

Directional Dipole Model for Subsurface Scattering

Jeppé Revall Frisvad

Toshiya Hachisuka

Thomas Kim Kjeldsen

Technical University of Denmark

The University of Tokyo

The Alexandra Institute

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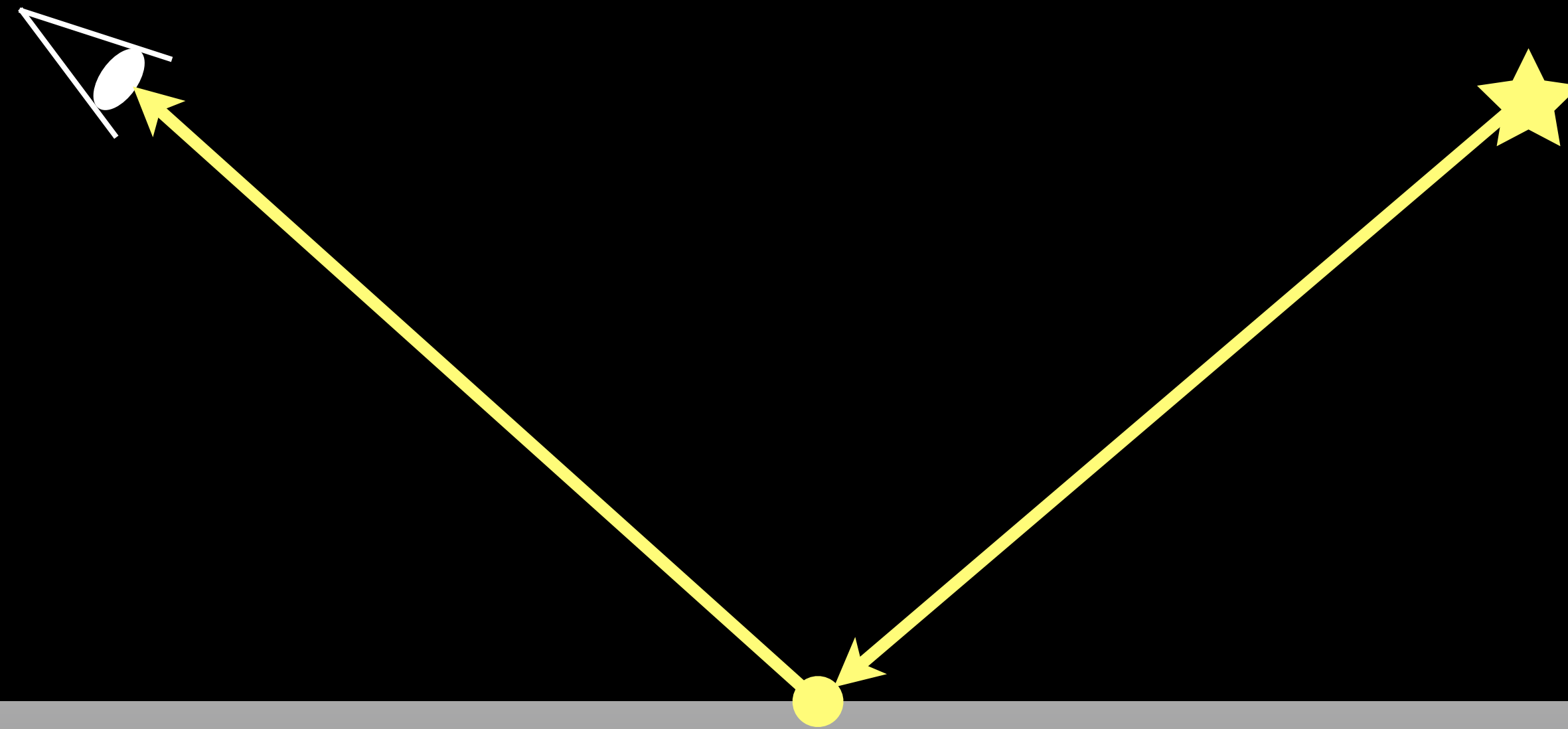




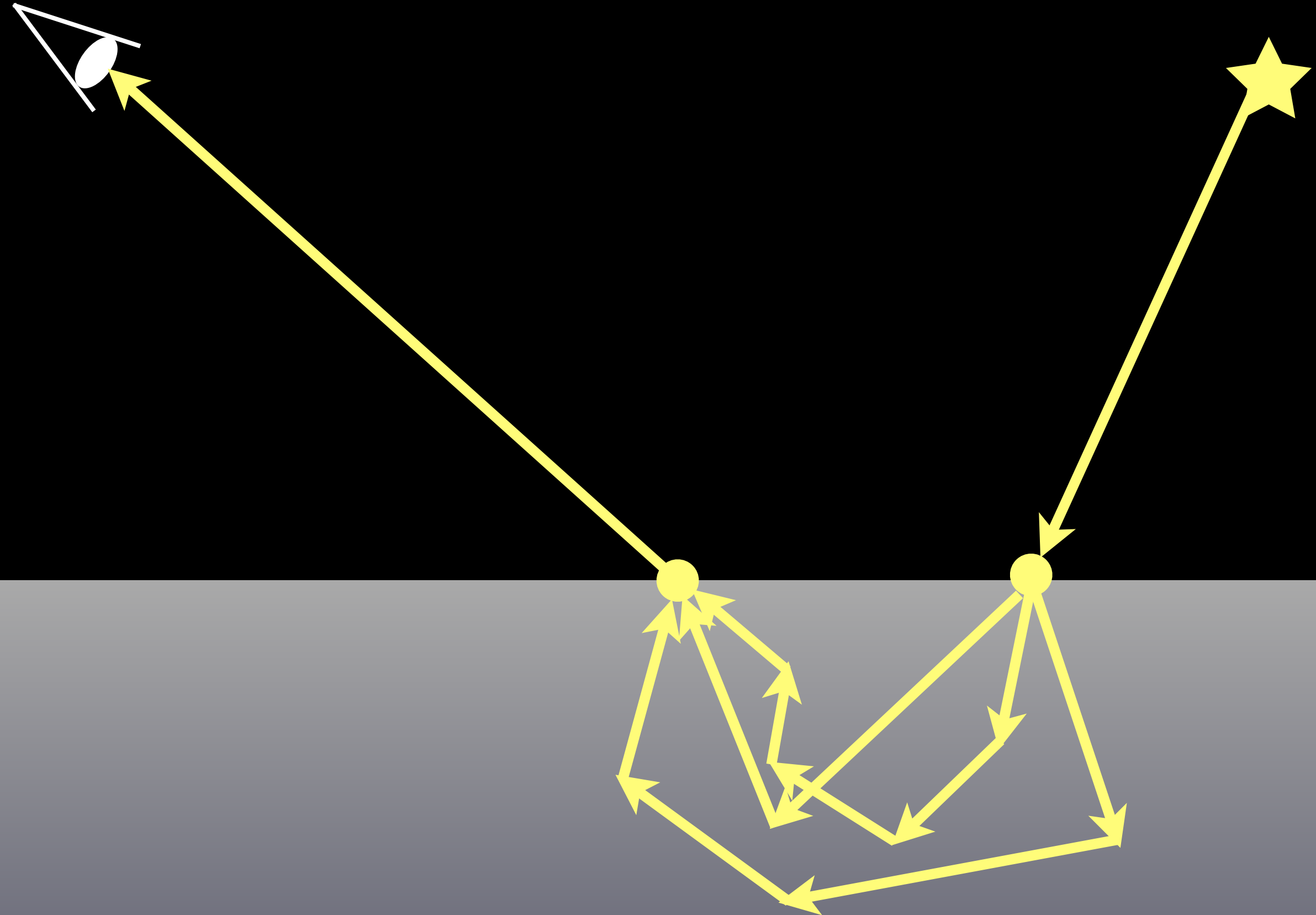




Bidirectional Reflectance Distribution Function



Bidirectional Surface Scattering Reflectance Distribution Function





BRDF



BSSRDF



Monte Carlo simulation - **Days**



BSSRDF approximation - **Minutes**

BSSRDF Models

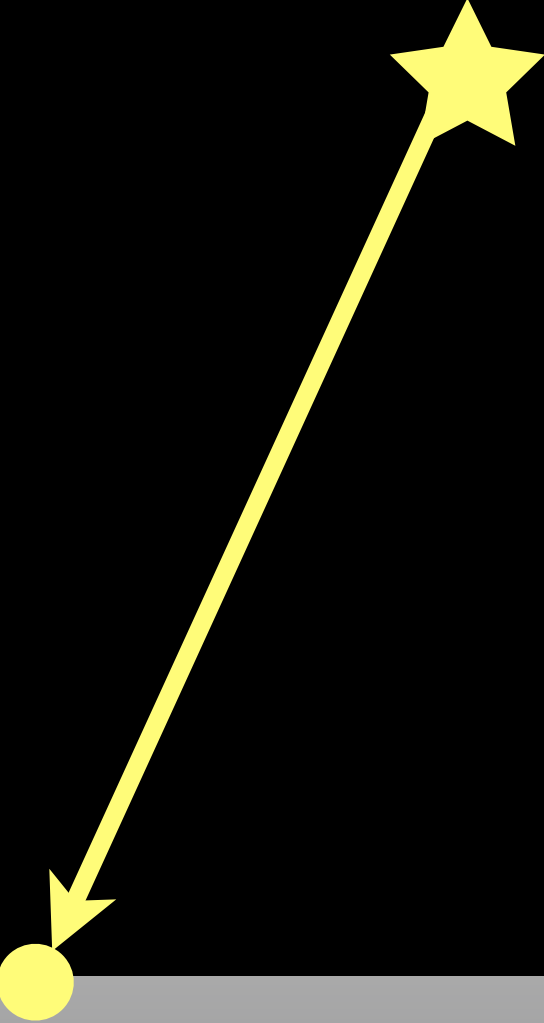
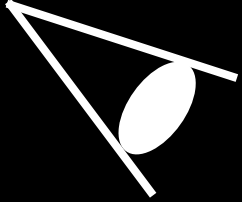
BSSRDF Models

- Dipole [Jensen et al. 2001]
- Multipole [Donner & Jensen 2005]
- Quantized diffusion [d'Eon & Irving 2011]
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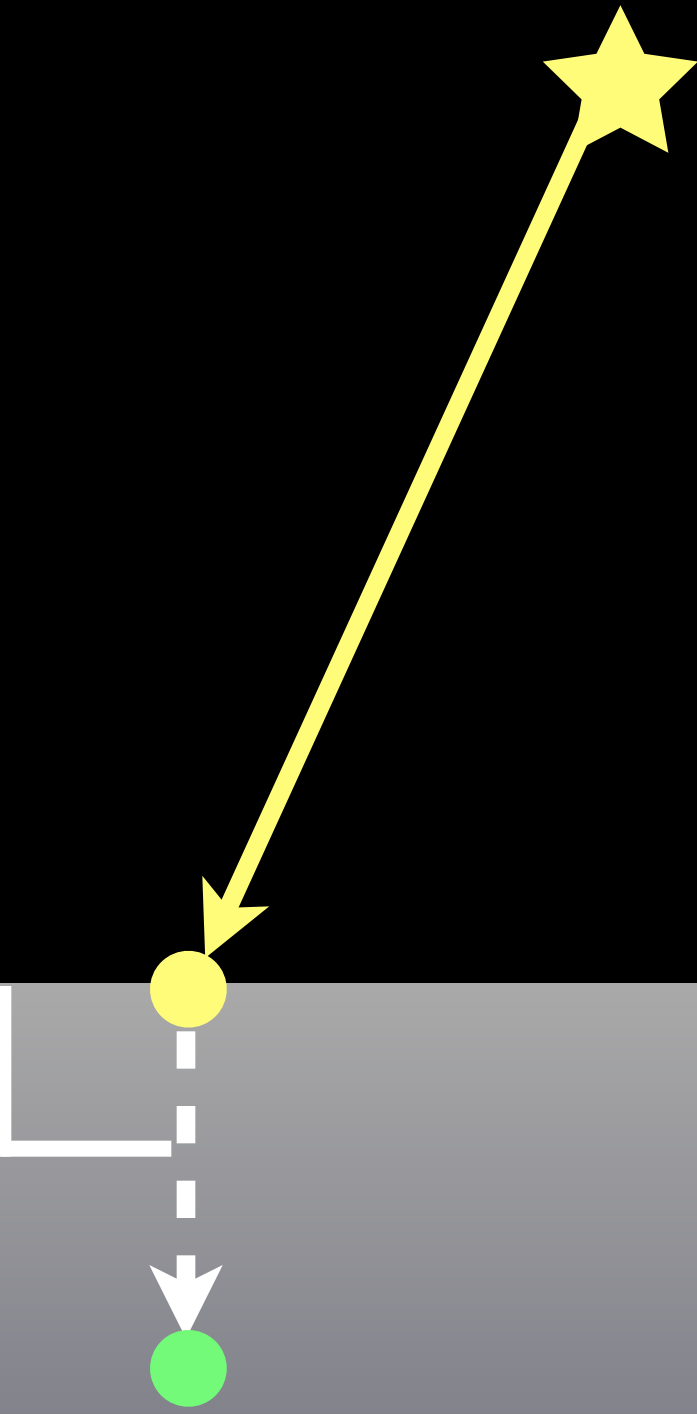
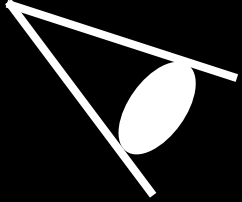
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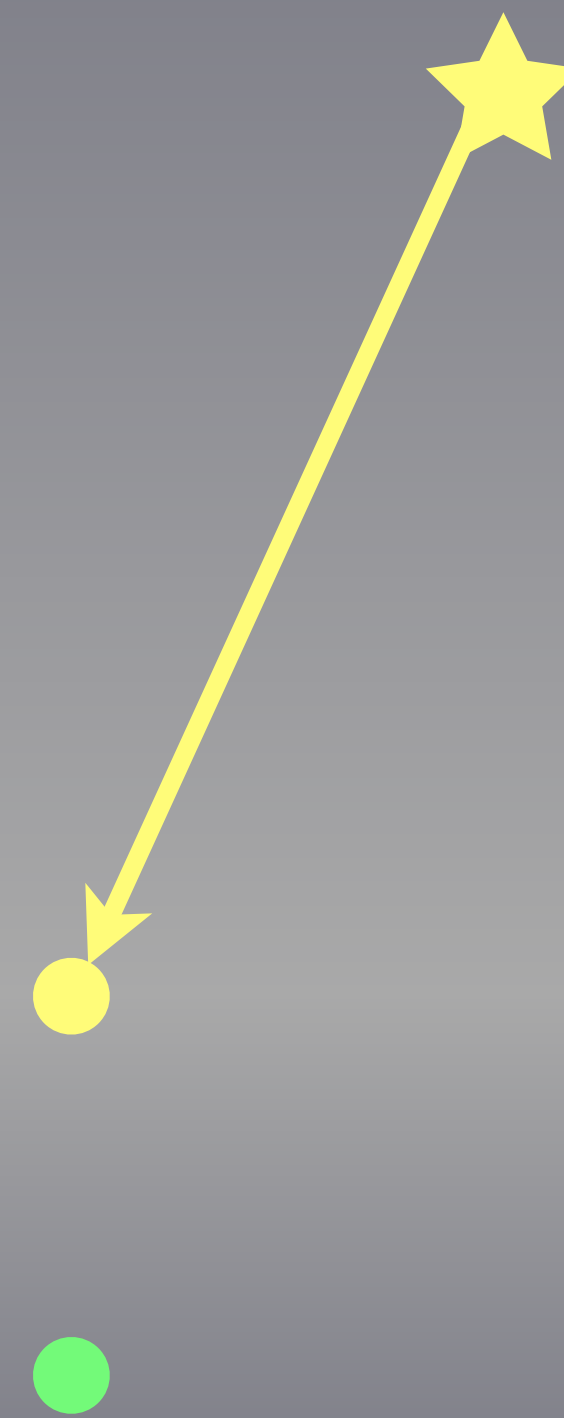
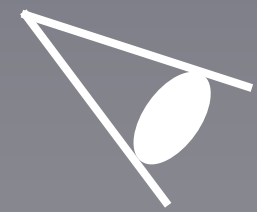
Dipole



