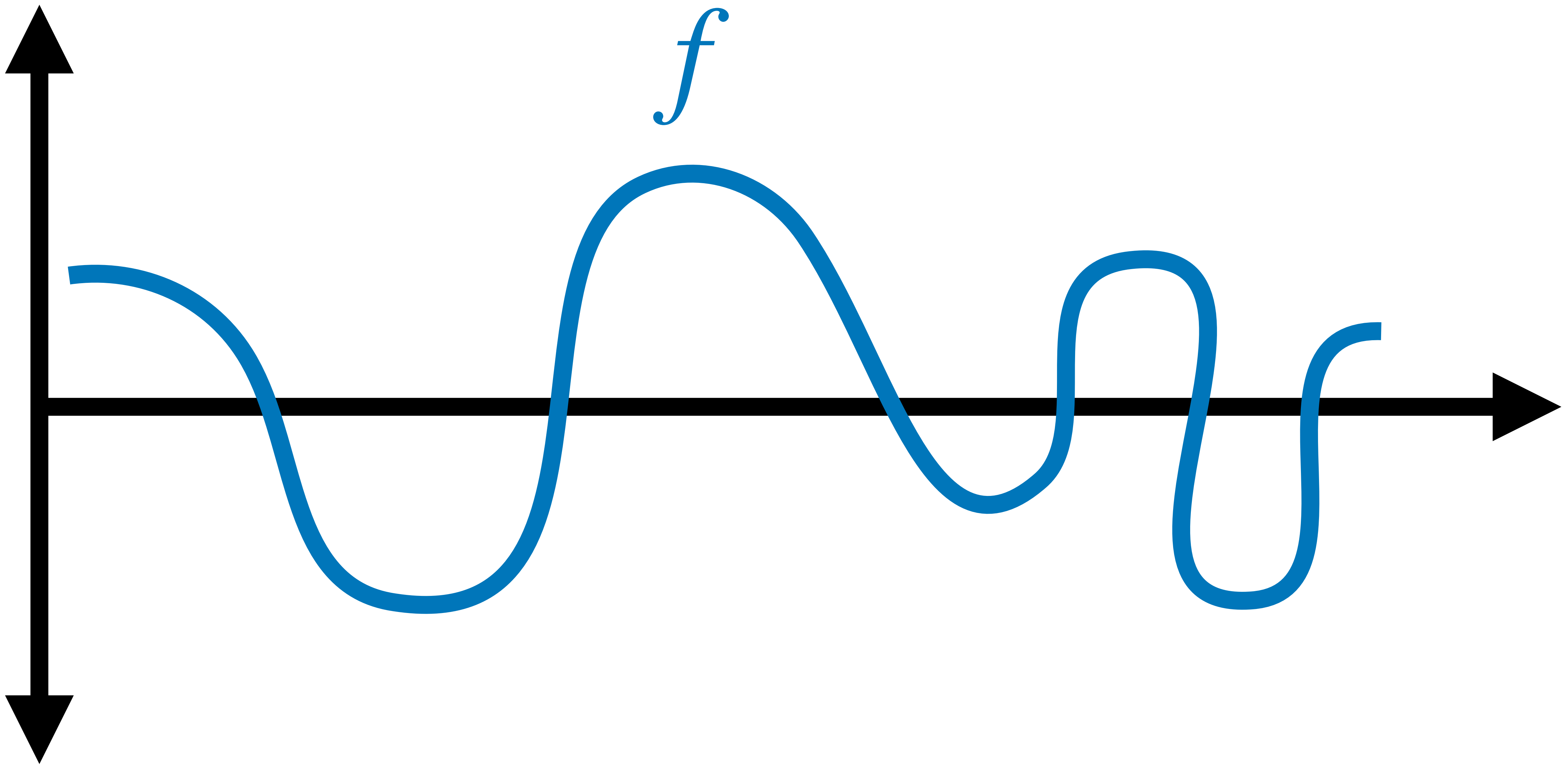
We can construct $p \propto |f|$?



$p \propto |f|$ has sign variance



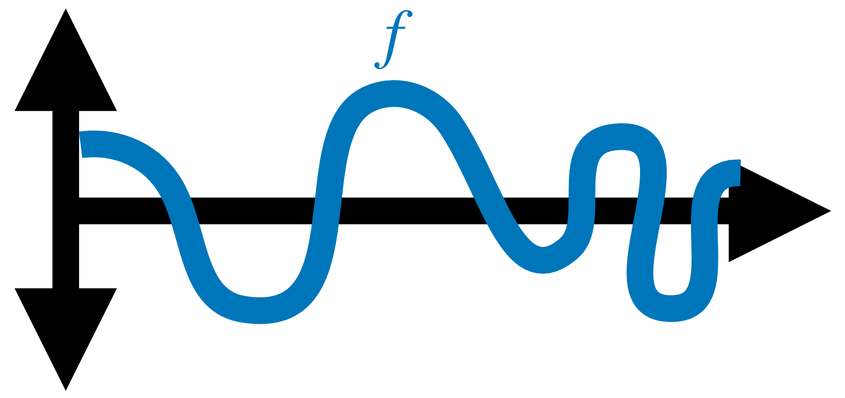
Key Idea: decompose real-valued into sum of positive and negative



precisely the decomposition is non-negative and non-positive

Key Idea: decompose real-valued into sum of positive and negative

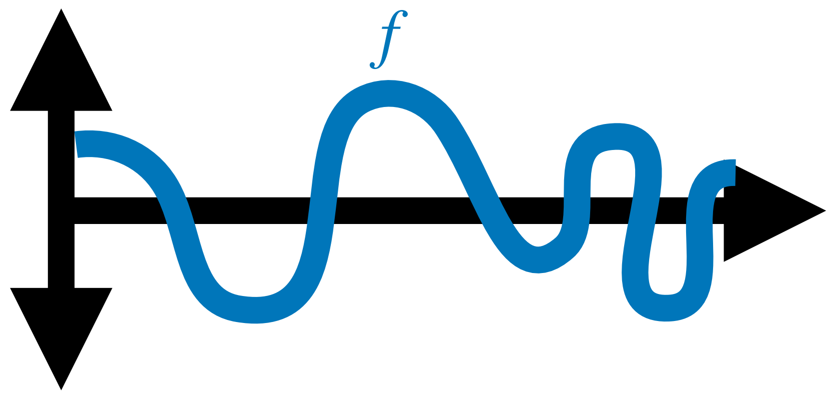
Positivization — Owen and Zhou 2000.