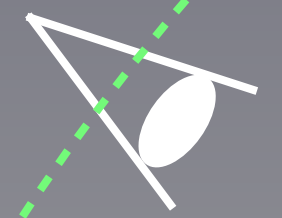
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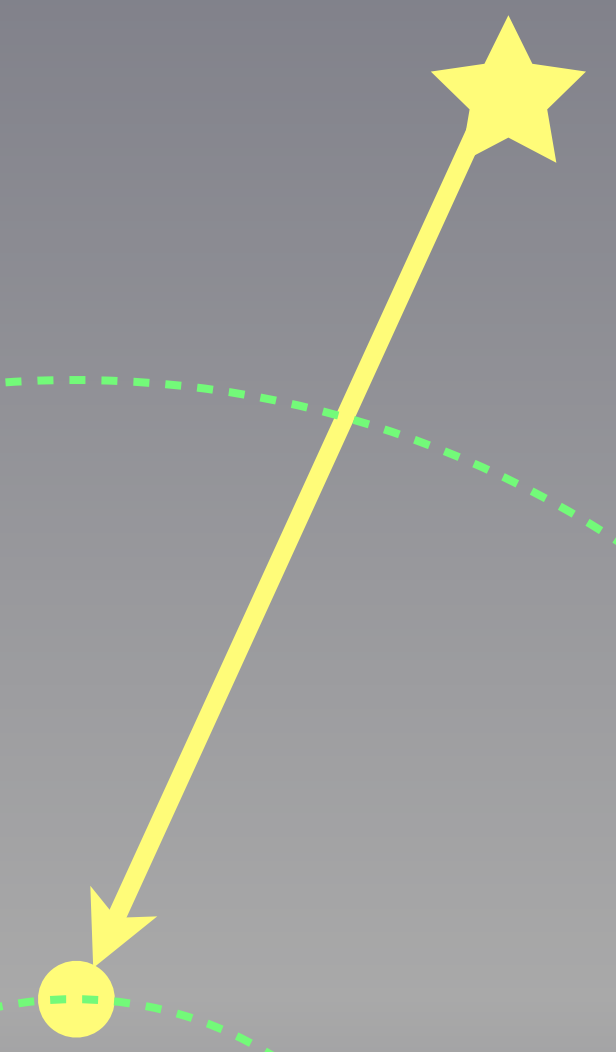
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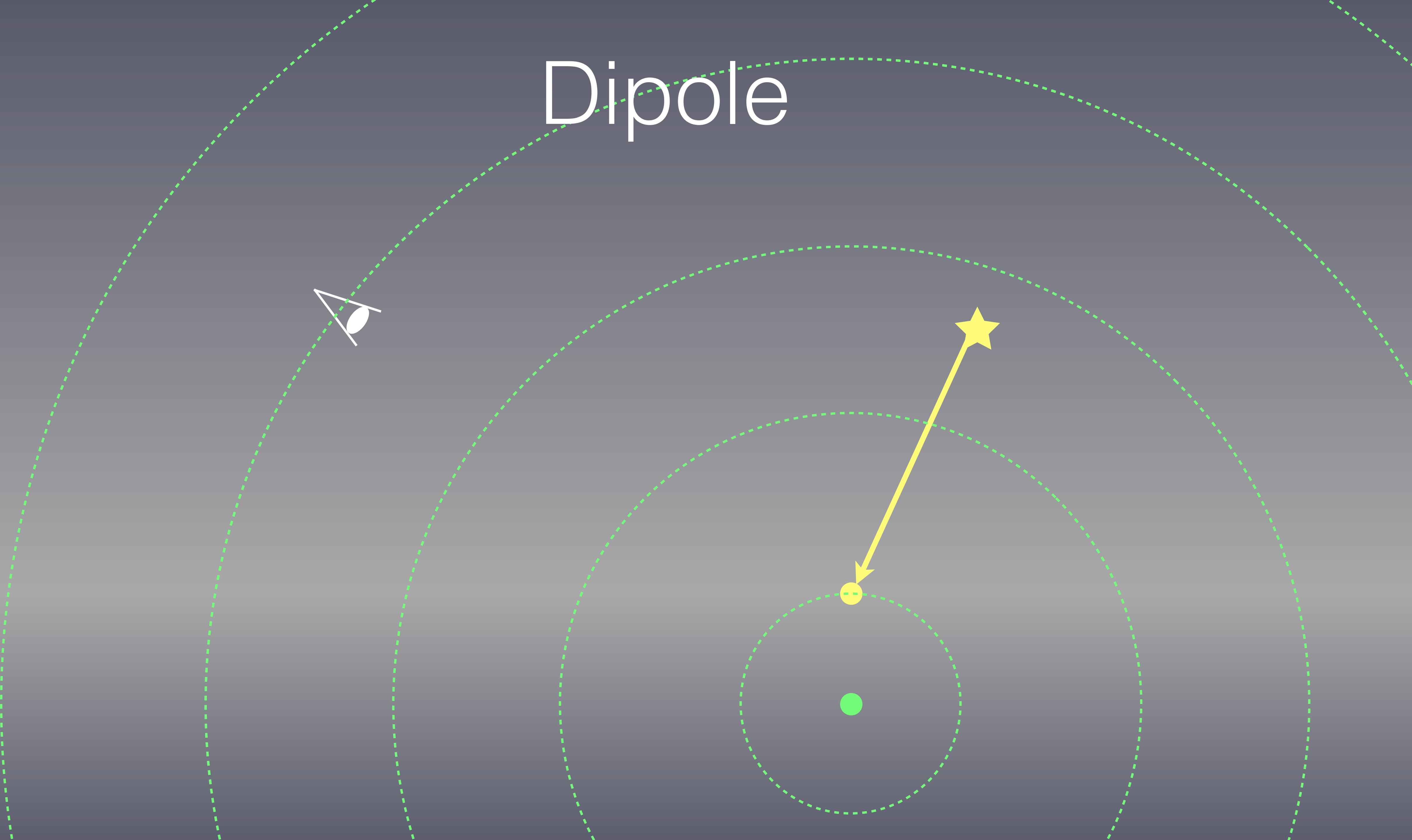
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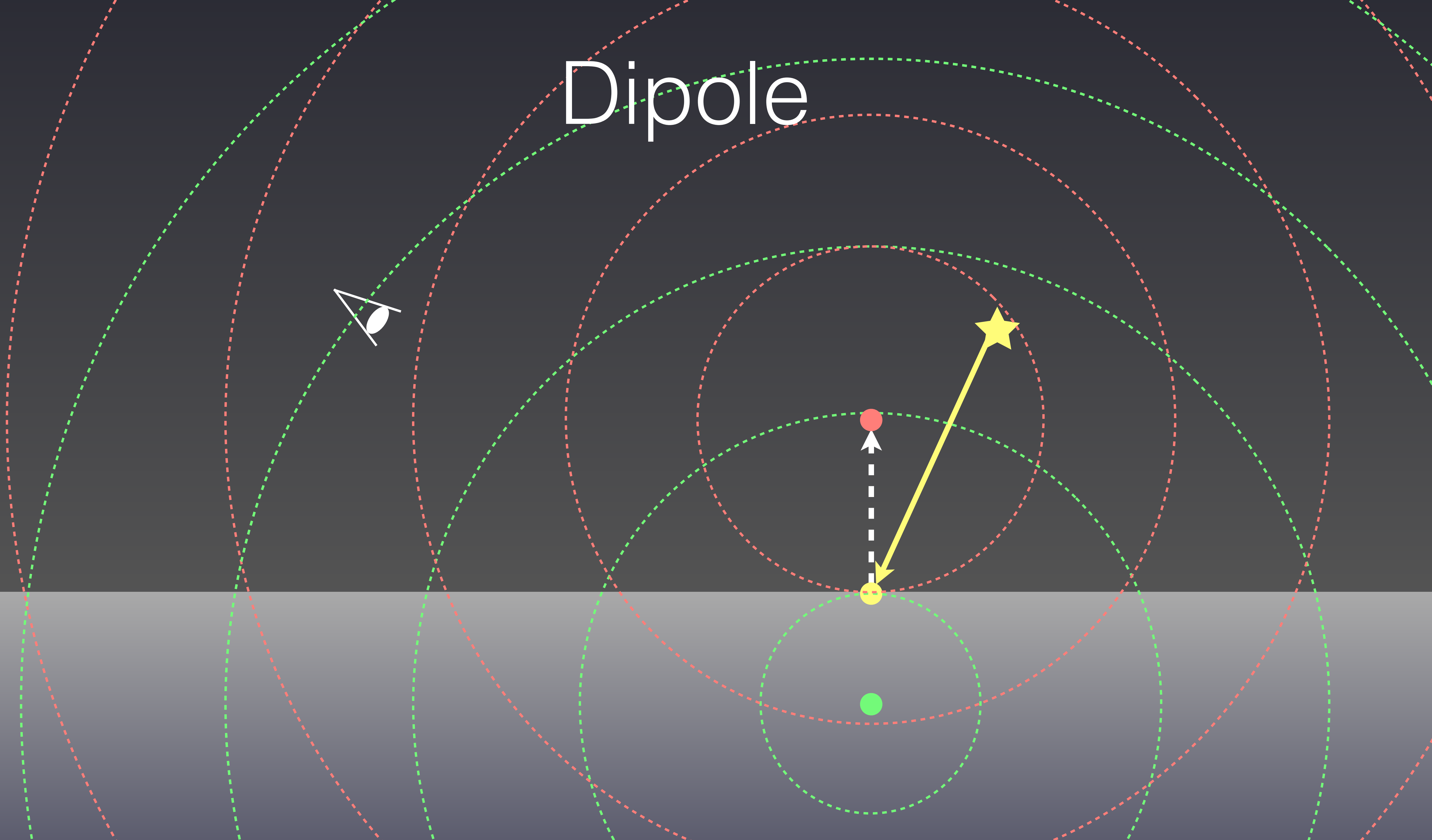
**Approximate solution
[Reynolds et al. 1976]**



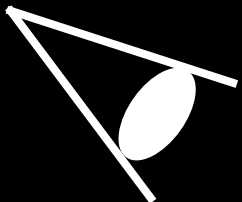
Dipole



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Dipole



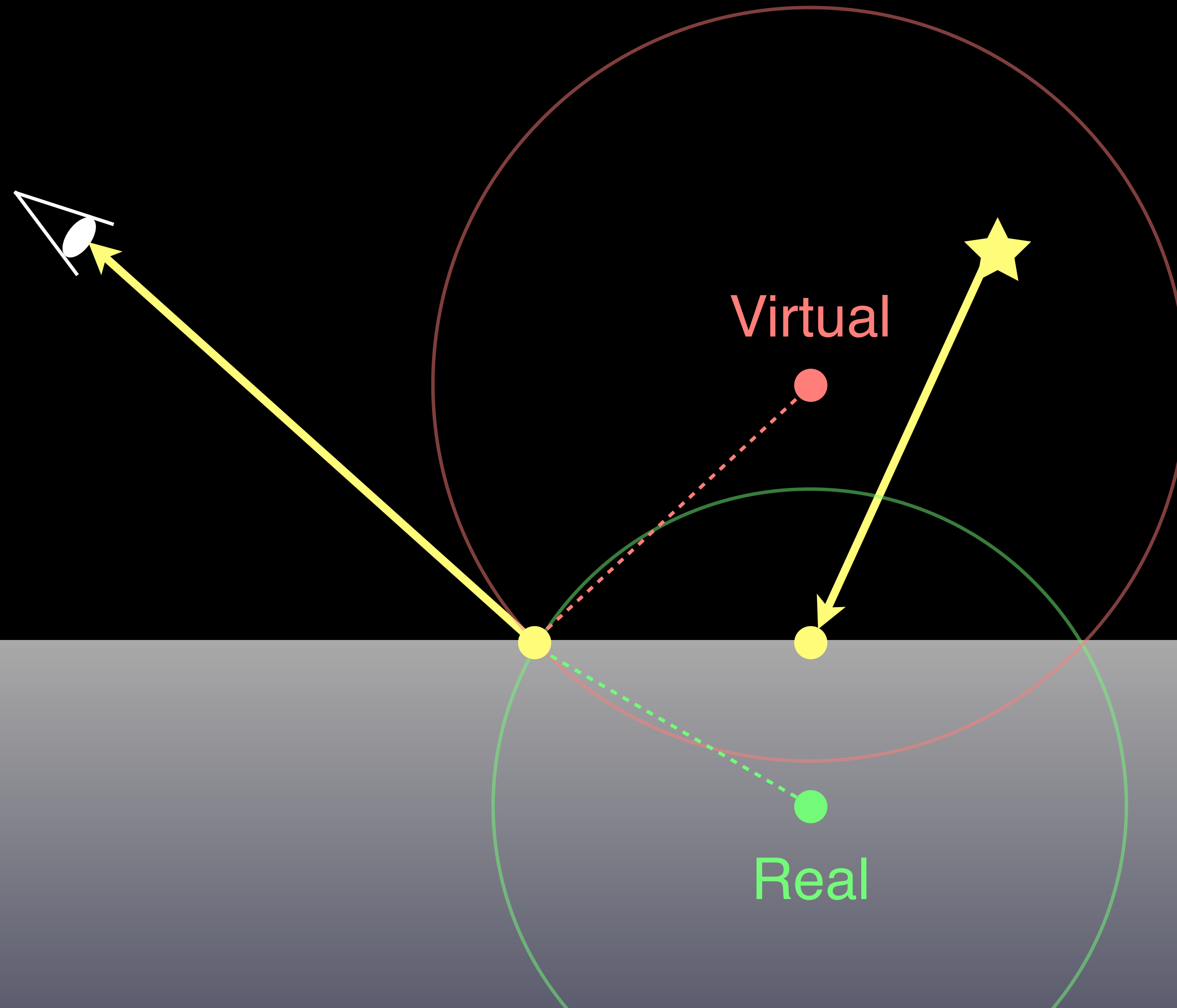
Virtual



Real



Dipole



Dipole

[Jensen et al. 2001]