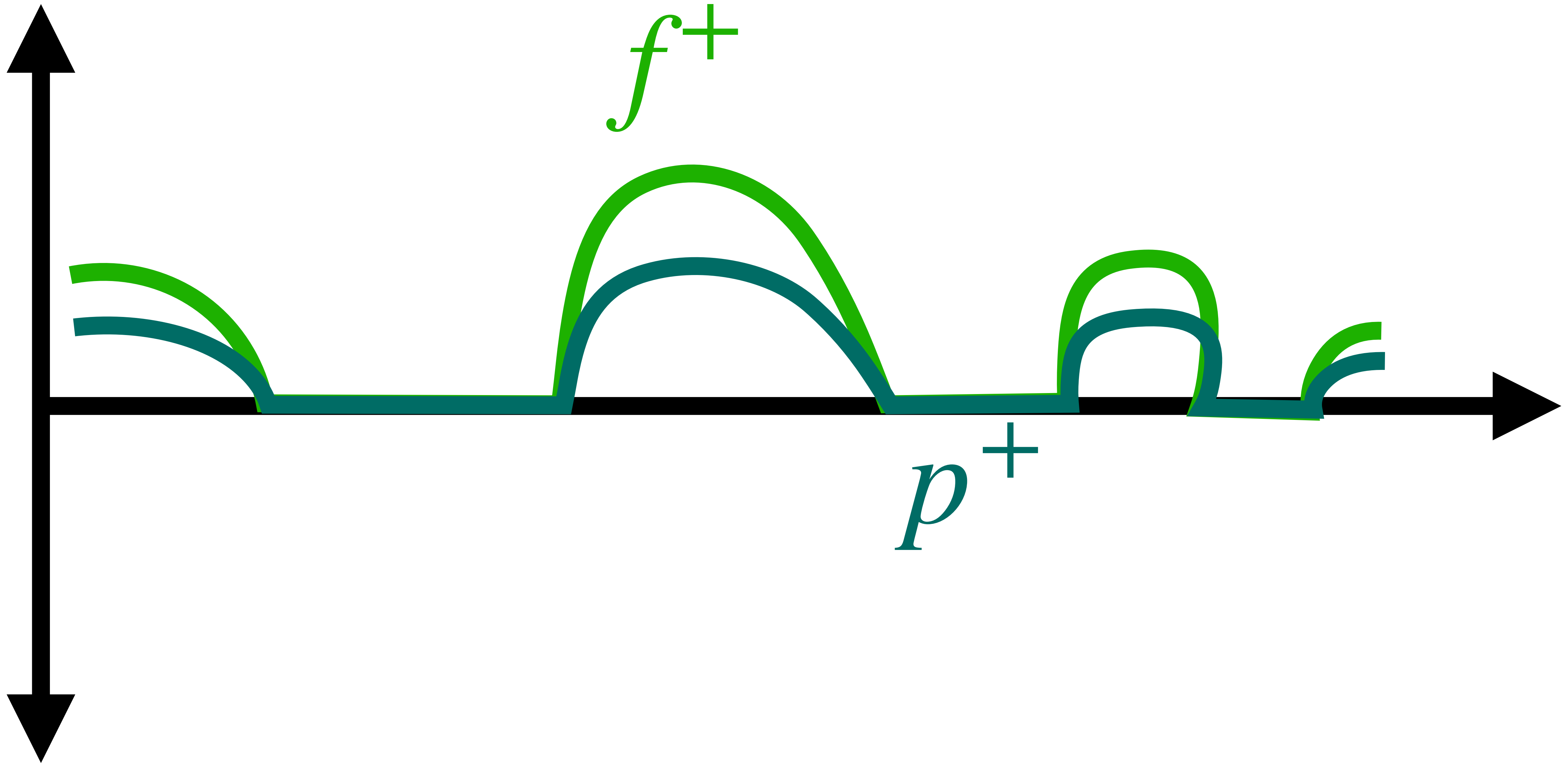
$=$

$p^+ \propto f^+$ $p^- \propto f^-$

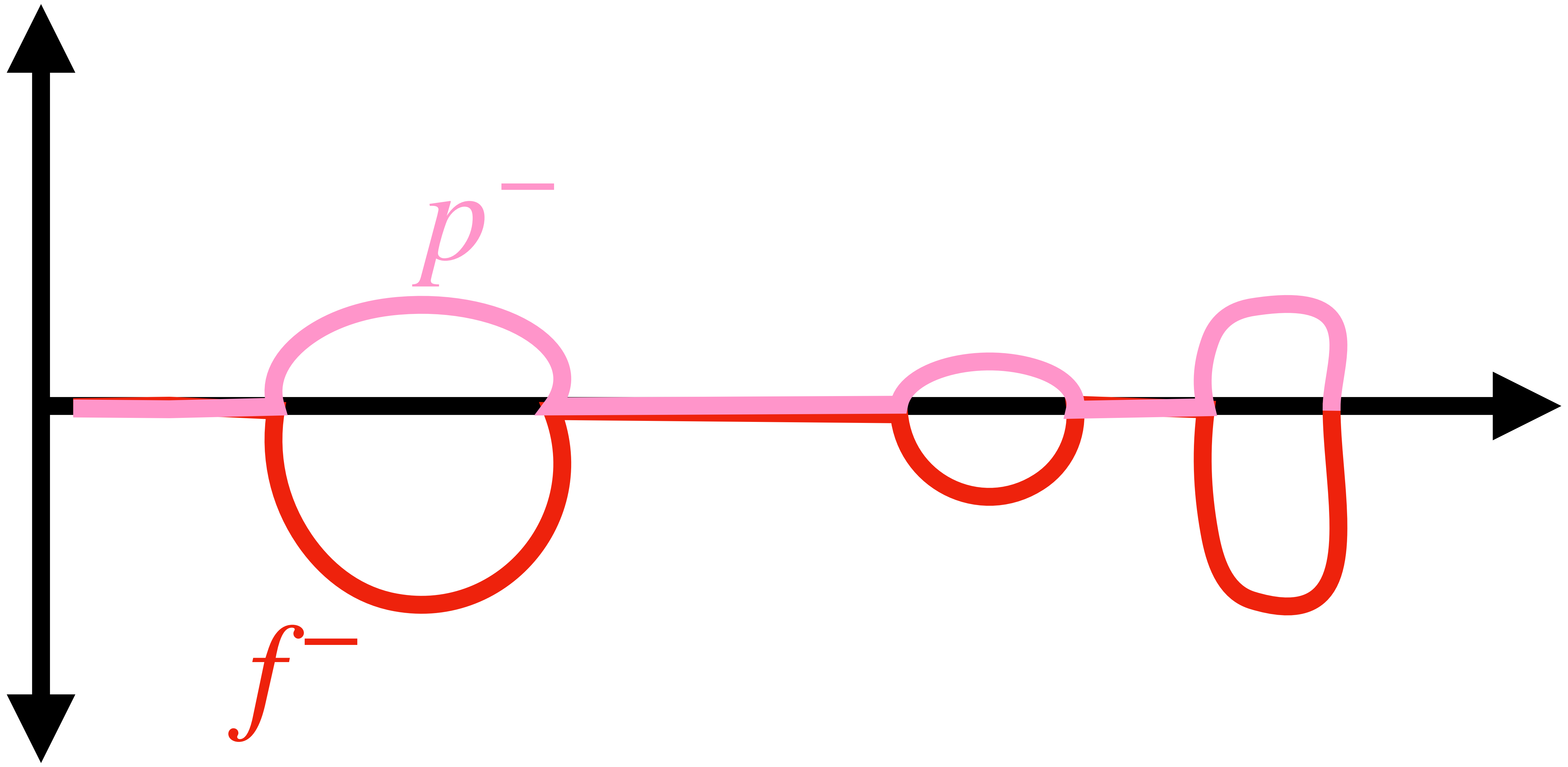
Positivization — Owen and Zhou 2000.



$=$



$+$



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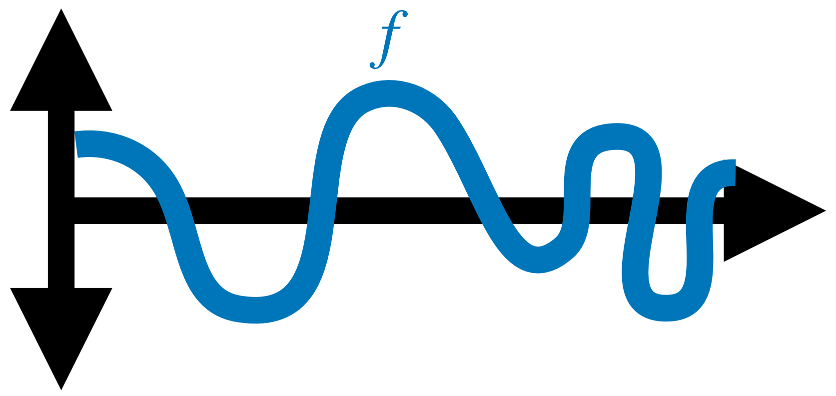
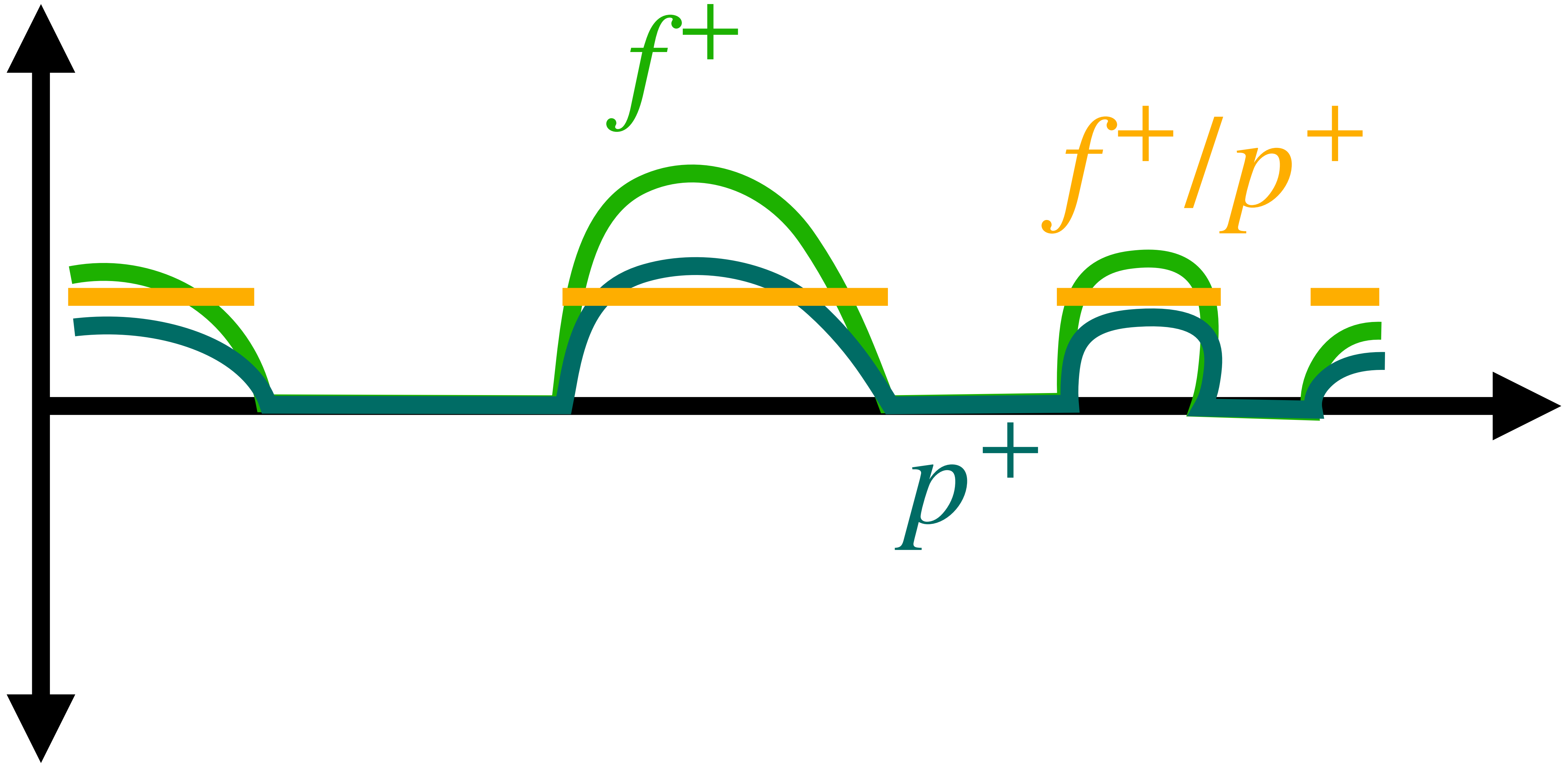
Positivization — Owen and Zhou 2000.