Diffuse BRDF

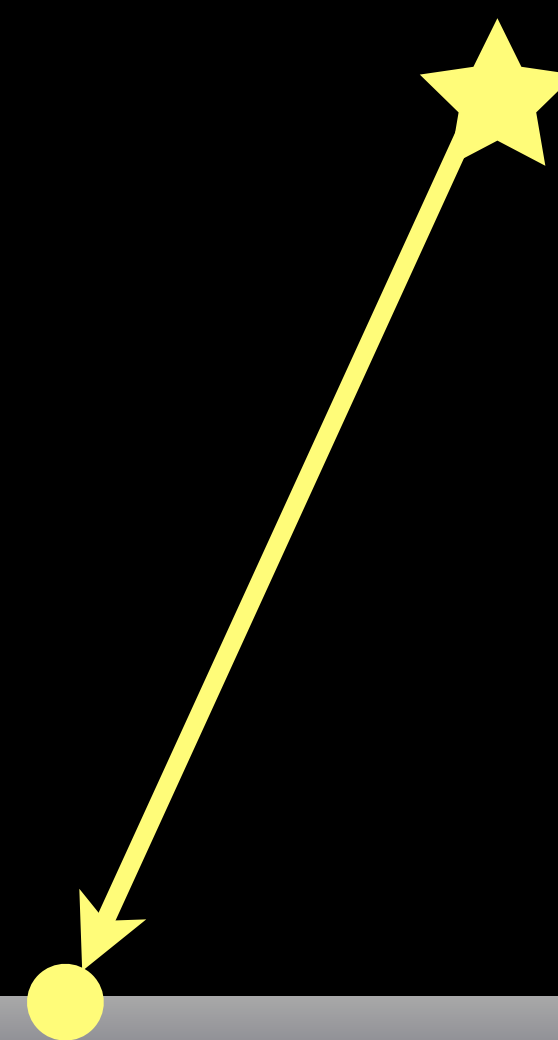
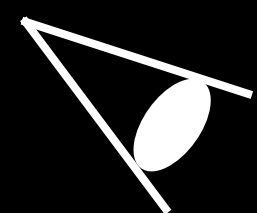


Dipole BSSRDF

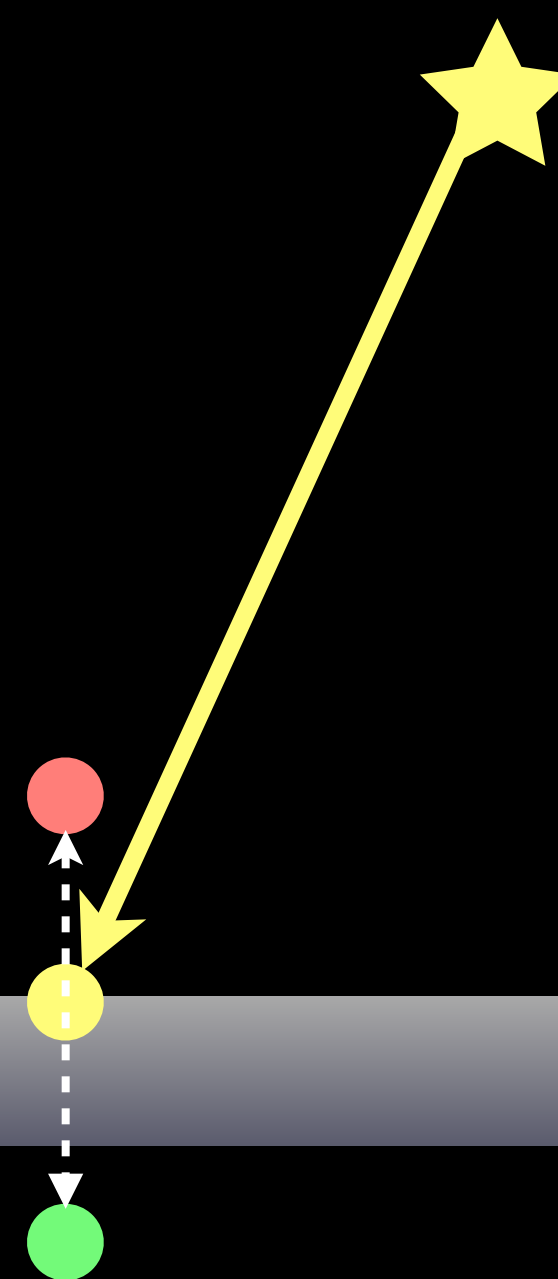
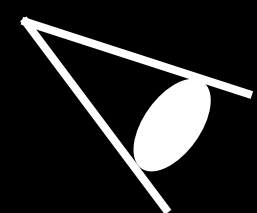
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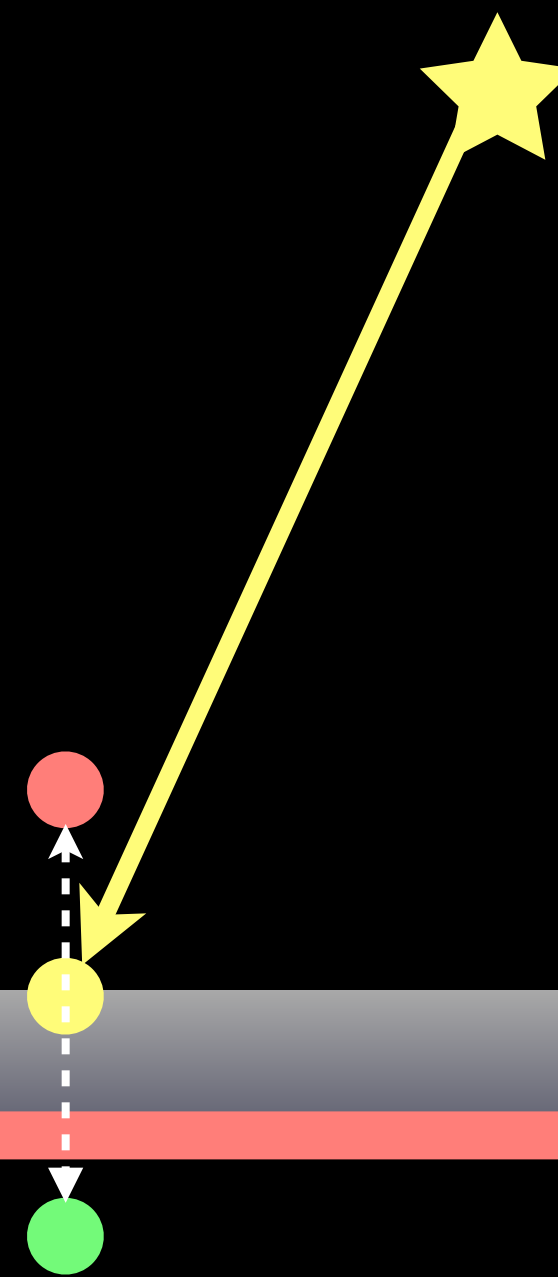
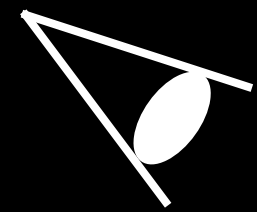
Multipole



Multipole

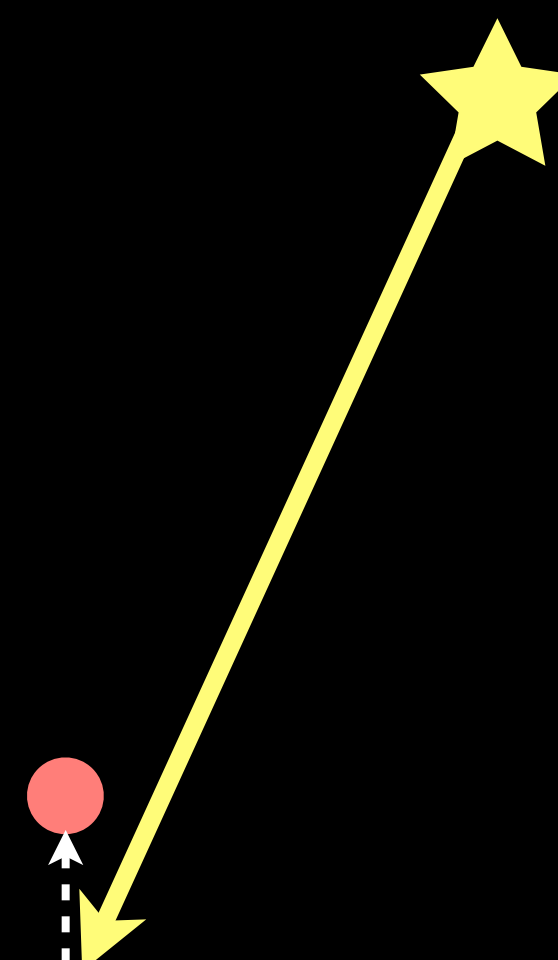
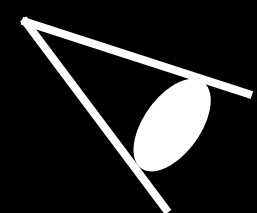


Multipole



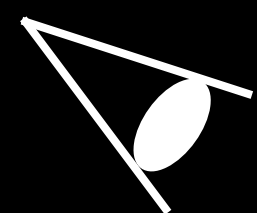
Underestimation

Multipole

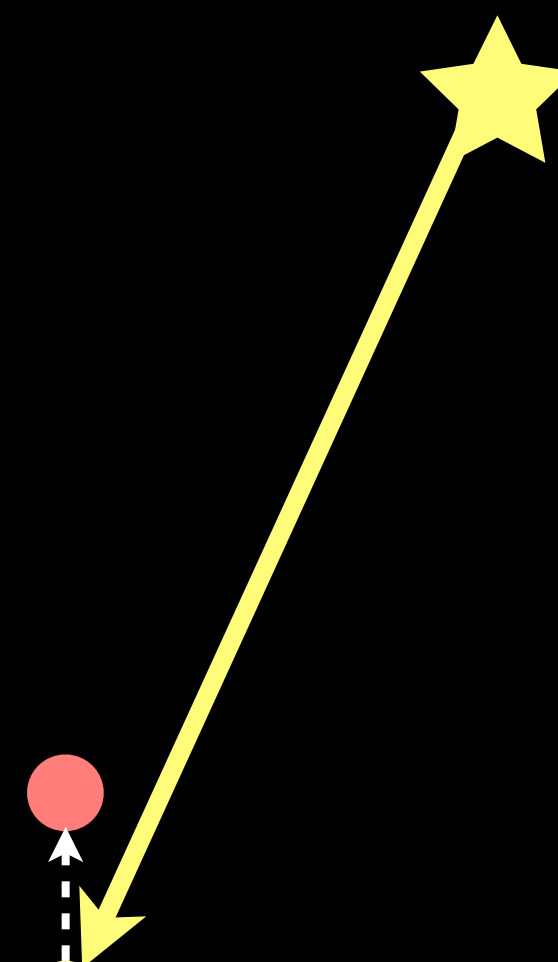
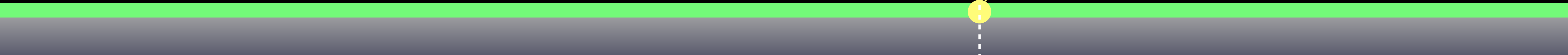


Additional dipole

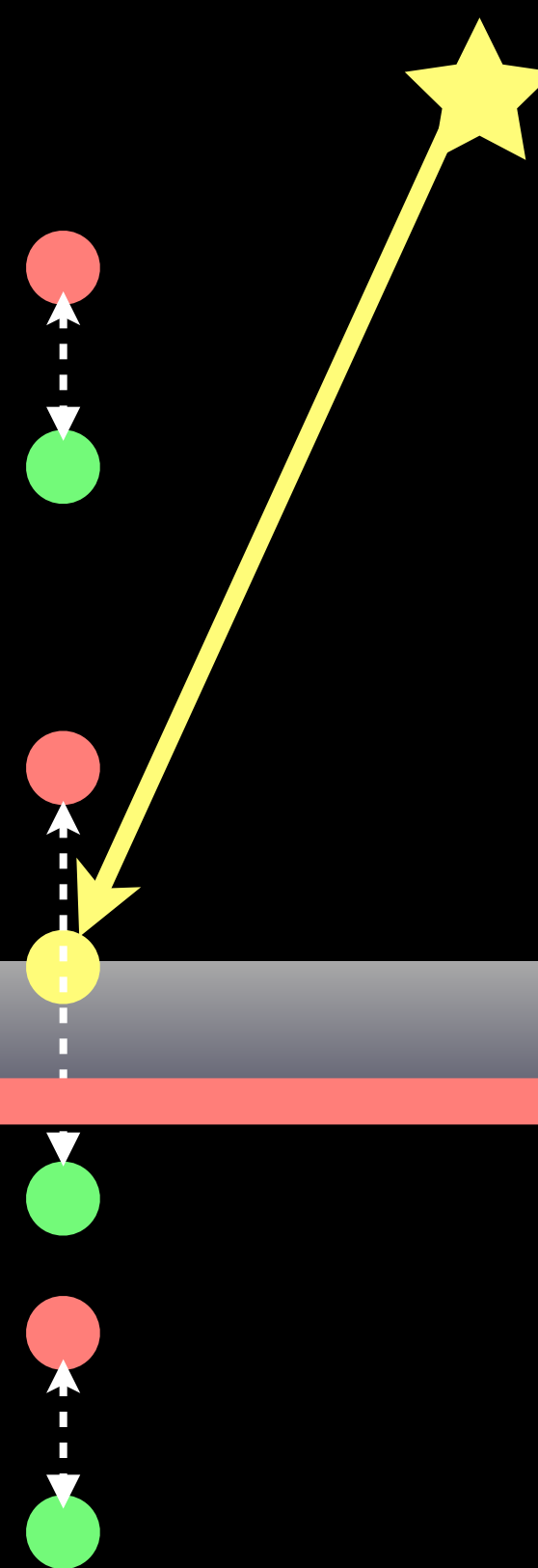
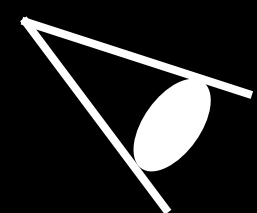
Multipole



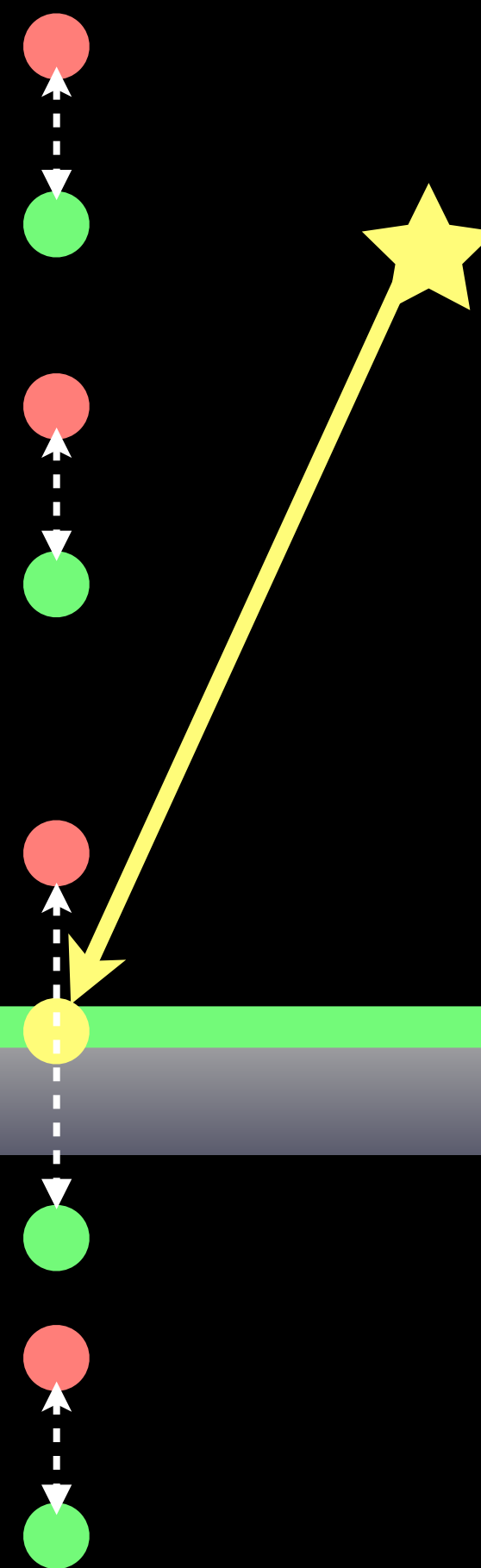
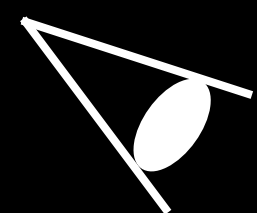
Overestimation



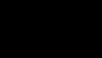
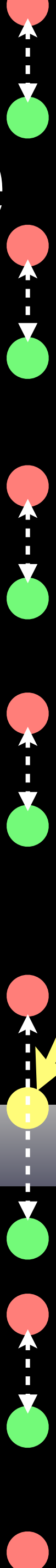
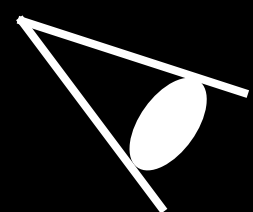
Multipole



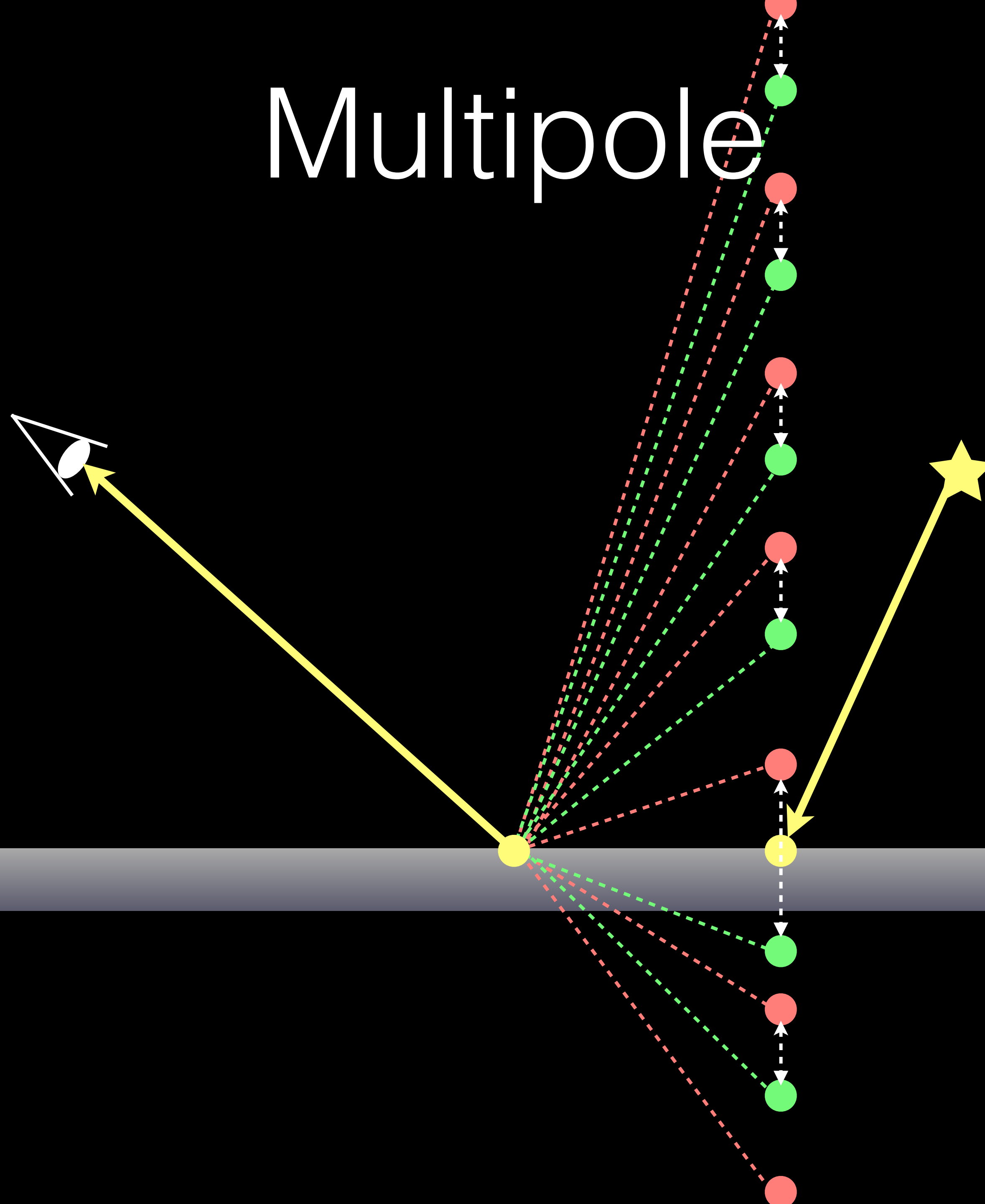
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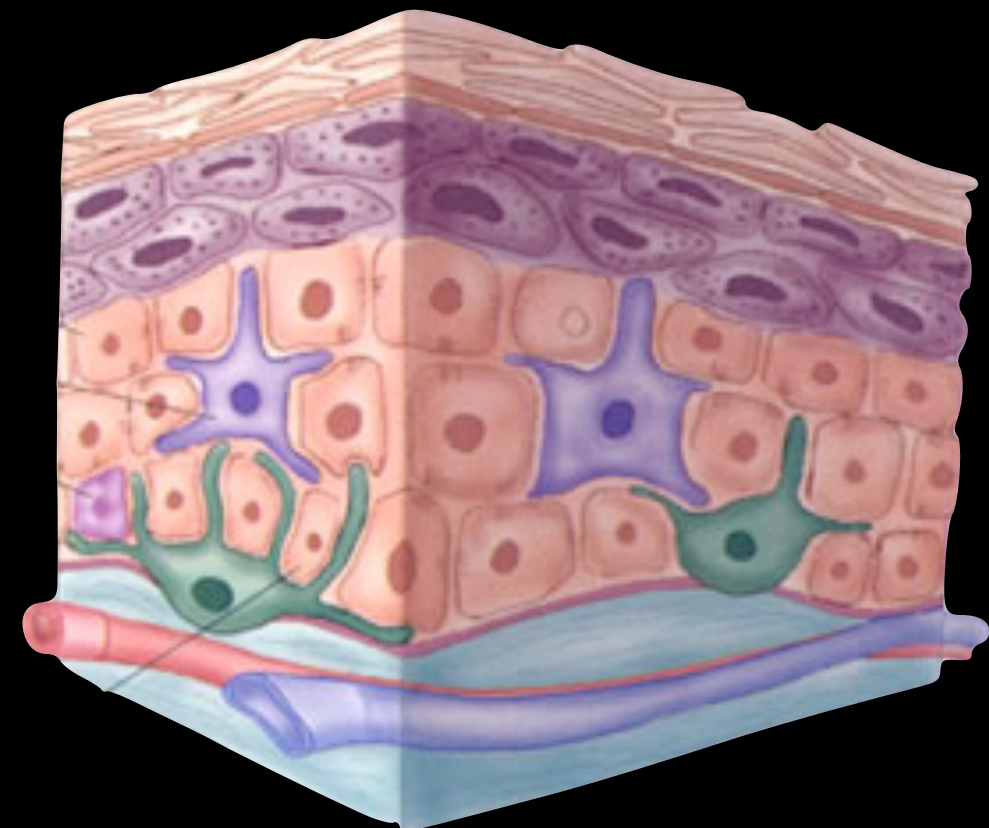
Multipole



Multipole



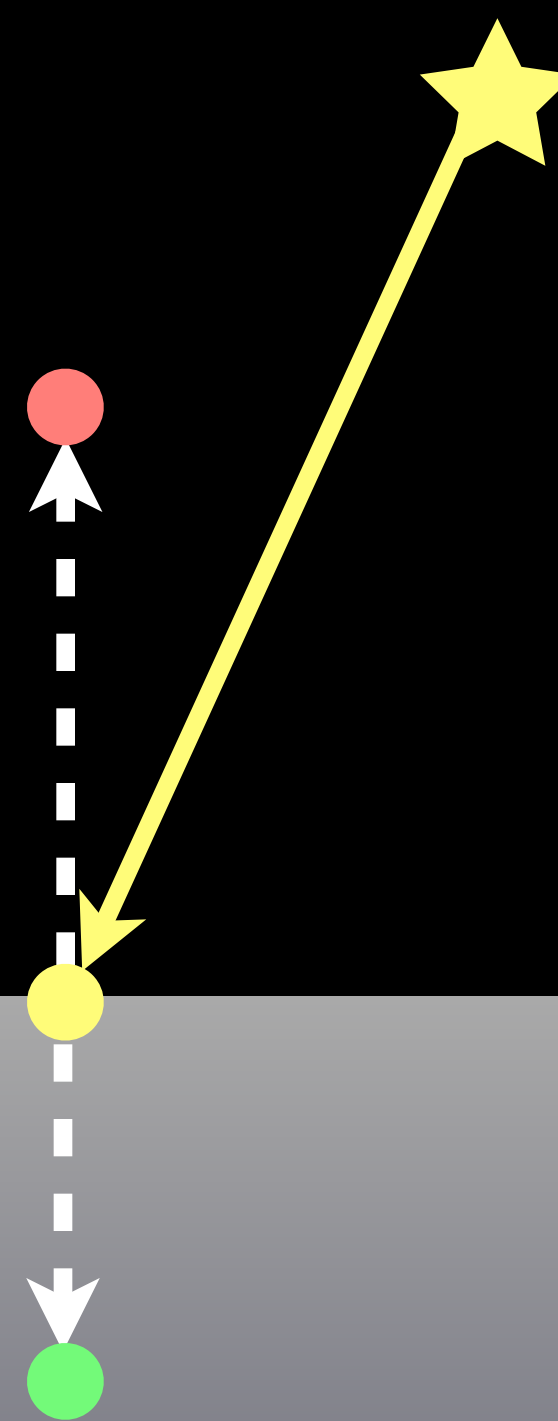
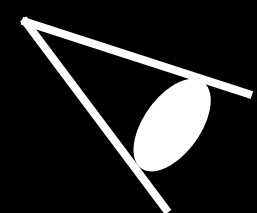
Multipole