$=$



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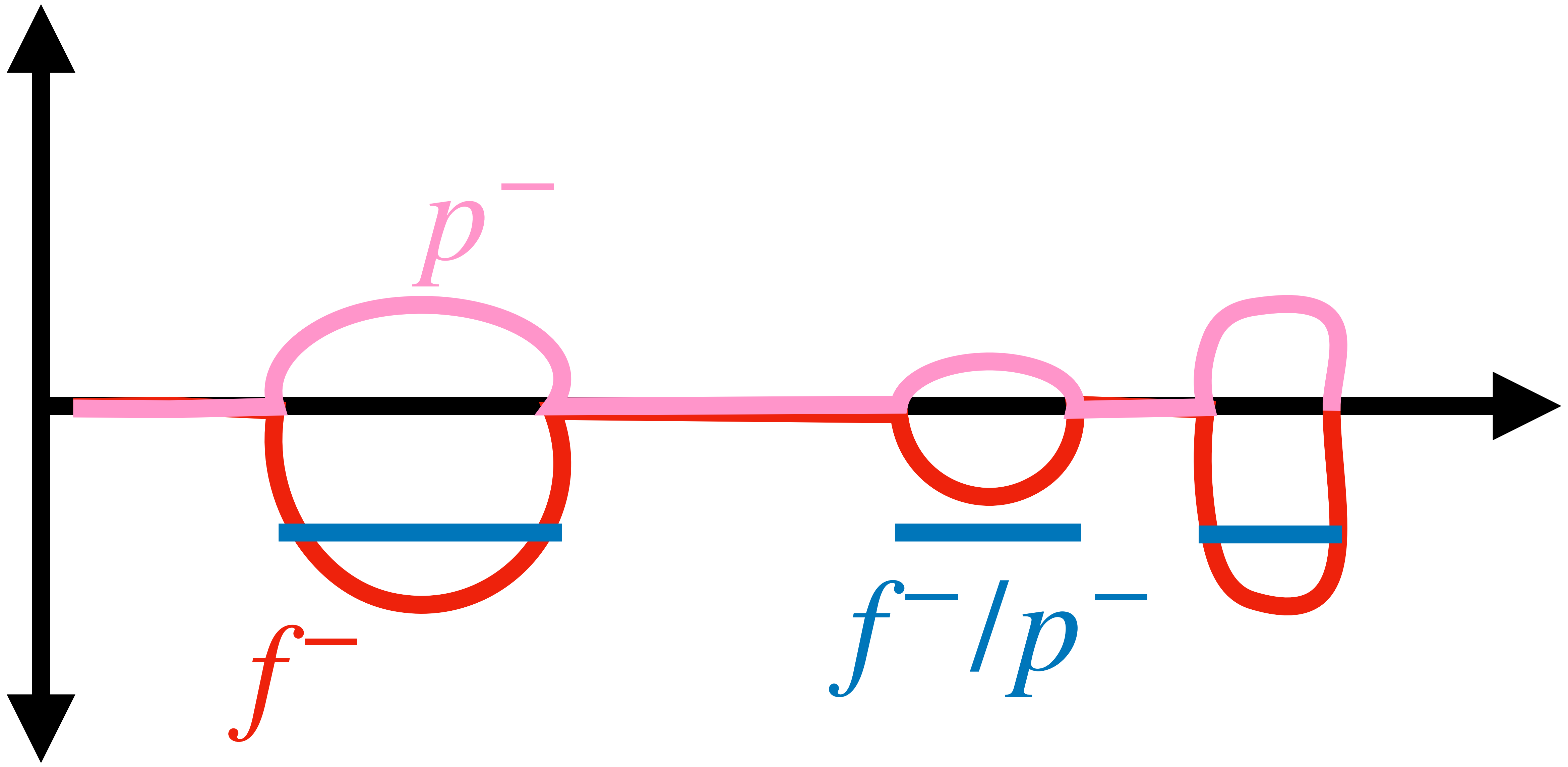
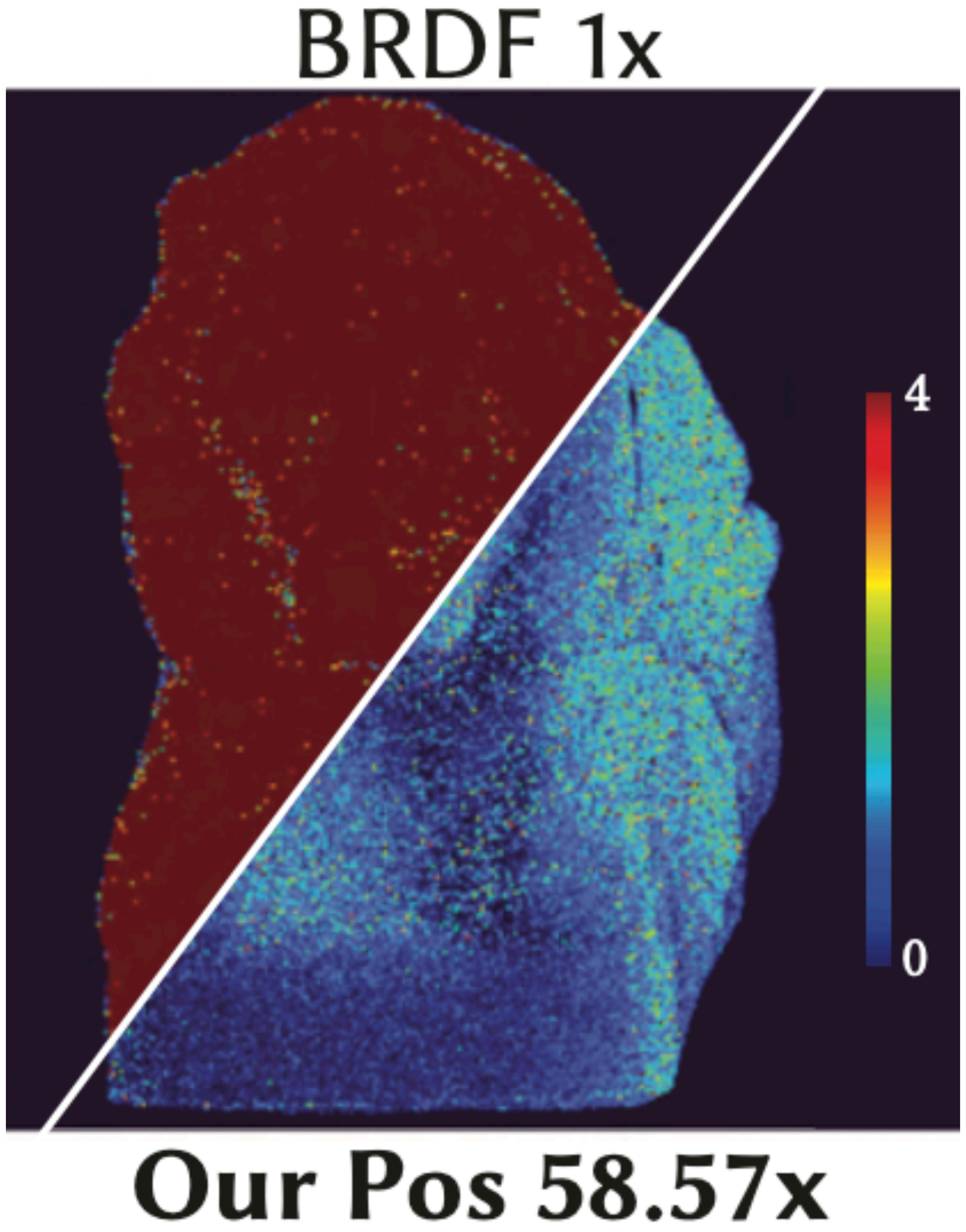


$p^+ \propto f^+$

$p^- \propto f^-$

Positivization reduces variance by 58x!

Forward rendering

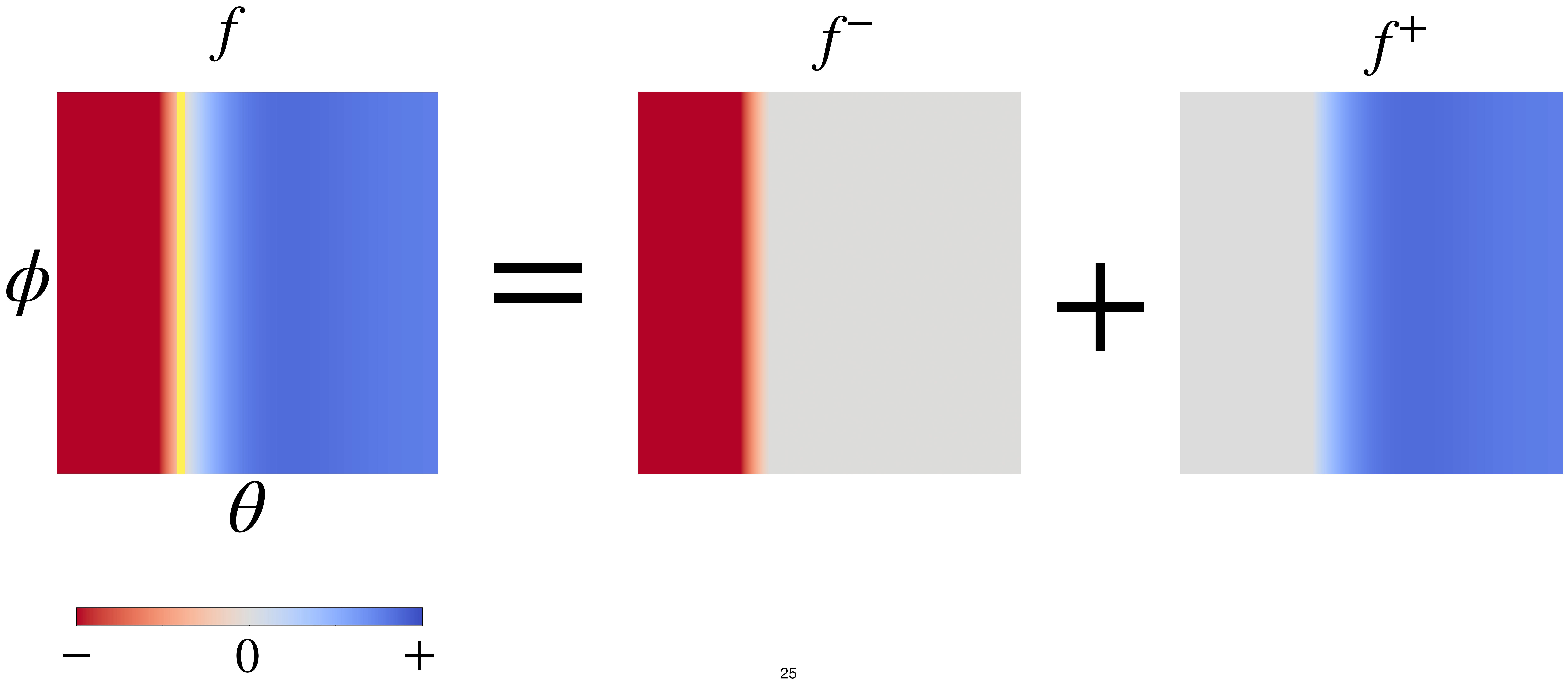


Variance

Positivization is applicable to several BRDF derivatives

- Roughness of isotropic **GGX, Beckmann**
- Exponent of **Blinn-Phong**
- Scattering parameter of **Hanrahan-Krueger BRDF**

Positivization requires analytic root locations



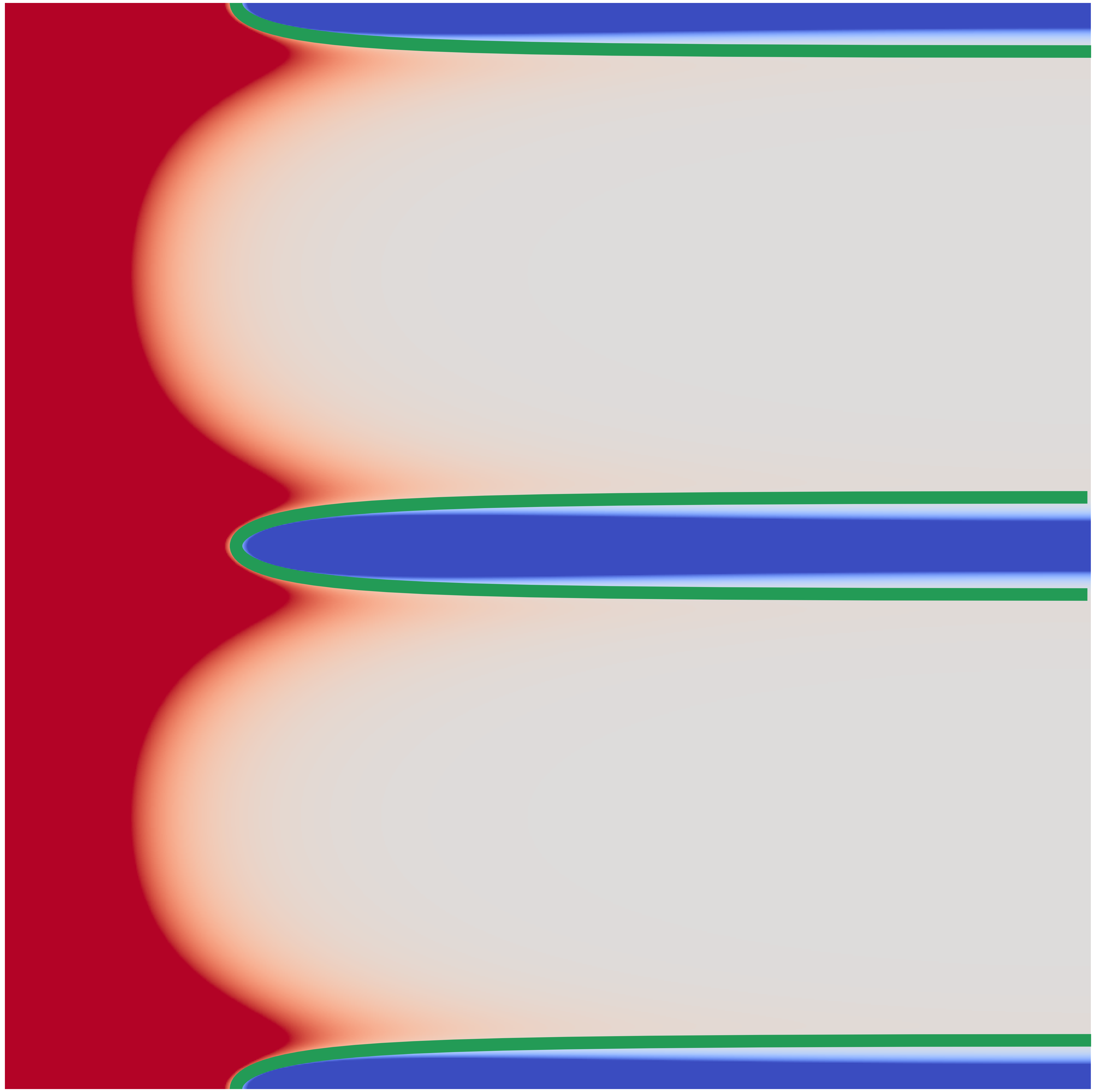
Positivization requires analytic integrability

$$c^- p^-(\theta, \phi) = f^-(\theta, \phi)$$

$$f^-(\theta, \phi)$$

$$c^- = \int$$

No analytic root locations — no positivization :(



No analytic integrability — no positivization :(

$$f^-(\theta, \phi)$$

$$c^- = \int$$

Positivization is inapplicable to several BRDF derivatives :(

- Directional roughness of anisotropic **Beckmann and GGX**
- Directional exponent of **Ashikhmin-Shirley**
- Width of **Burley's BSSRDF**
- Weights of mixture BRDFs
  - All layered BRDFs (**Disney Principled, Autodesk Standard Surface**, etc.)
  - **Oren-Nayar**
  - **Microcylinder BRDF**
- and many others…

Our product and mixture decomposition can handle these!