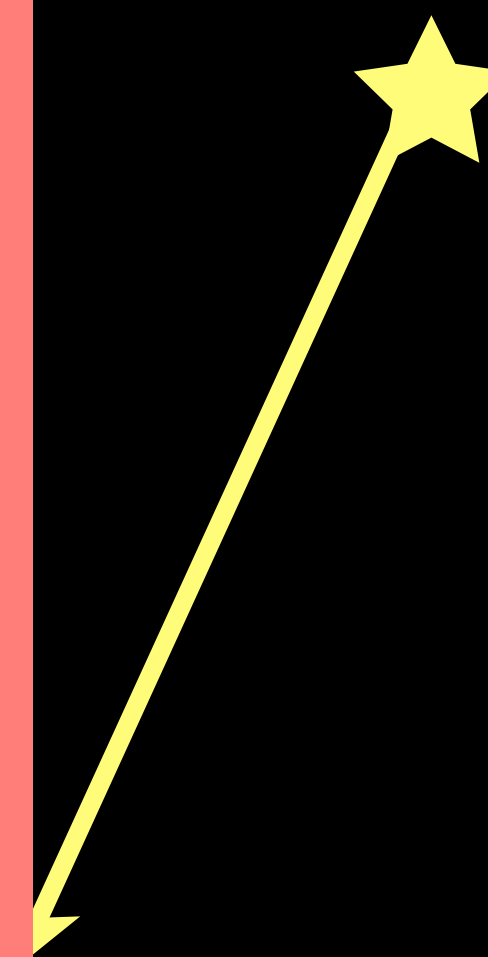
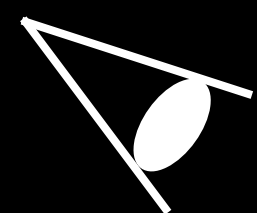
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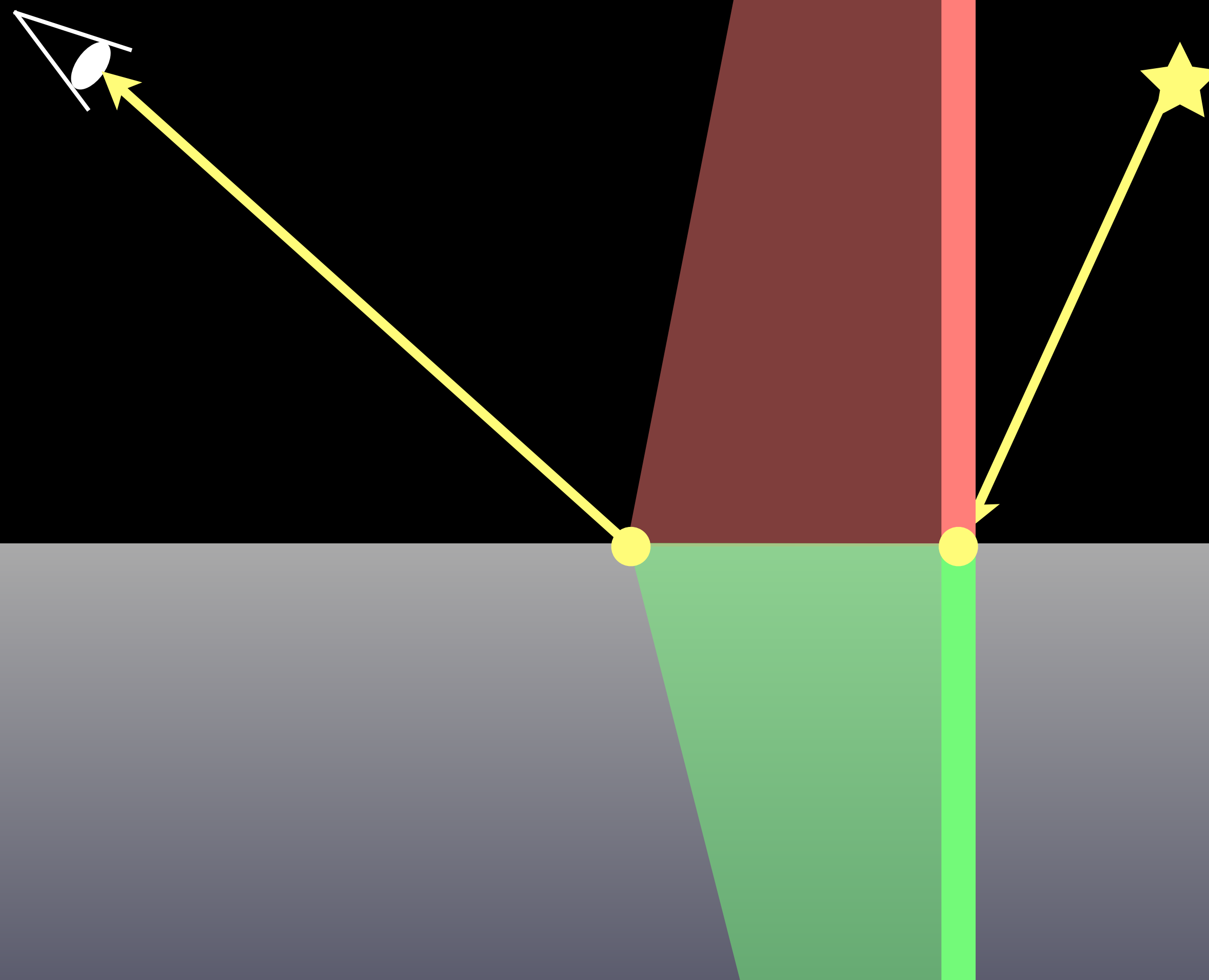
Quantized Diffusion



Quantized Diffusion

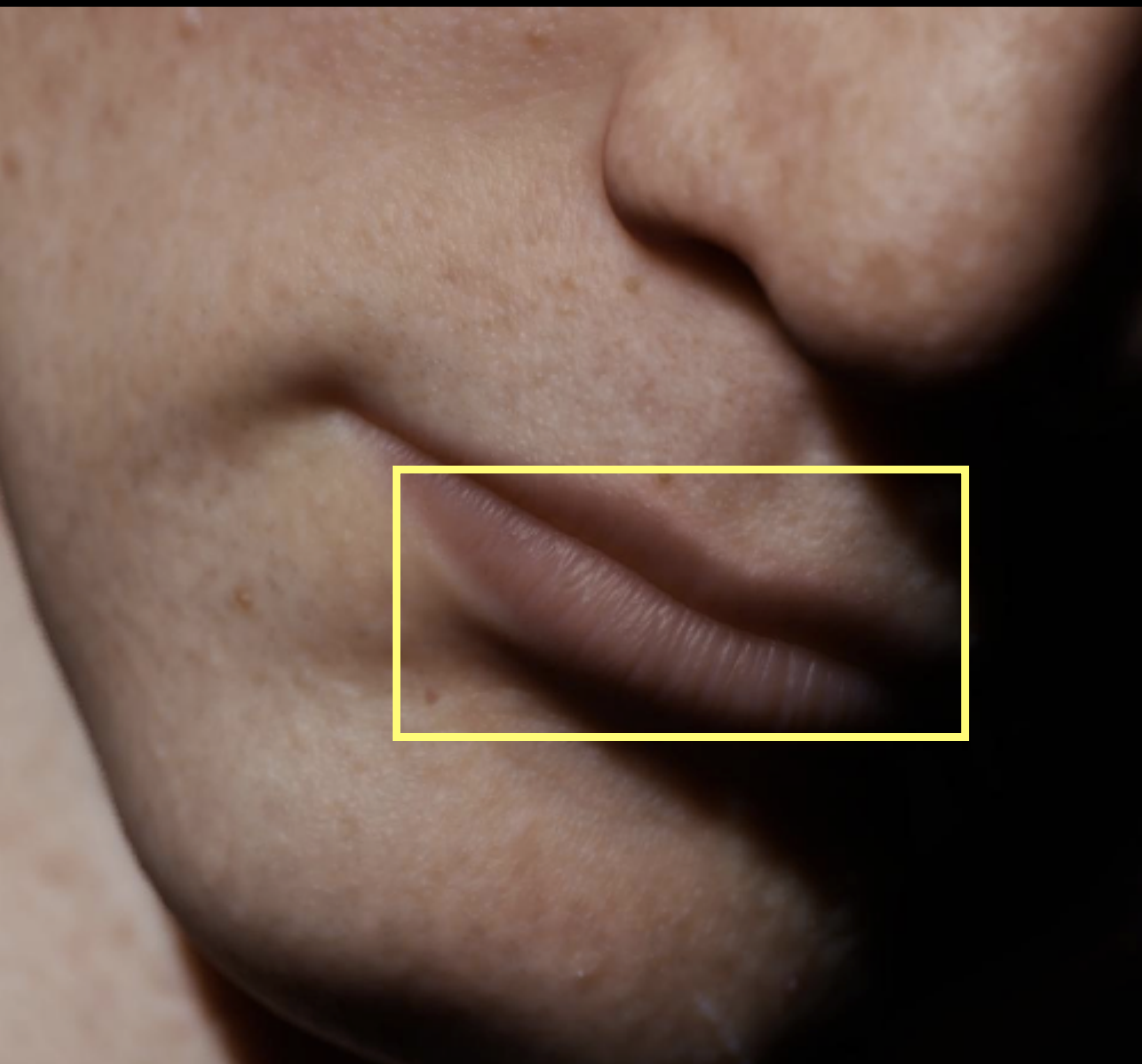


Quantized Diffusion



Quantized Diffusion

[d'Eon & Irving 2011]



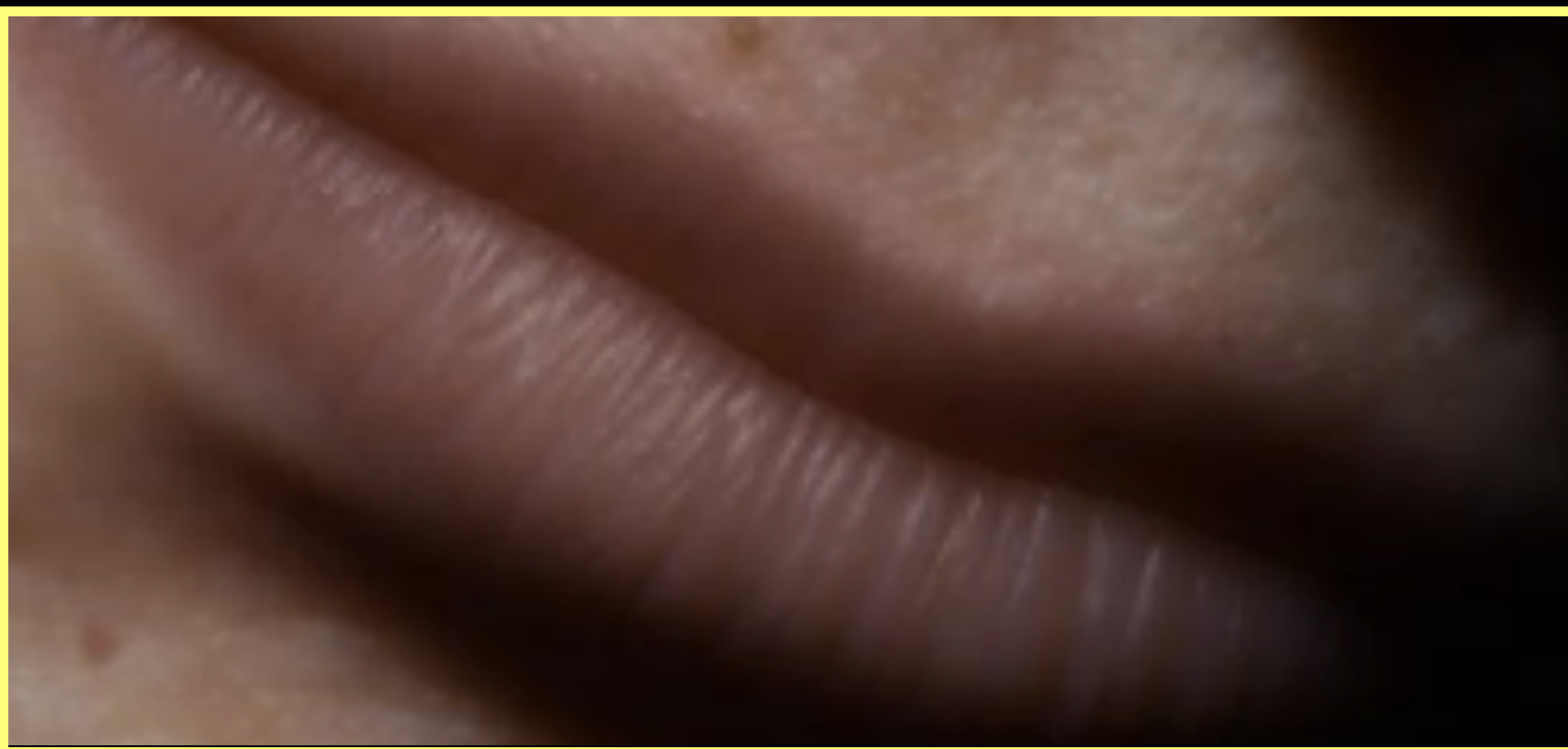
Dipole



Quantized diffusion

Quantized Diffusion

[d'Eon & Irving 2011]



Dipole

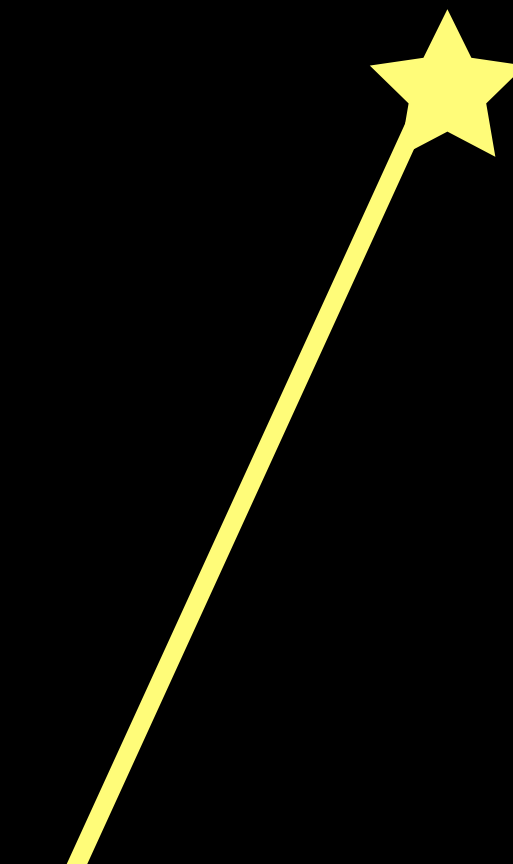
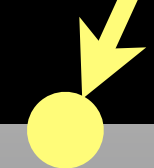
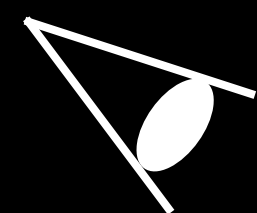


Quantized diffusion

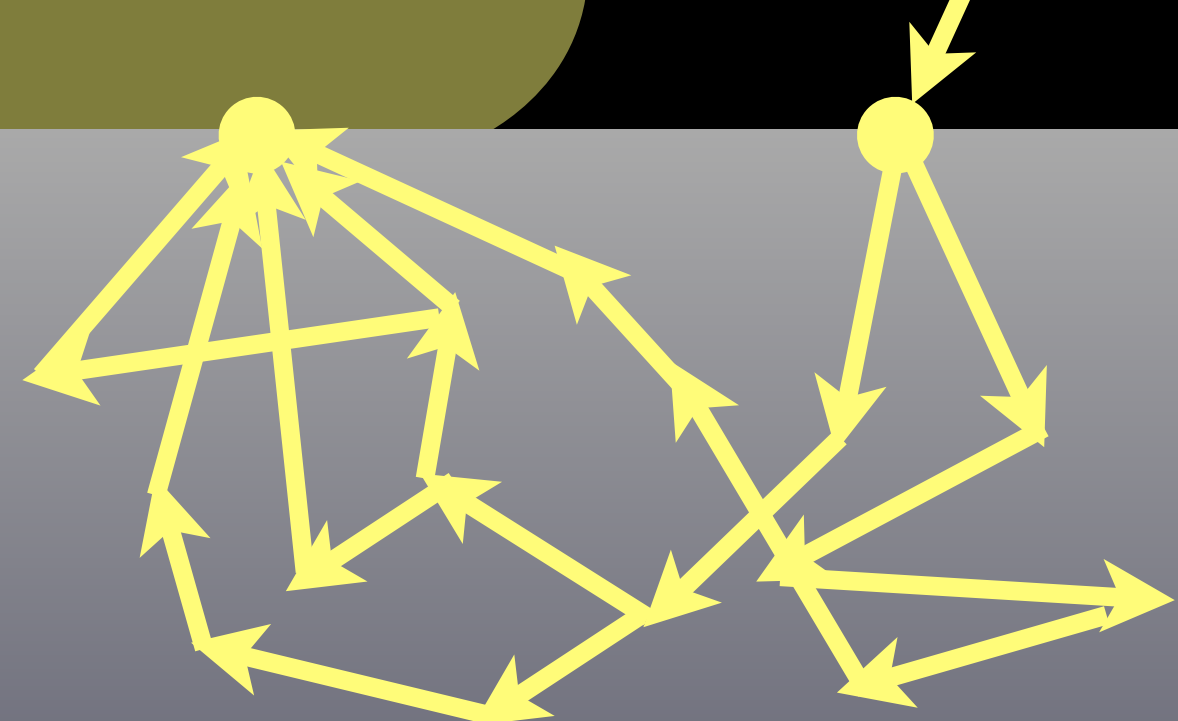
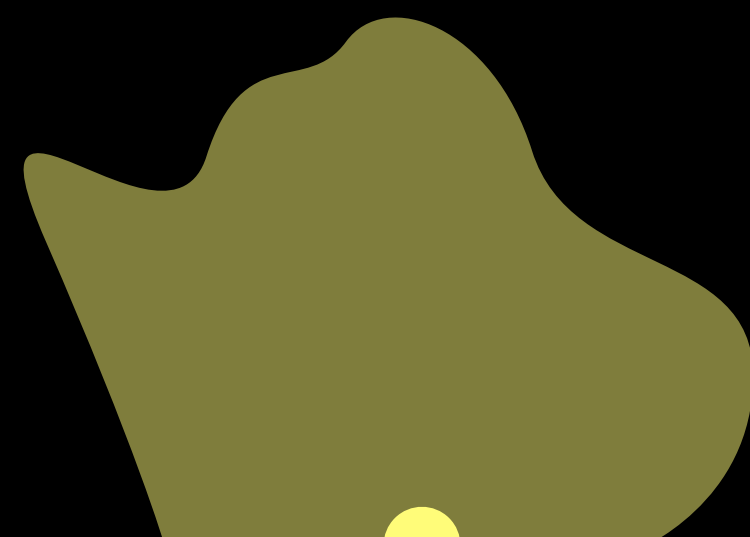
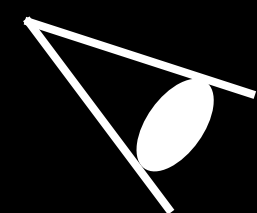
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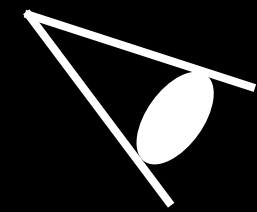
Precomputed BSSRDF



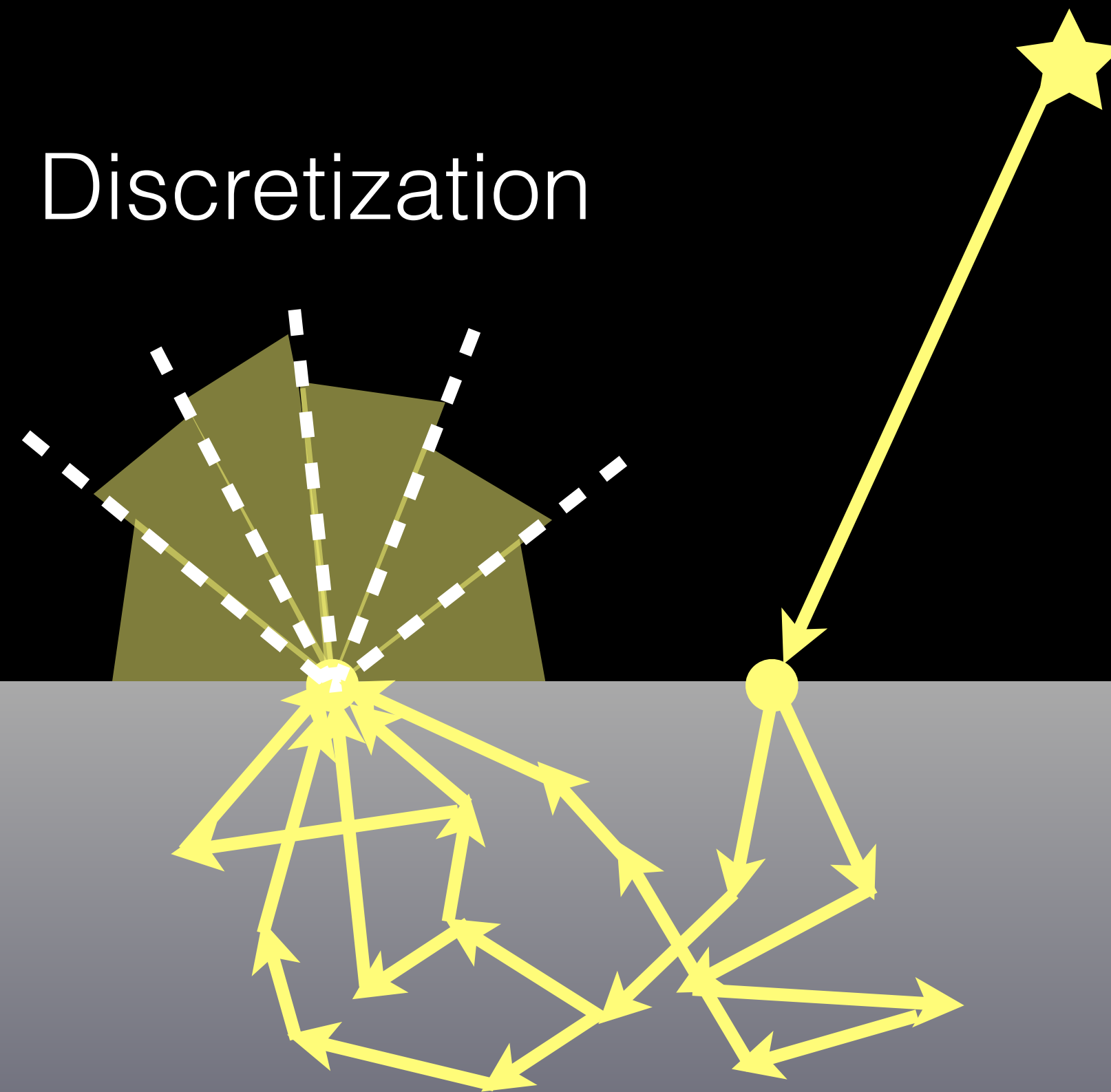
Precomputed BSSRDF



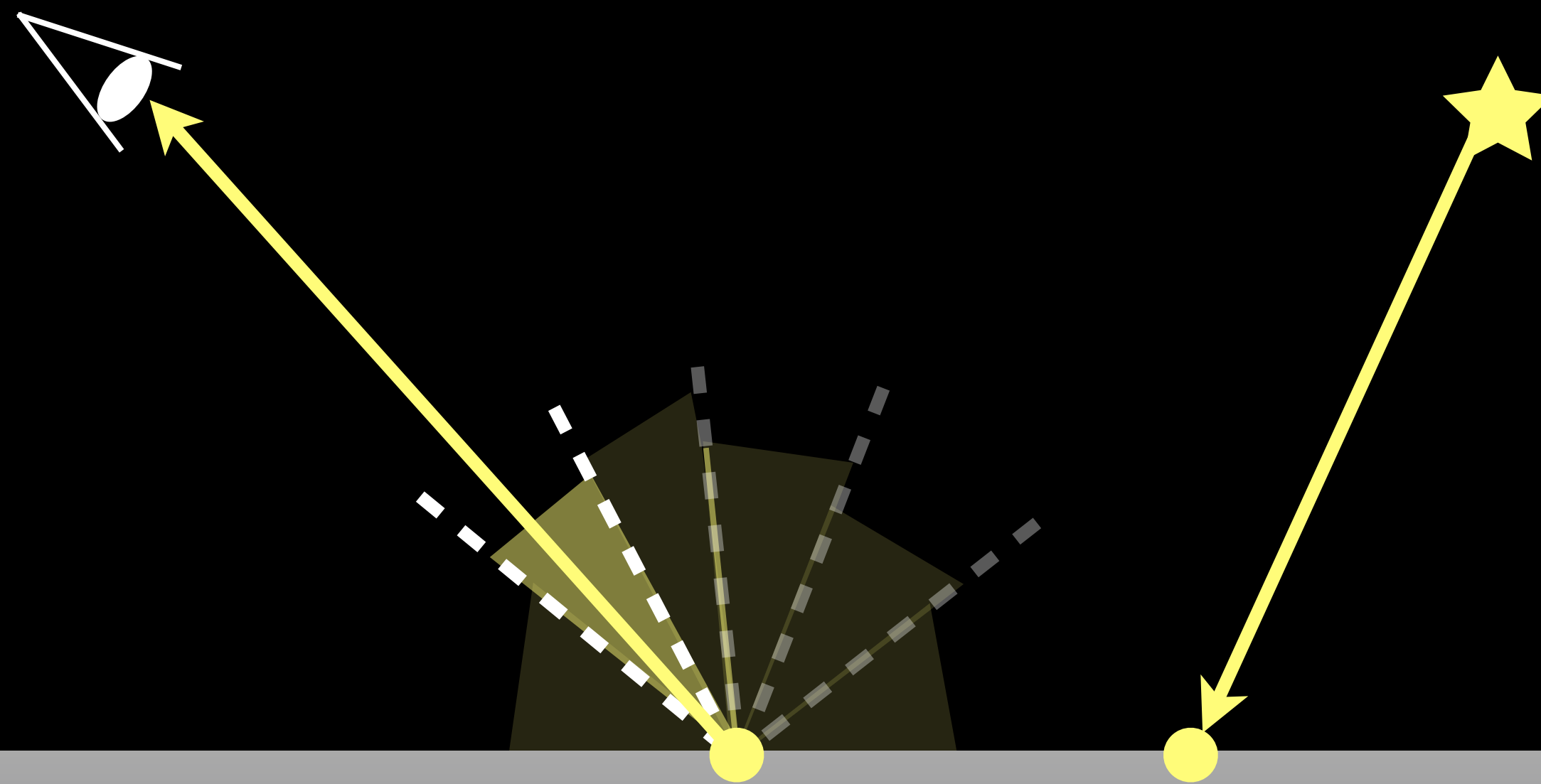
Precomputed BSSRDF



Discretization



Precomputed BSSRDF



Precomputed BSSRDF

[Donner et al. 2009]