- Directional roughness of anisotropic **Beckmann and GGX**
- Directional exponent of **Ashikhmin-Shirley**
- Width of **Burley's BSSRDF**

Product decomposition

- Weights of mixture BRDFs
  - All layered BRDFs (**Disney Principled, Autodesk Standard Surface**, etc.)
  - **Oren-Nayar**
  - **Microcylinder BRDF**
- and many others…

Mixture decomposition

Key idea: let positive and negative parts overlap!

Recall: Positivization has non-overlapping support

A decomposition with overlapping support

Another decomposition with overlapping support

Our Mixture Decomposition

$$g = \beta g_s + (1 - \beta) g_d$$

Our Mixture Decomposition

$$g = \beta g_s + (1 - \beta) g_d$$

$$\partial_\beta g = f = g_s - g_d$$

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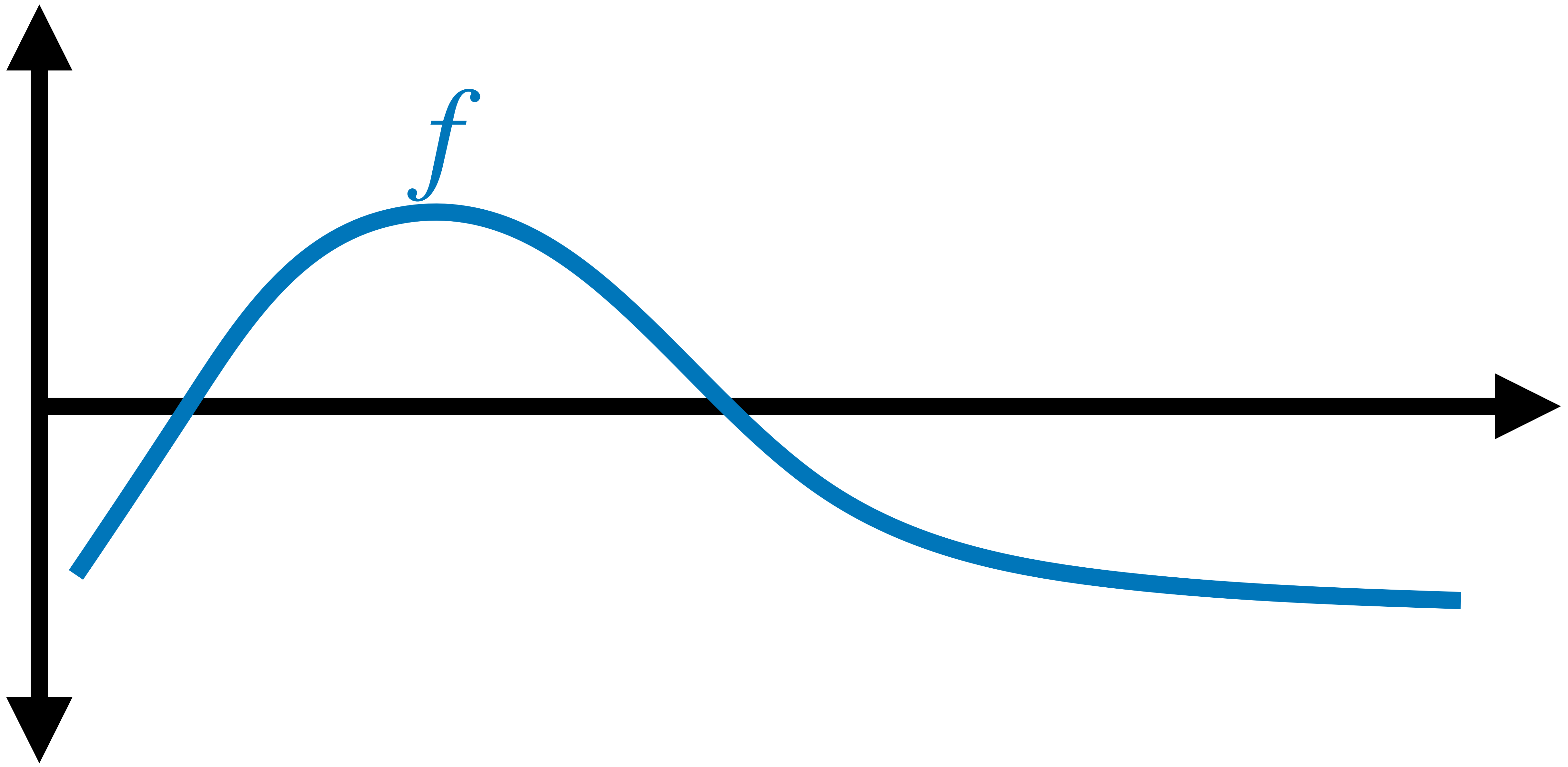

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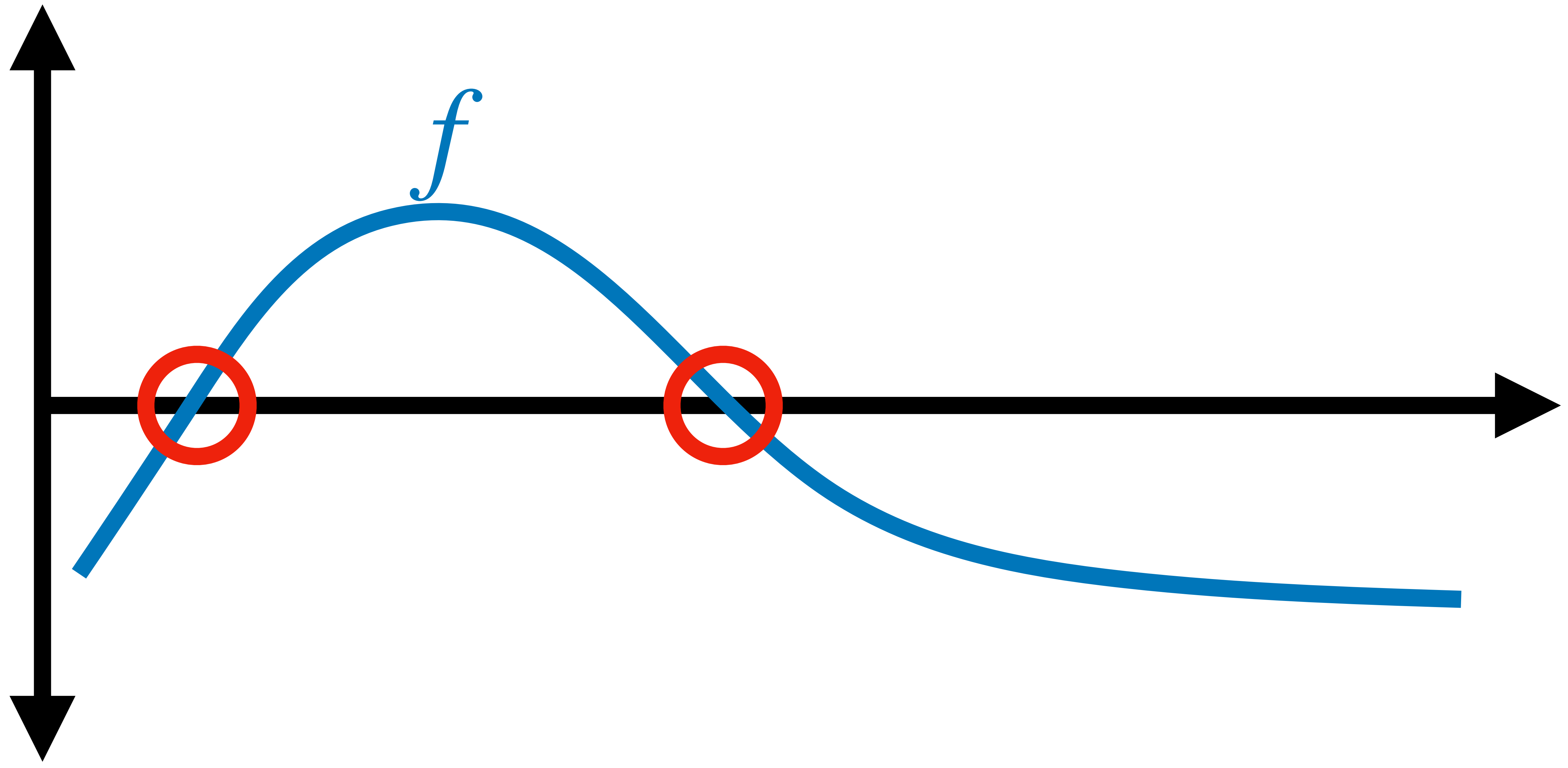
$$g = \beta g_s + (1 - \beta) g_d$$

$$\partial_\beta g = f = g_s - g_d$$



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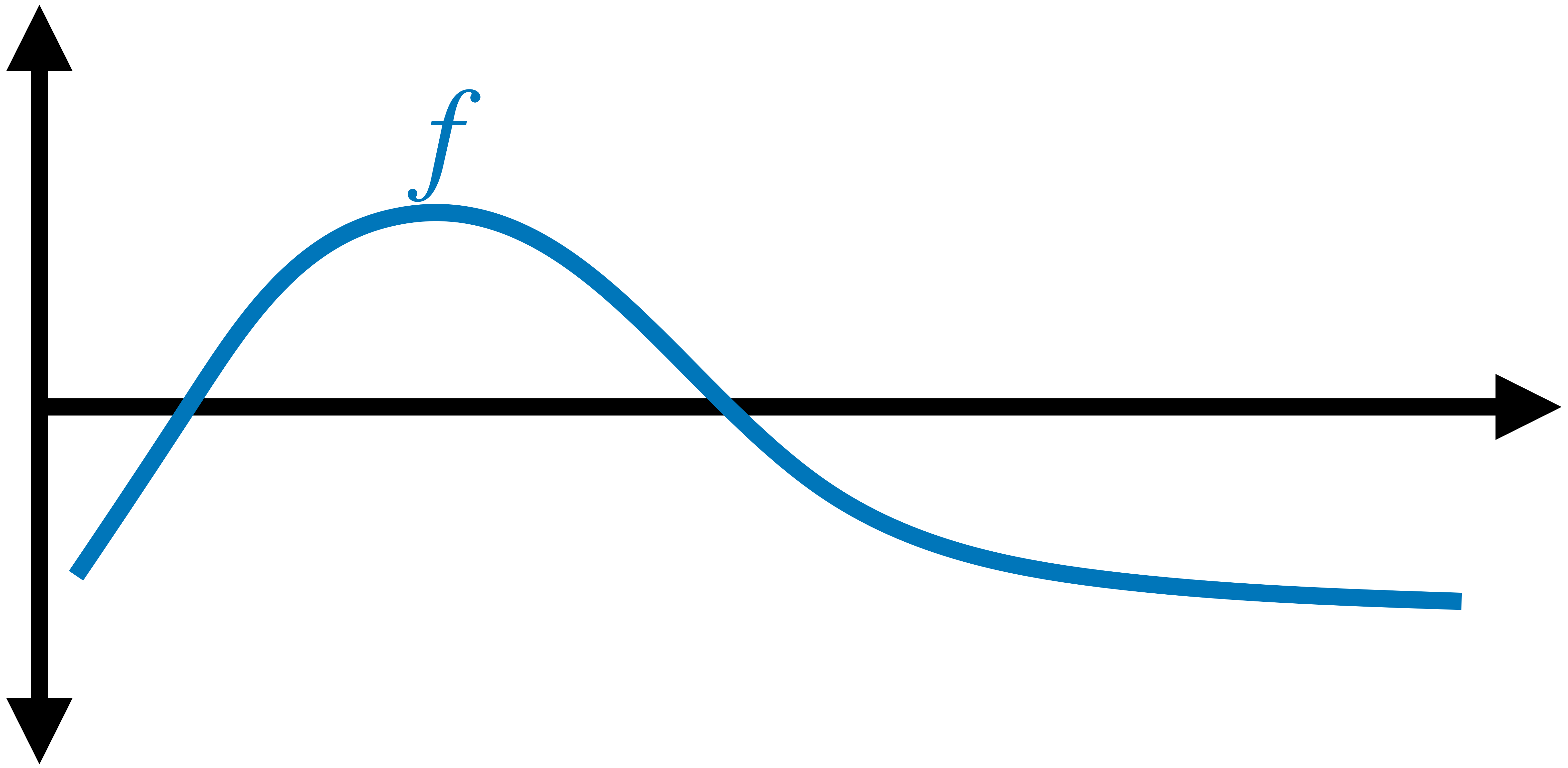

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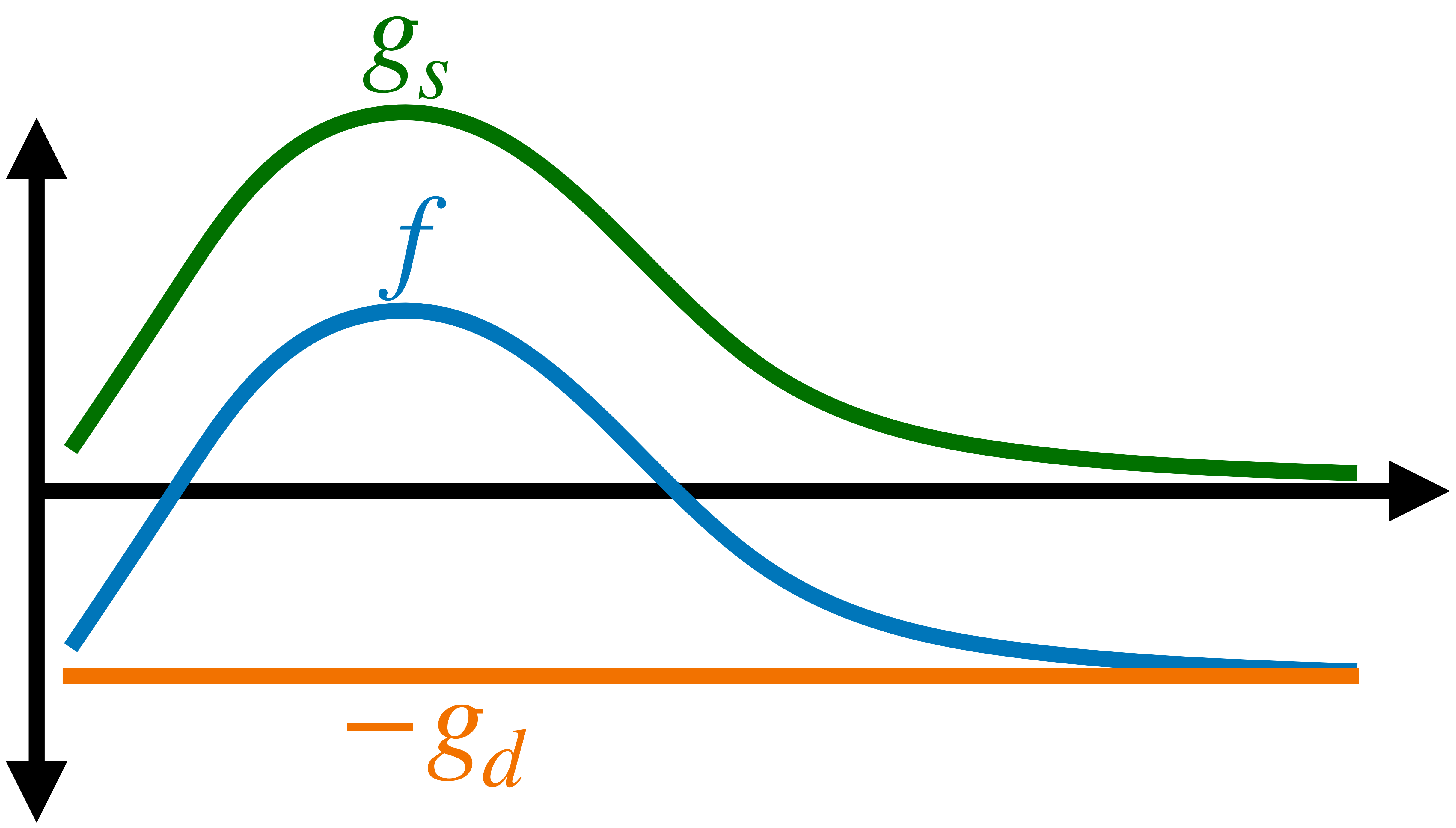