Path tracing



Dipole

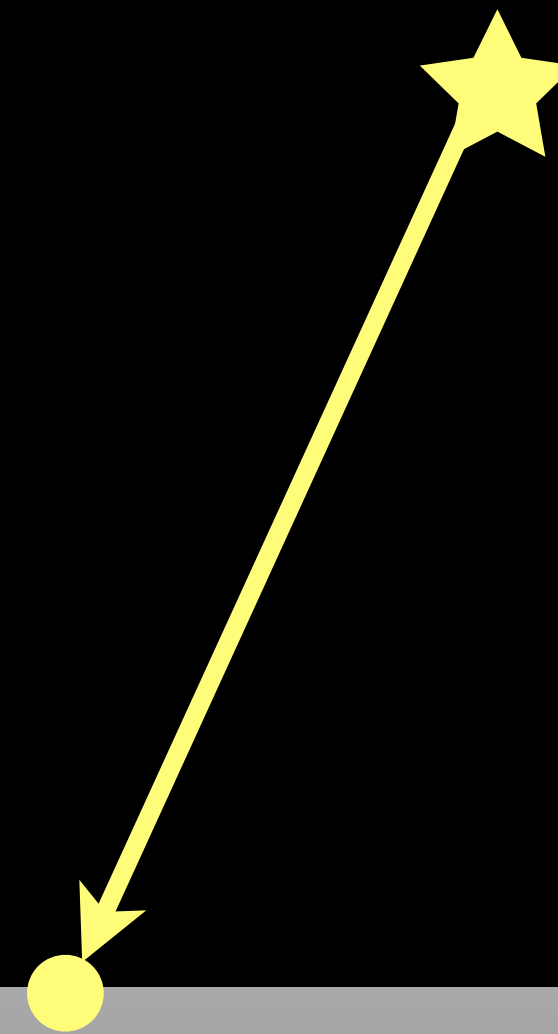
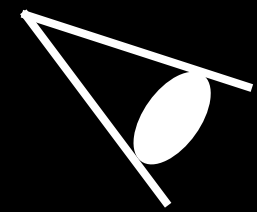


Precomputed

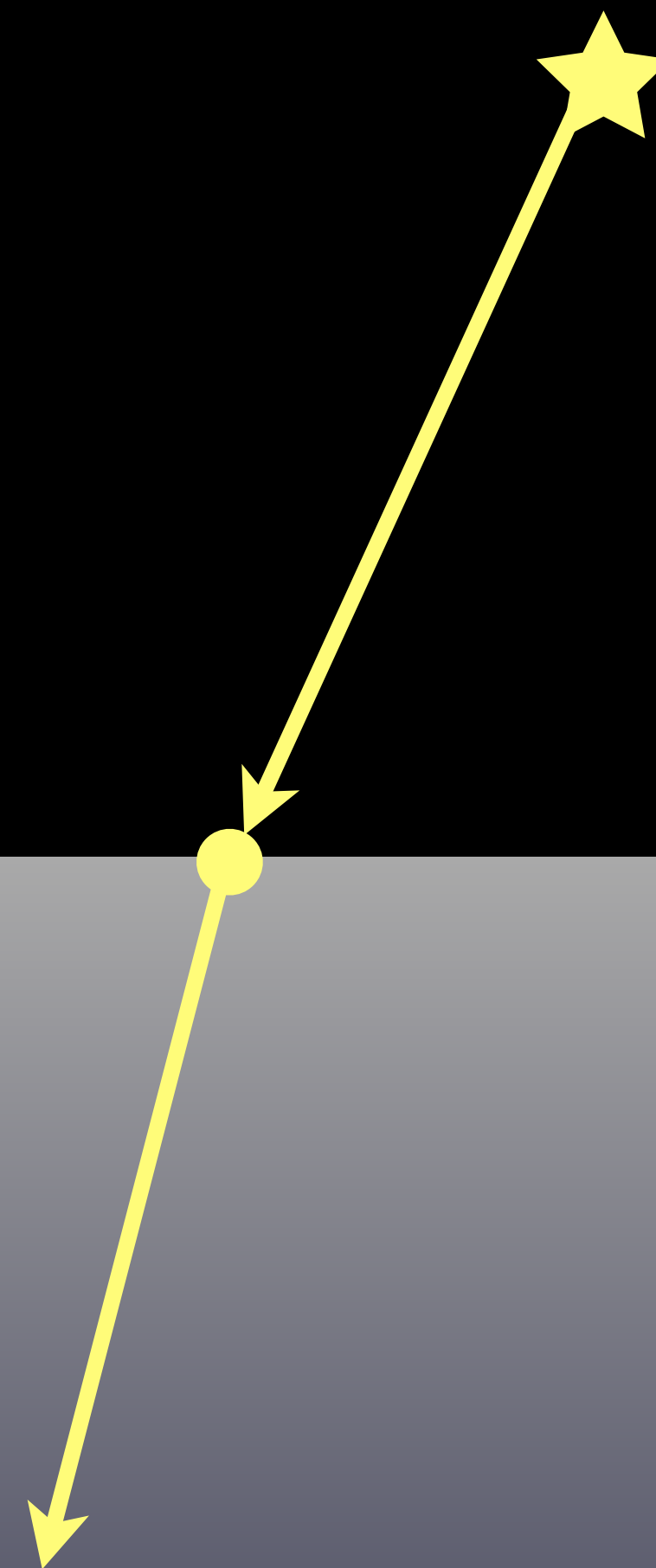
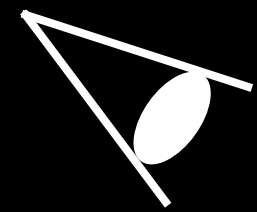
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Photon Diffusion

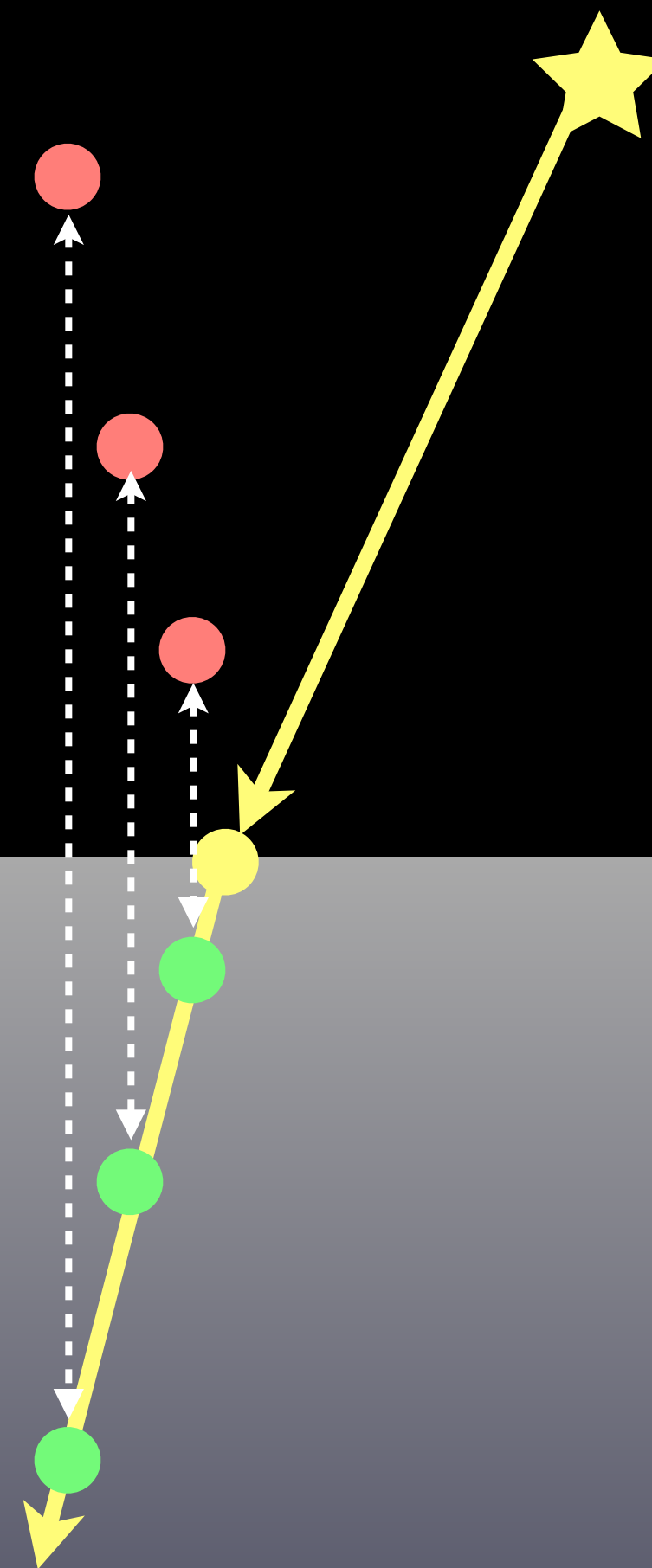
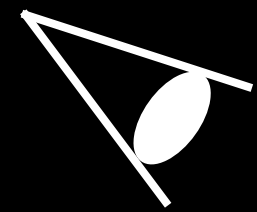


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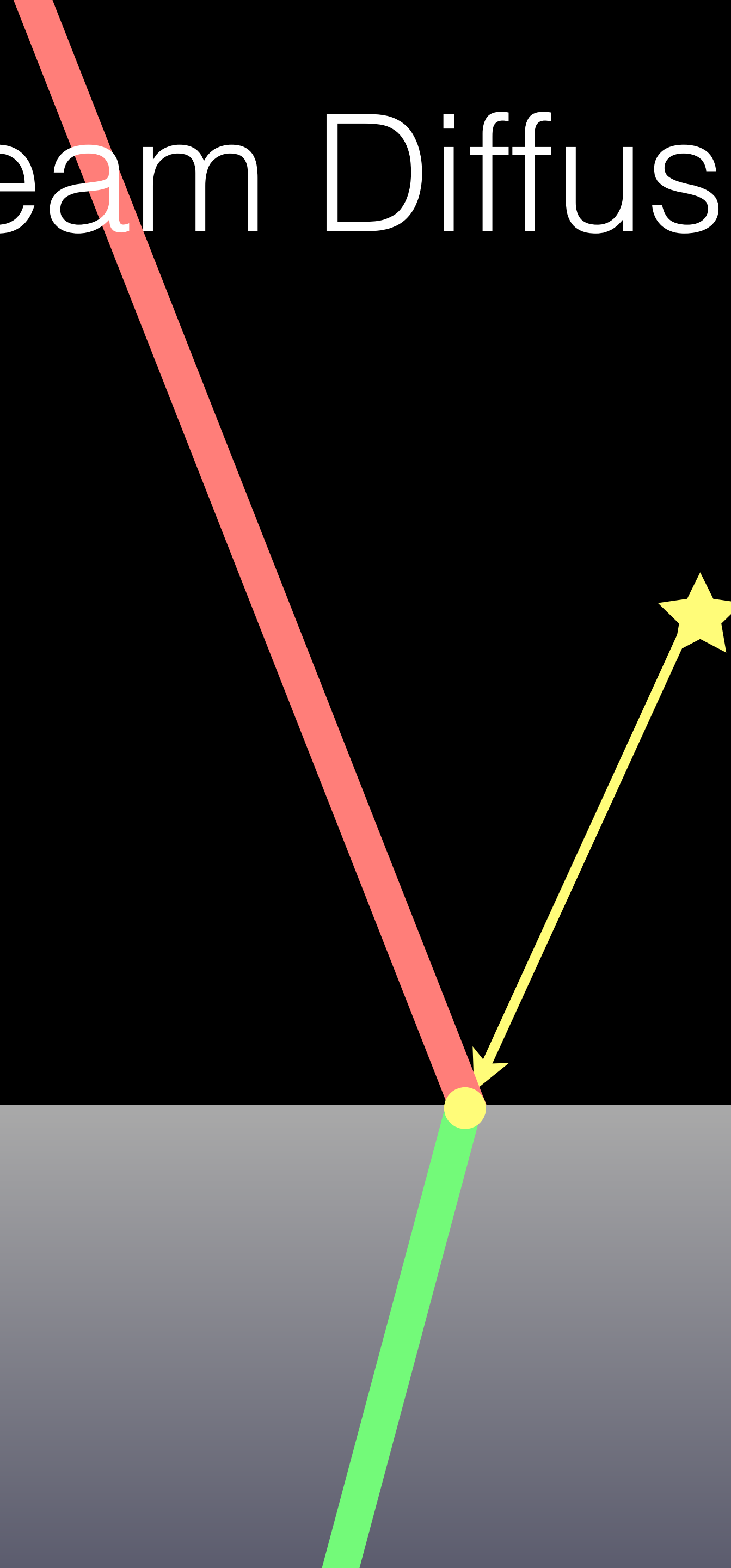
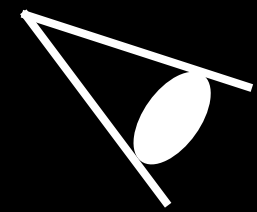
Photon Diffusion

[Donner & Jensen 2007]