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Our Mixture Decomposition

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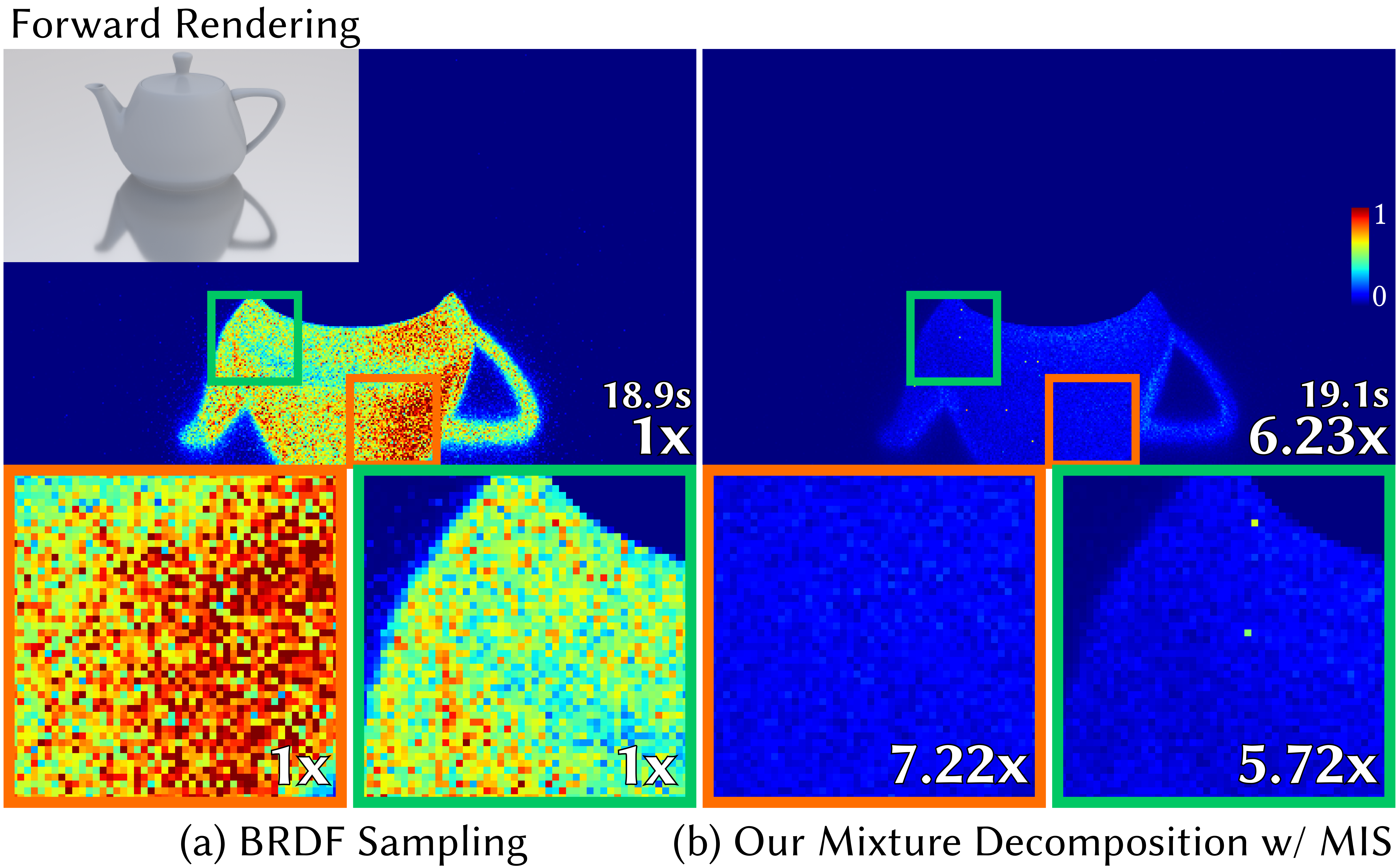
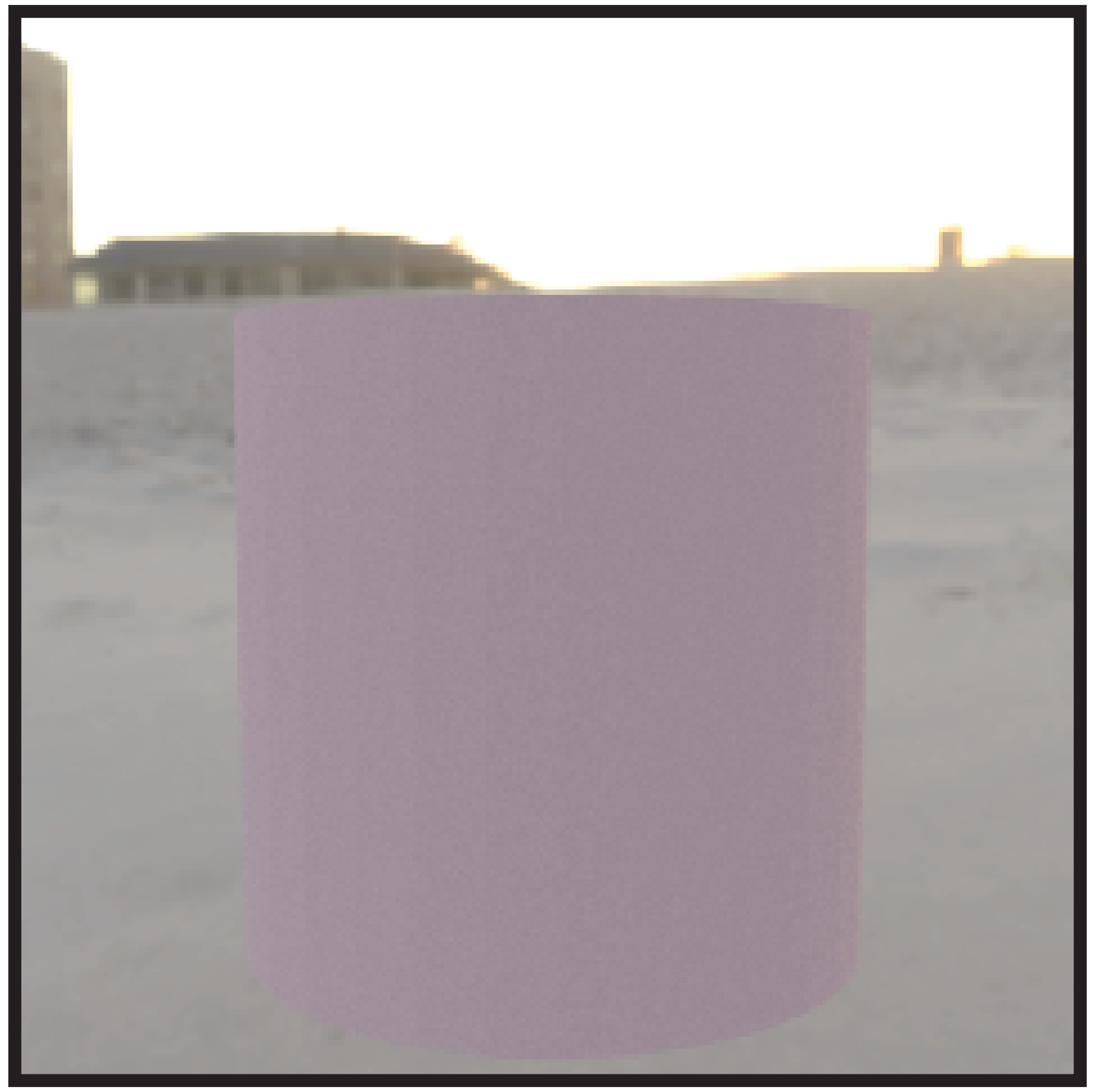
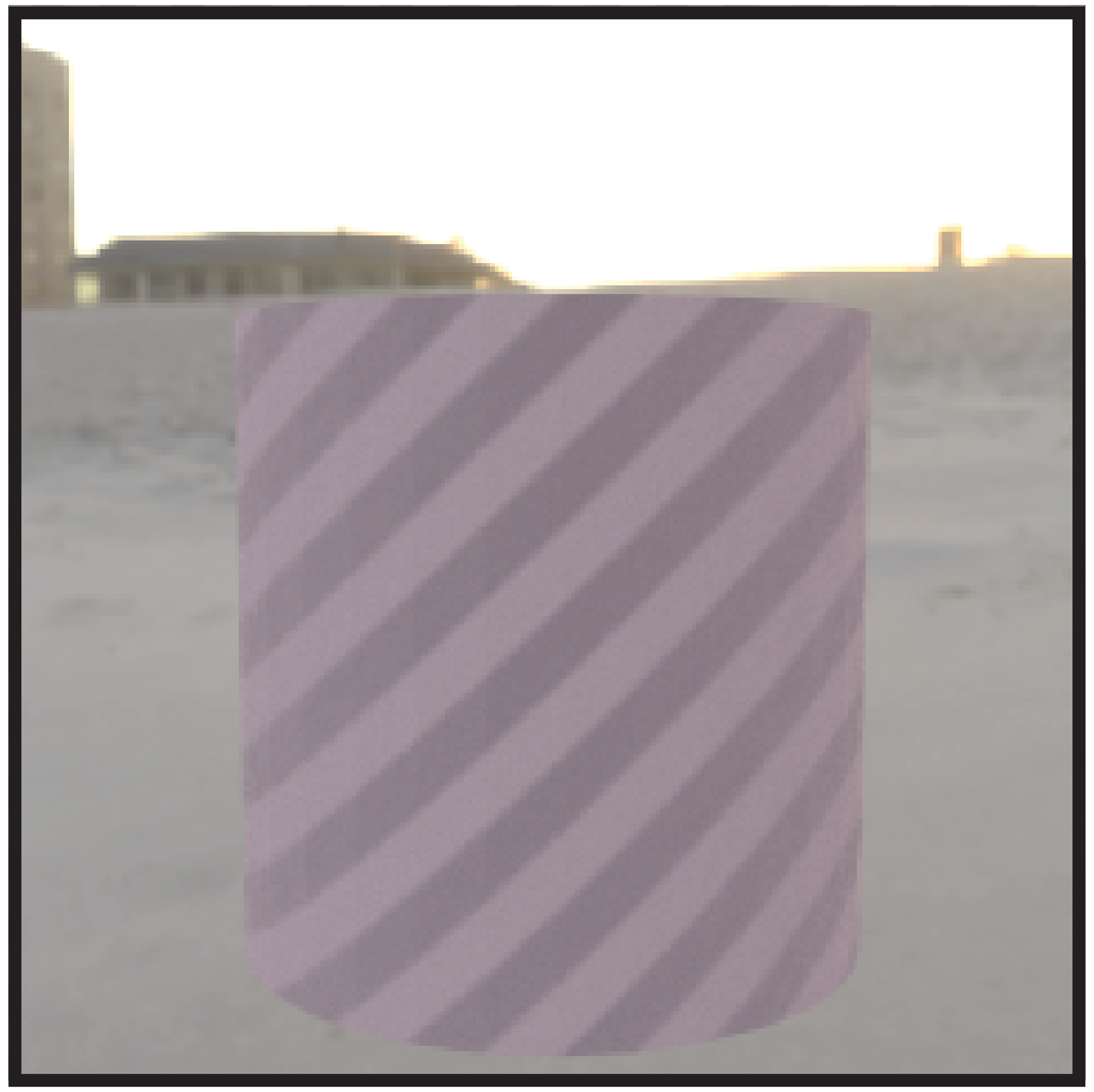
Mixture decomposition reduces variance of glossy reflections



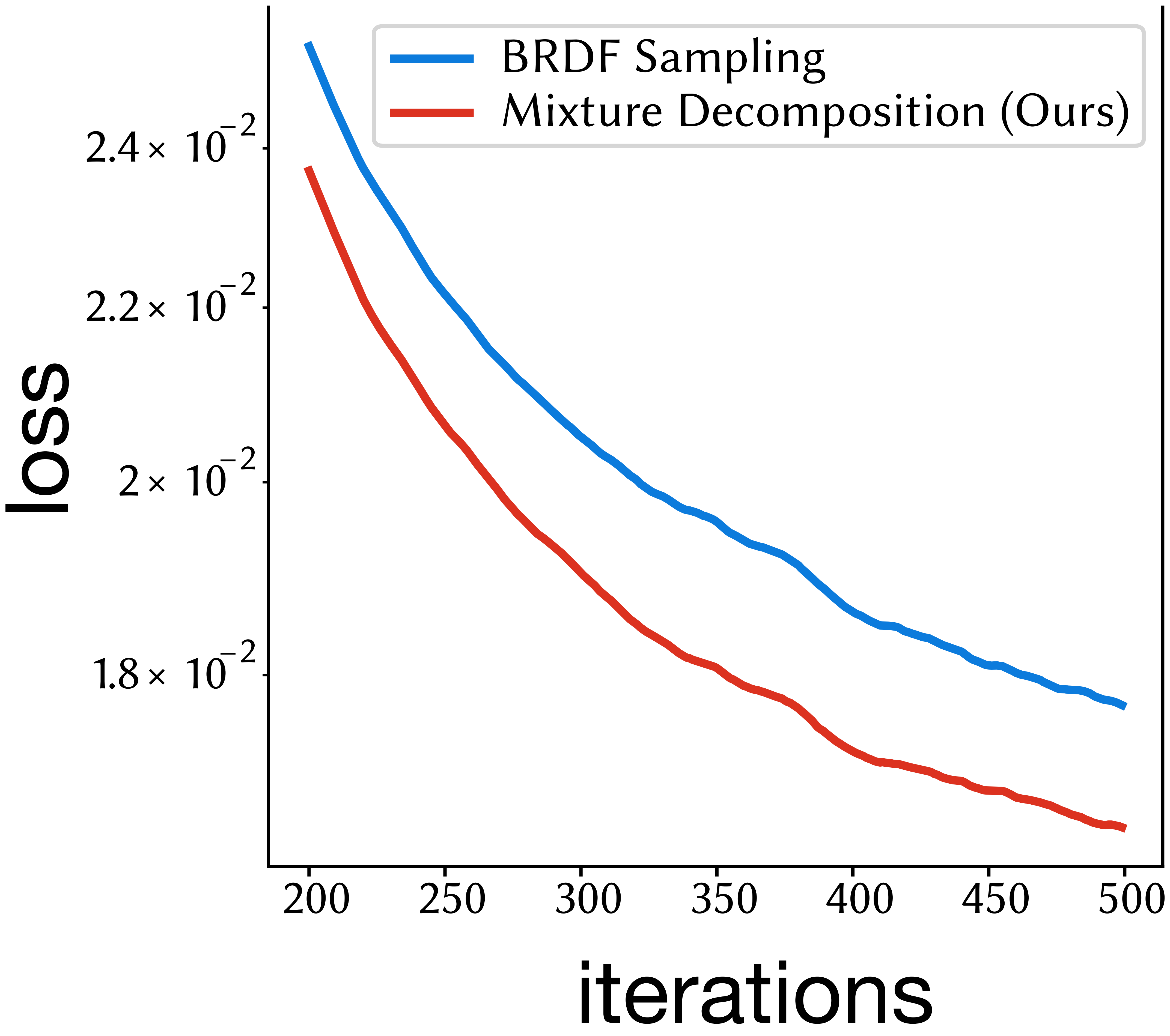
Mixture decomposition improves inverse rendering



initialization



recovery



- Weights of mixture BRDFs
    - All layered BRDFs (**Disney Principled, Autodesk Standard Surface**, etc.)
    - **Oren-Nayar**
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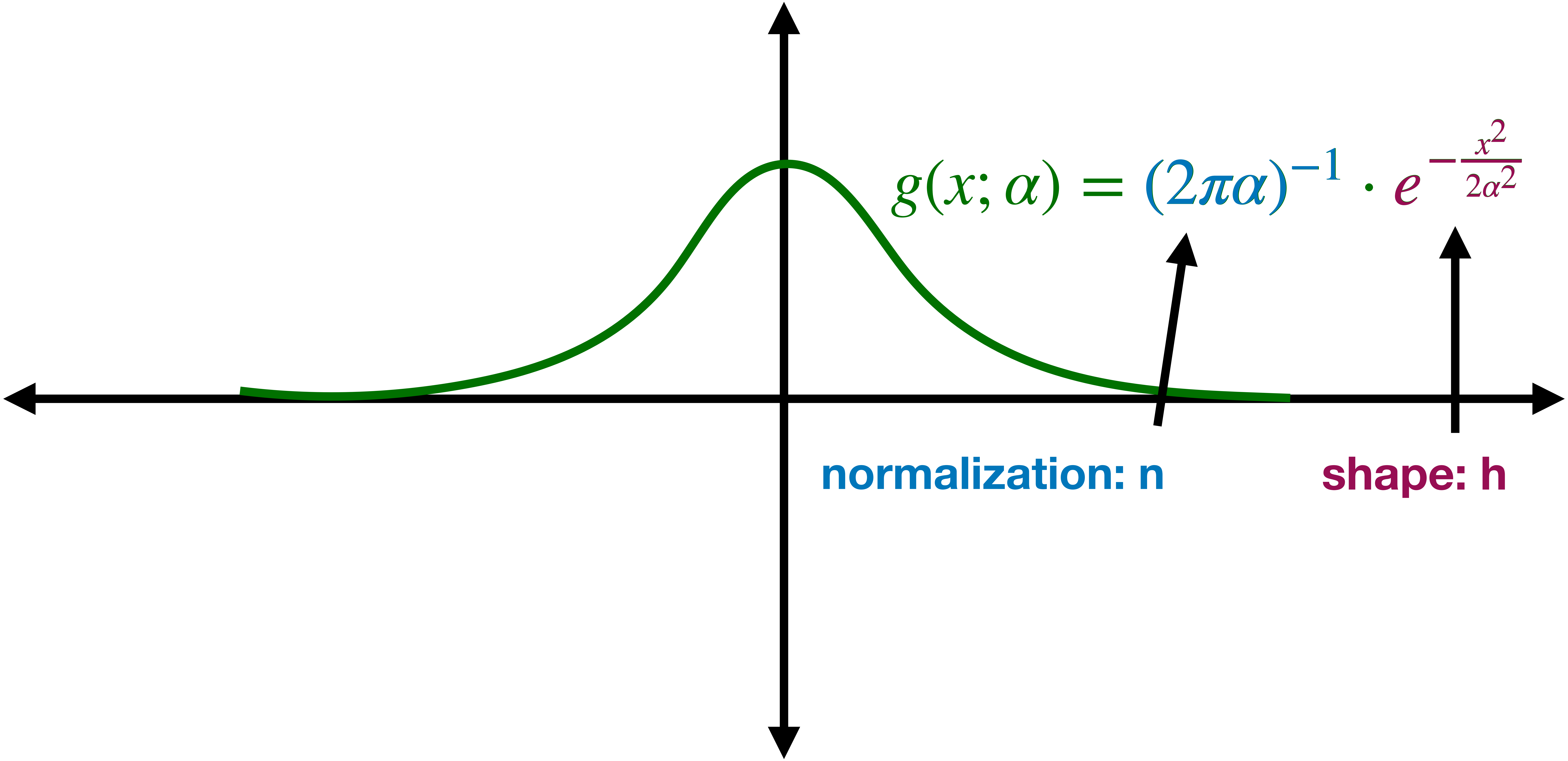
- and many others…

Our mixture decomposition

Our product decomposition

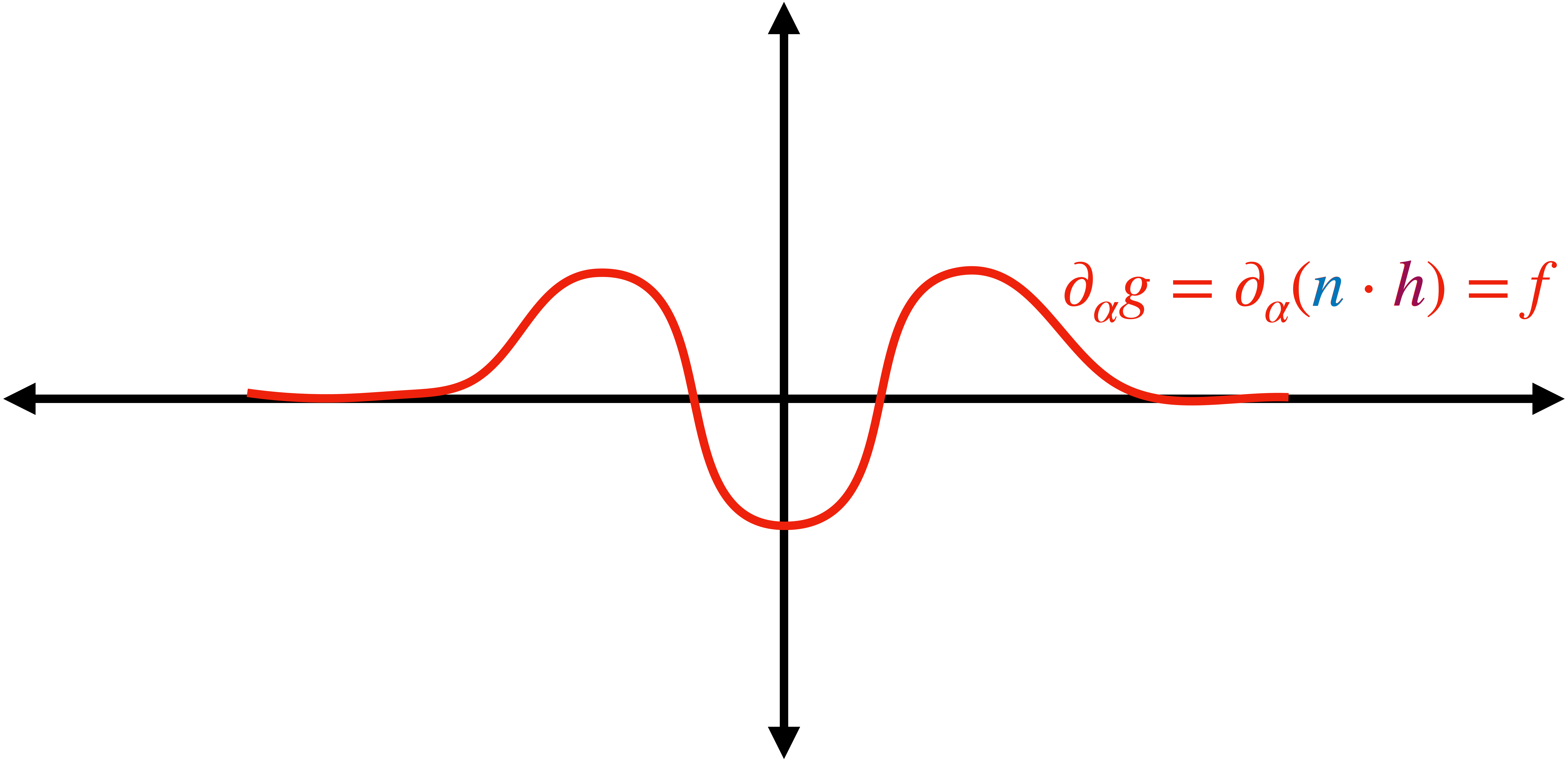


$$g(x;\alpha) = (2\pi\alpha)^{-1} \cdot e^{-\frac{x^2}{2\alpha^2}}$$

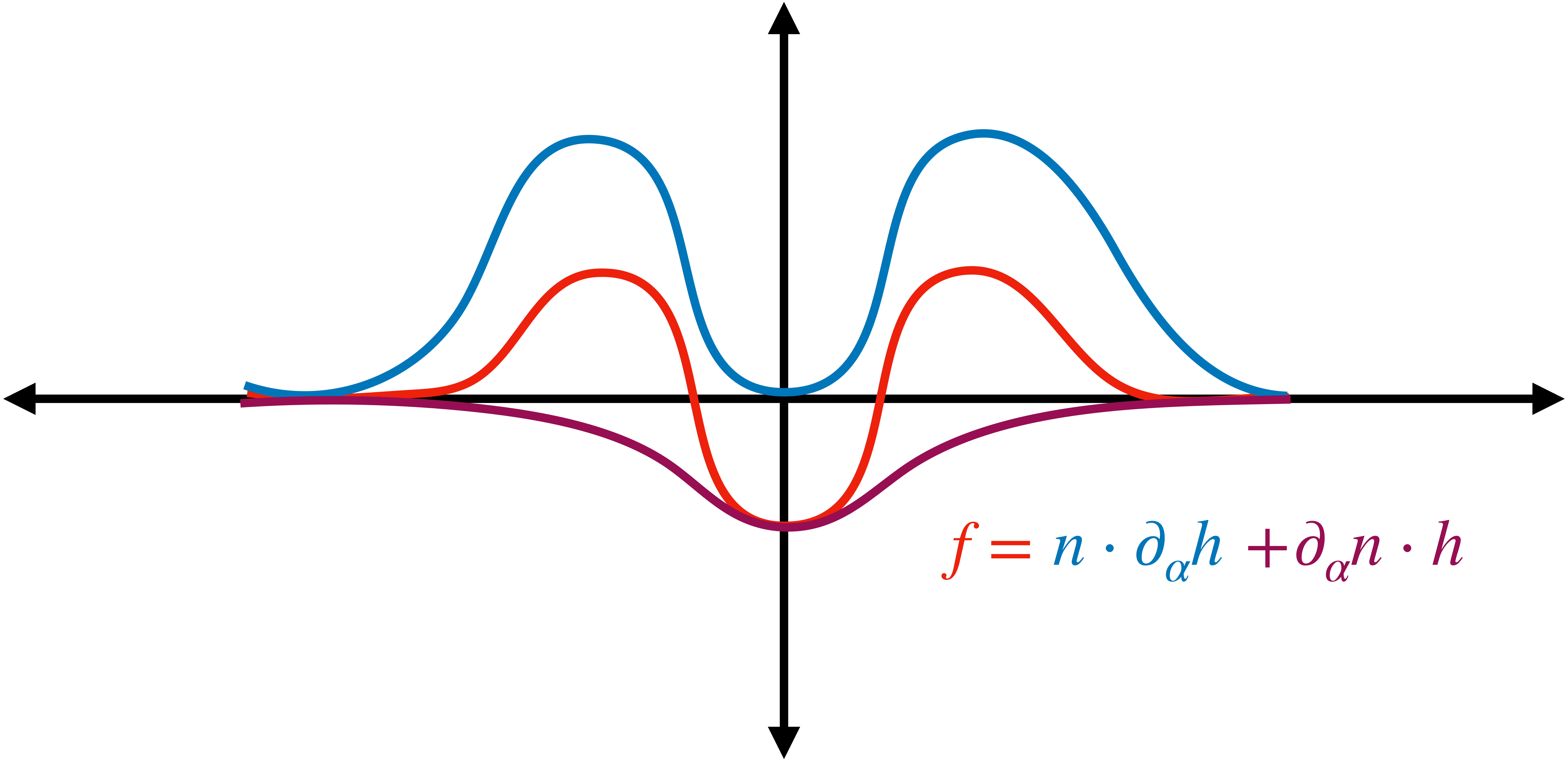
normalization: n

shape: h

Our product decomposition



Our product decomposition

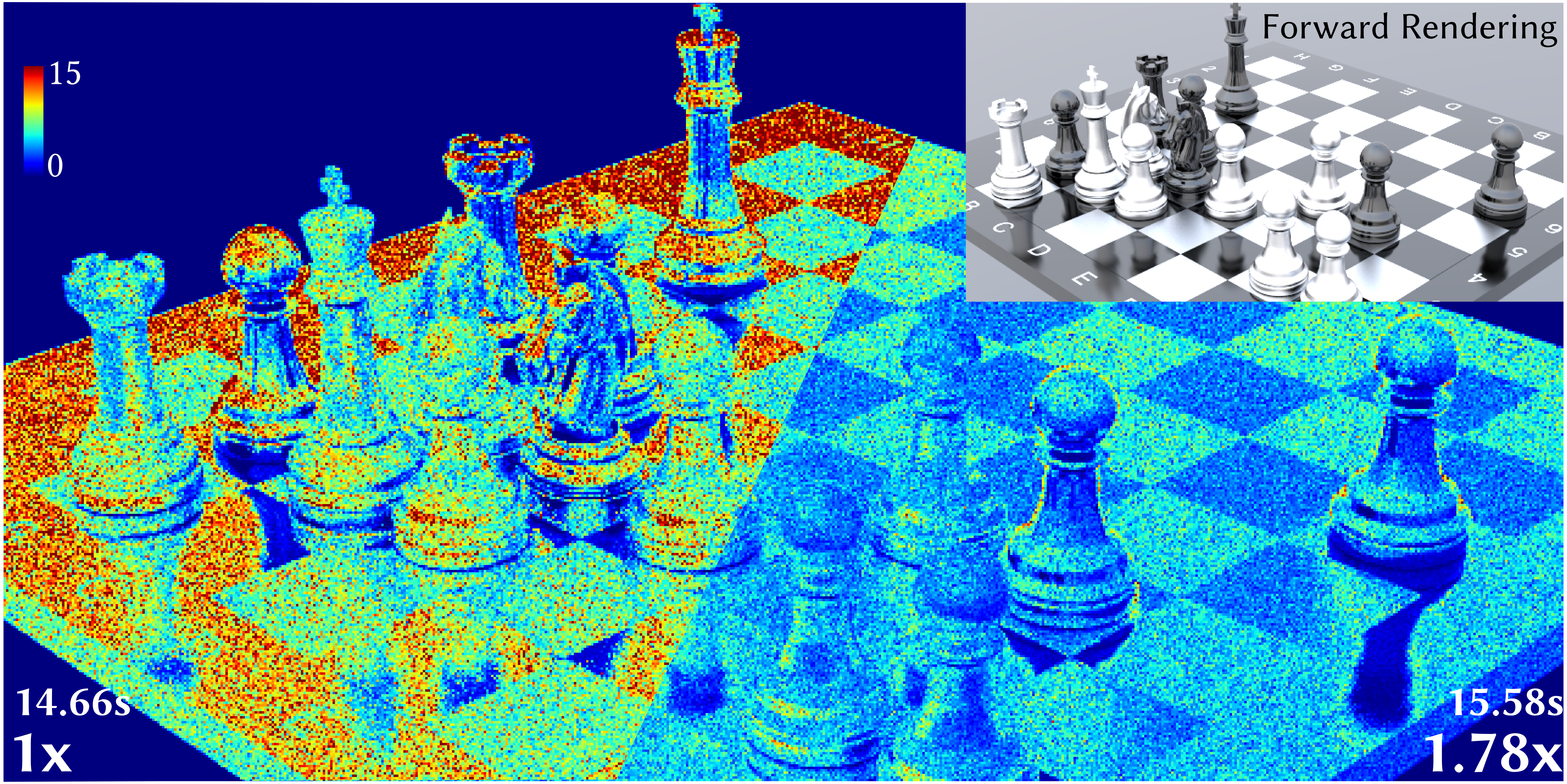


$$f = n \cdot \partial_\alpha h + \partial_\alpha n \cdot h$$

Product decomposition of anisotropic GGX derivative

$$f = n \cdot \partial_\alpha h + \partial_\alpha n \cdot h$$

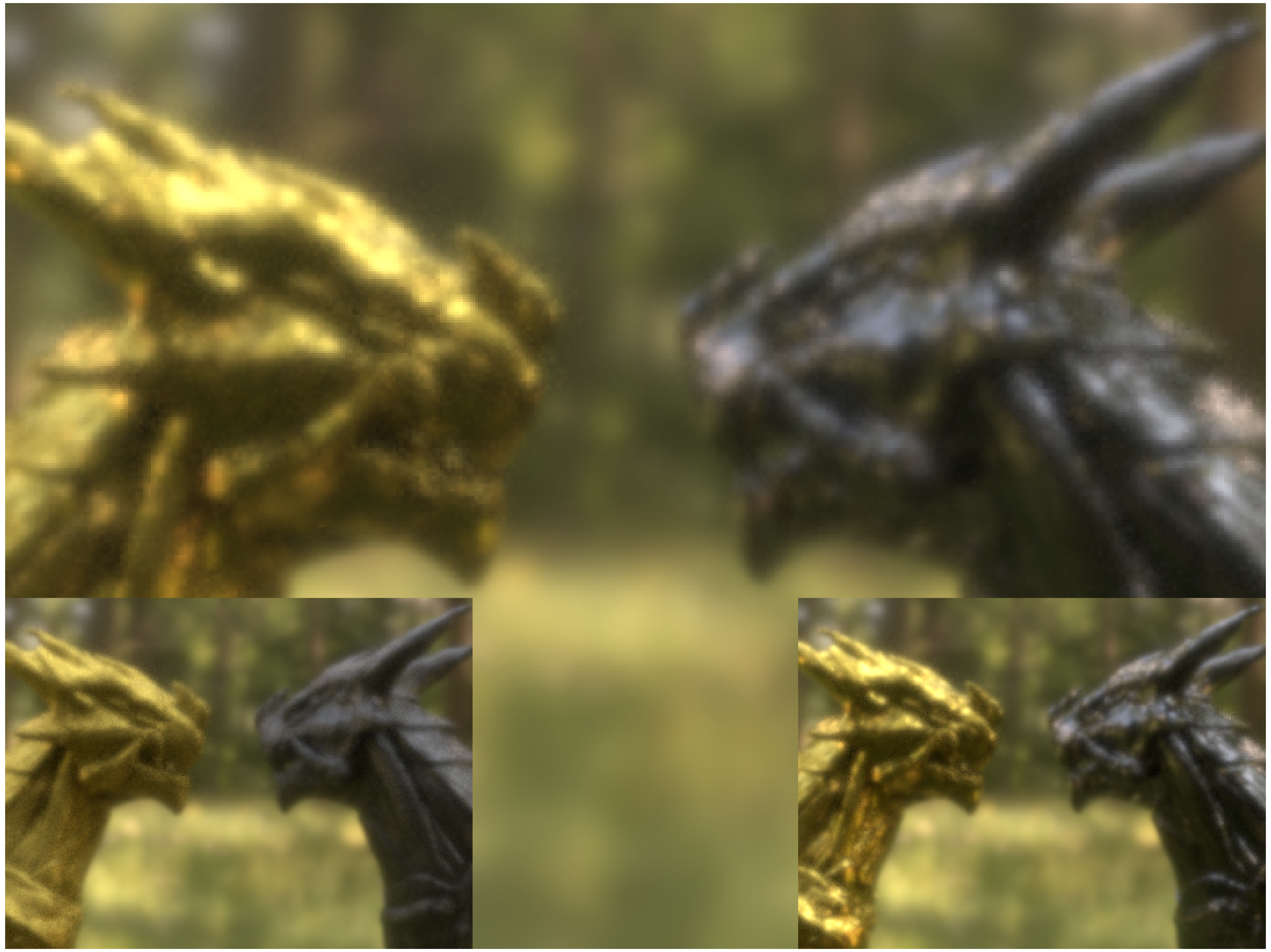
Product decomposition under global illumination



(a) BRDF Sampling (b) Our Product Decomposition with MIS

Product decomposition improves inverse rendering

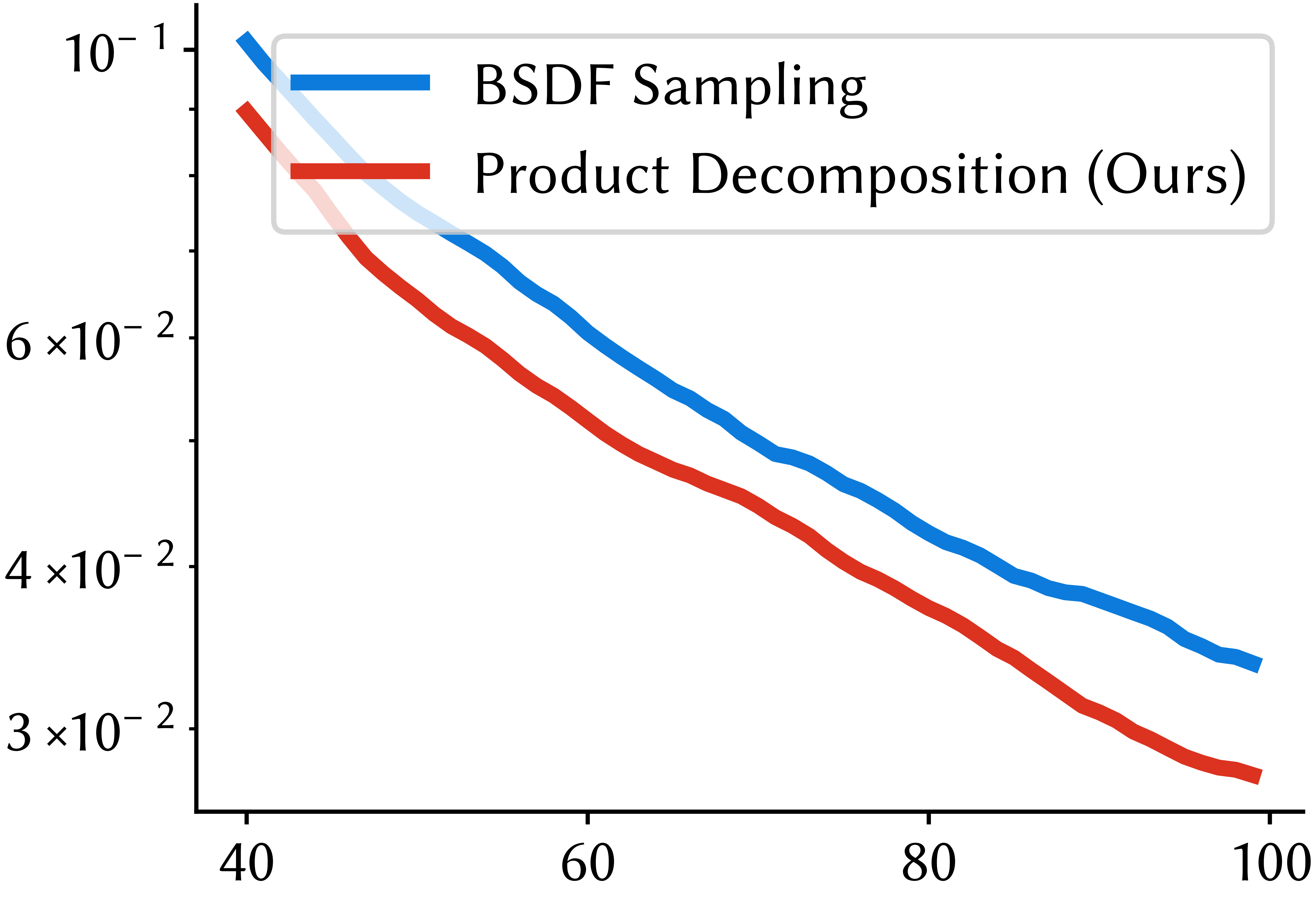
(a) Forward Rendering of Target



Initialization

Our Recovery Rendering

(b) α_x Recovery Loss (L1) over Iterations



- Directional roughness of anisotropic **Beckmann and GGX**
- Directional exponent of **Ashikhmin-Shirley**
- Width of **Burley's BSSRDF**

Our product decomposition

We now have good importance sampling techniques for BRDF in differentiable rendering