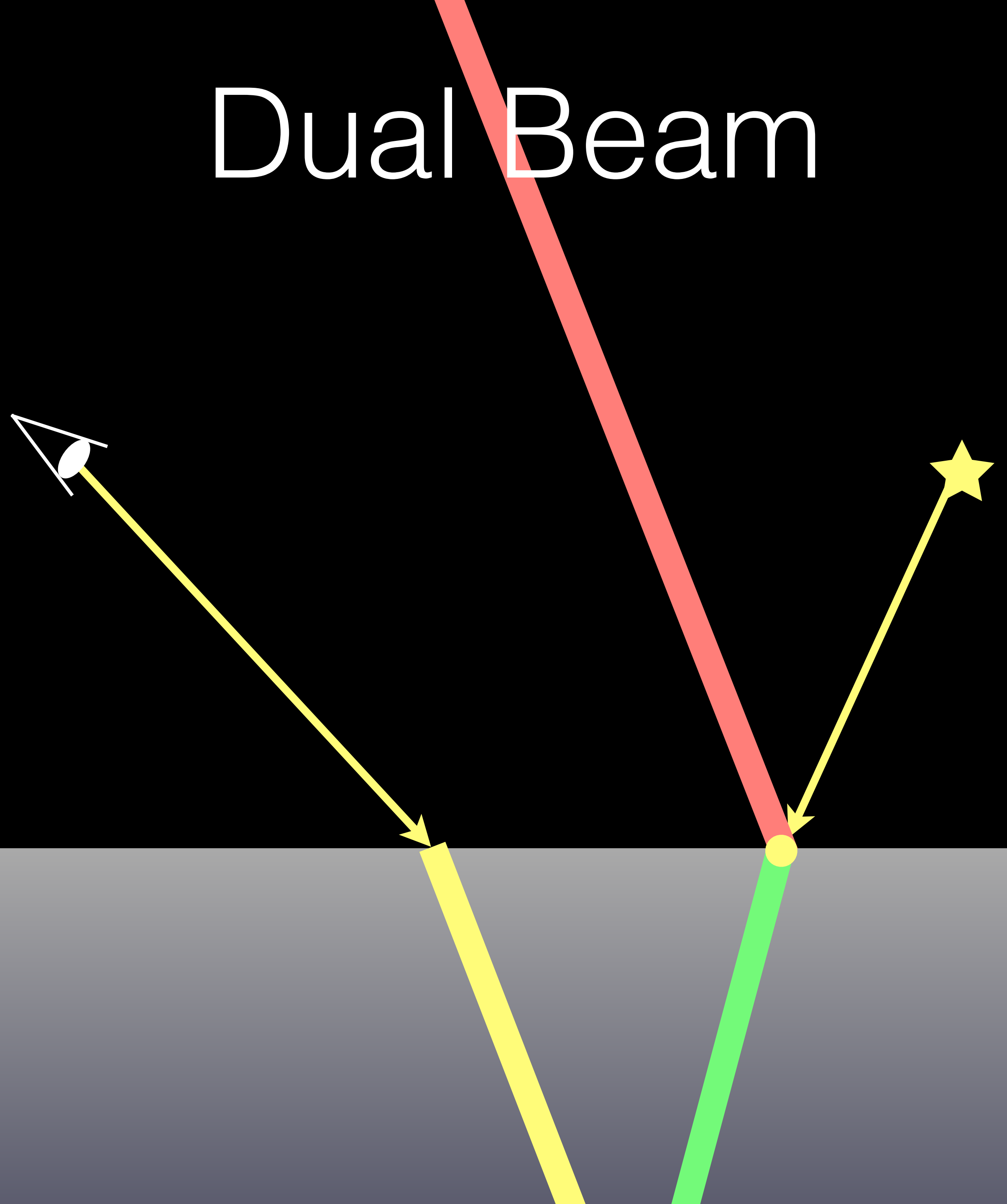
Photon Beam Diffusion

[Habel et al. 2013]



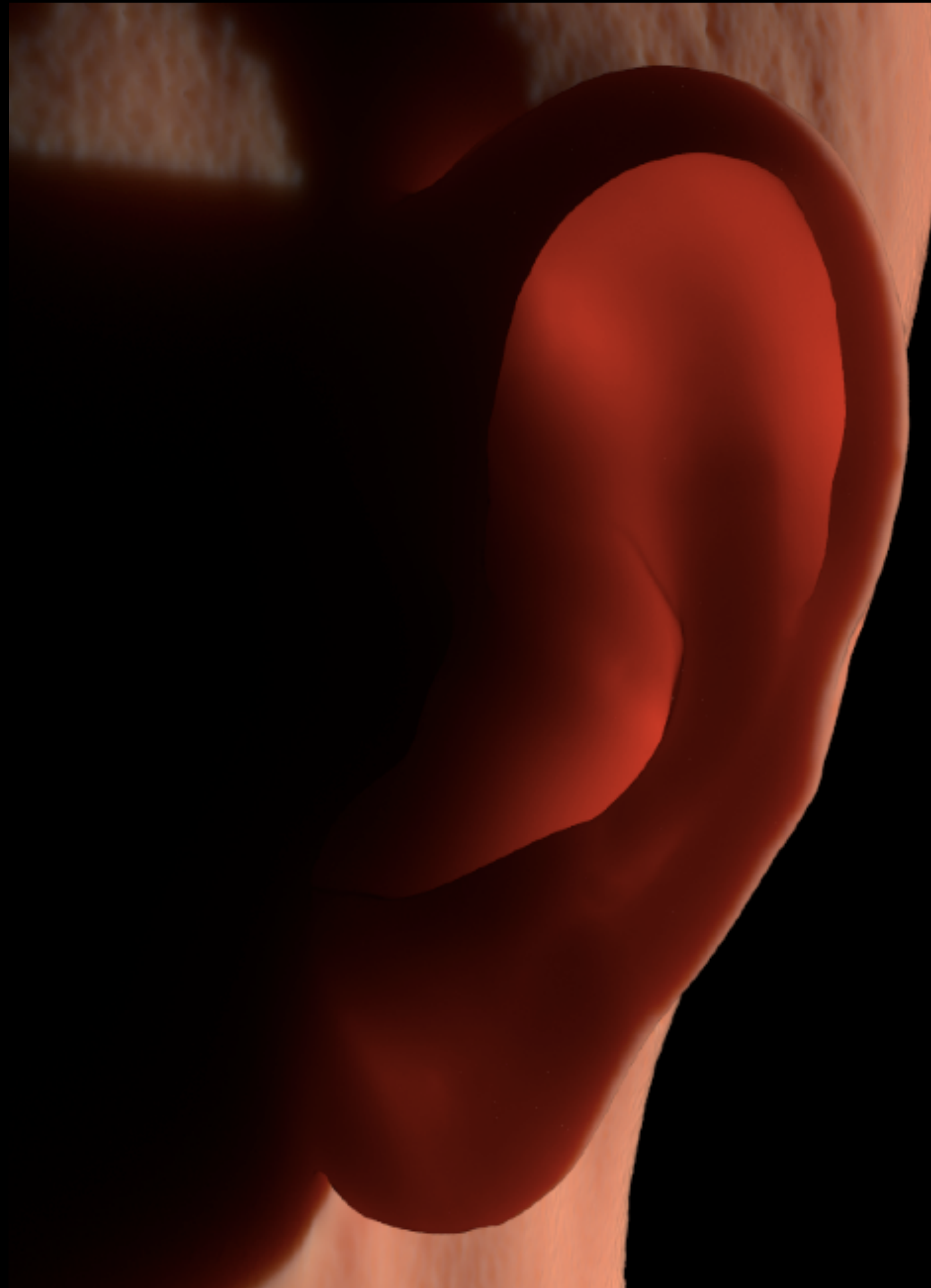
Dual Beam

[d'Eon 2014]

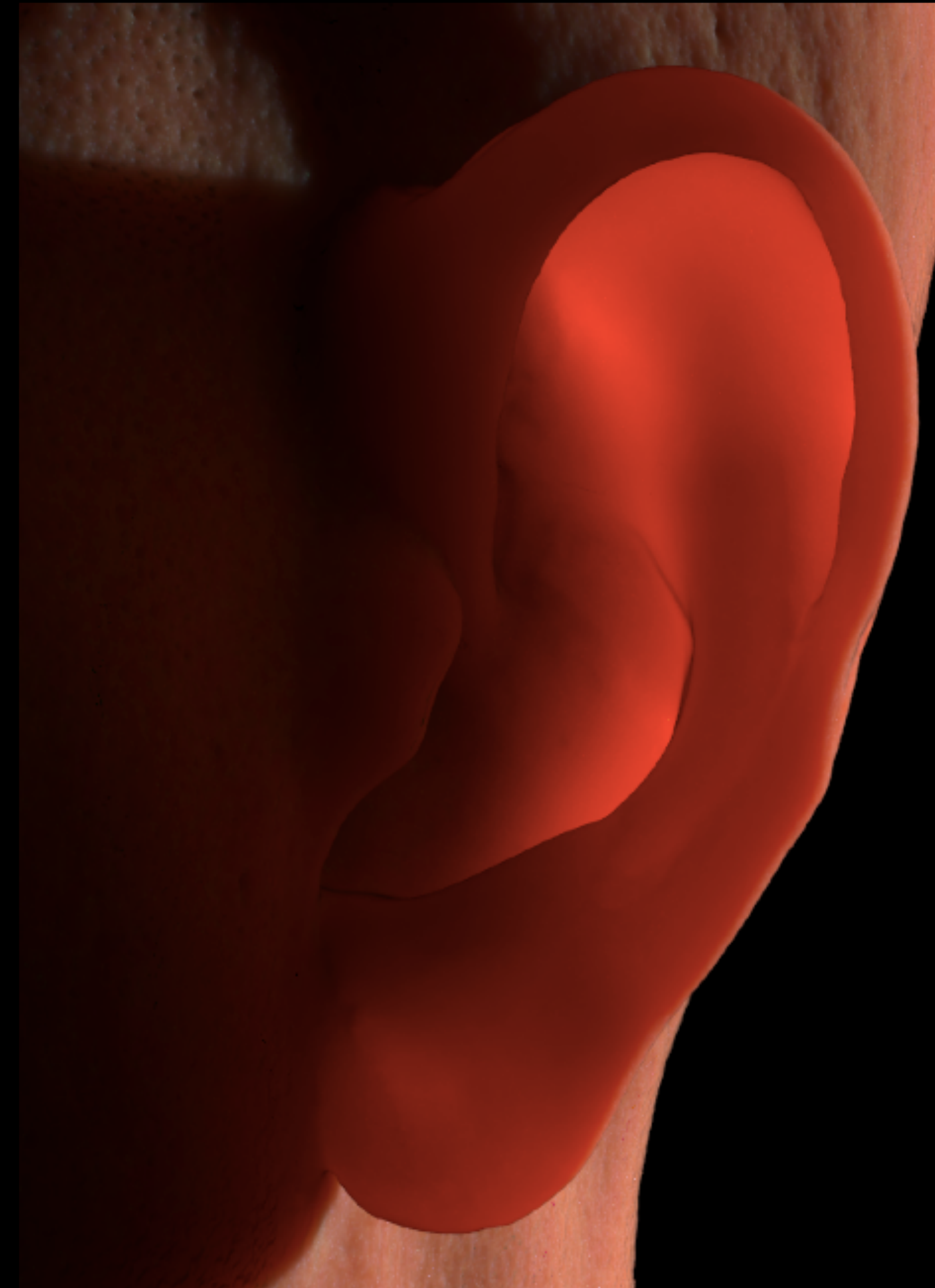


Photon Diffusion

[Donner & Jensen 2007]



Dipole



Photon diffusion

Comparisons

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 - Ignores incoming light direction
 - Requires no precomputation
 - Provides fully analytical function

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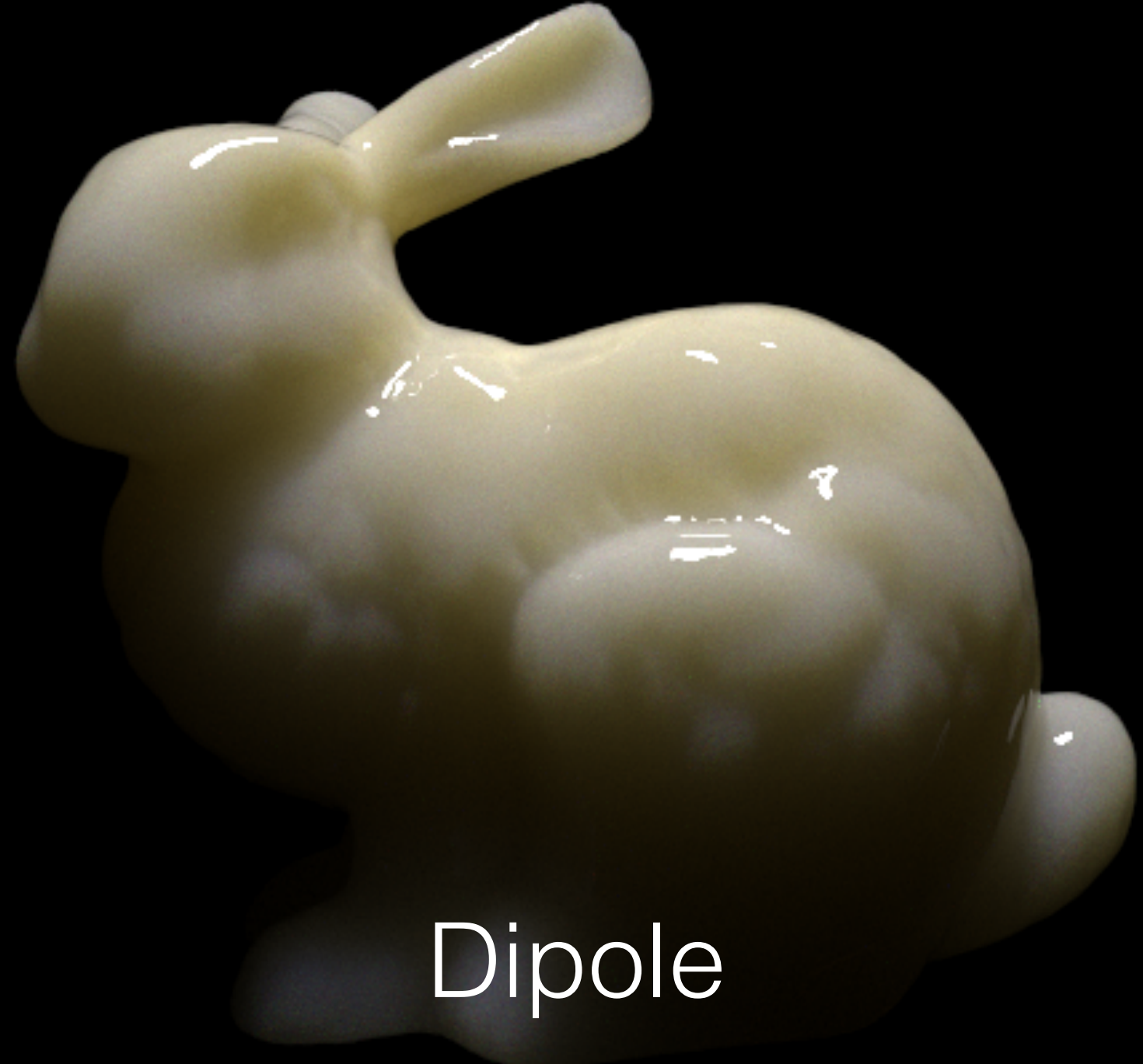
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 - **Considers incoming light direction**
 - **Requires no precomputation**
 - **Relies on numerical integration**

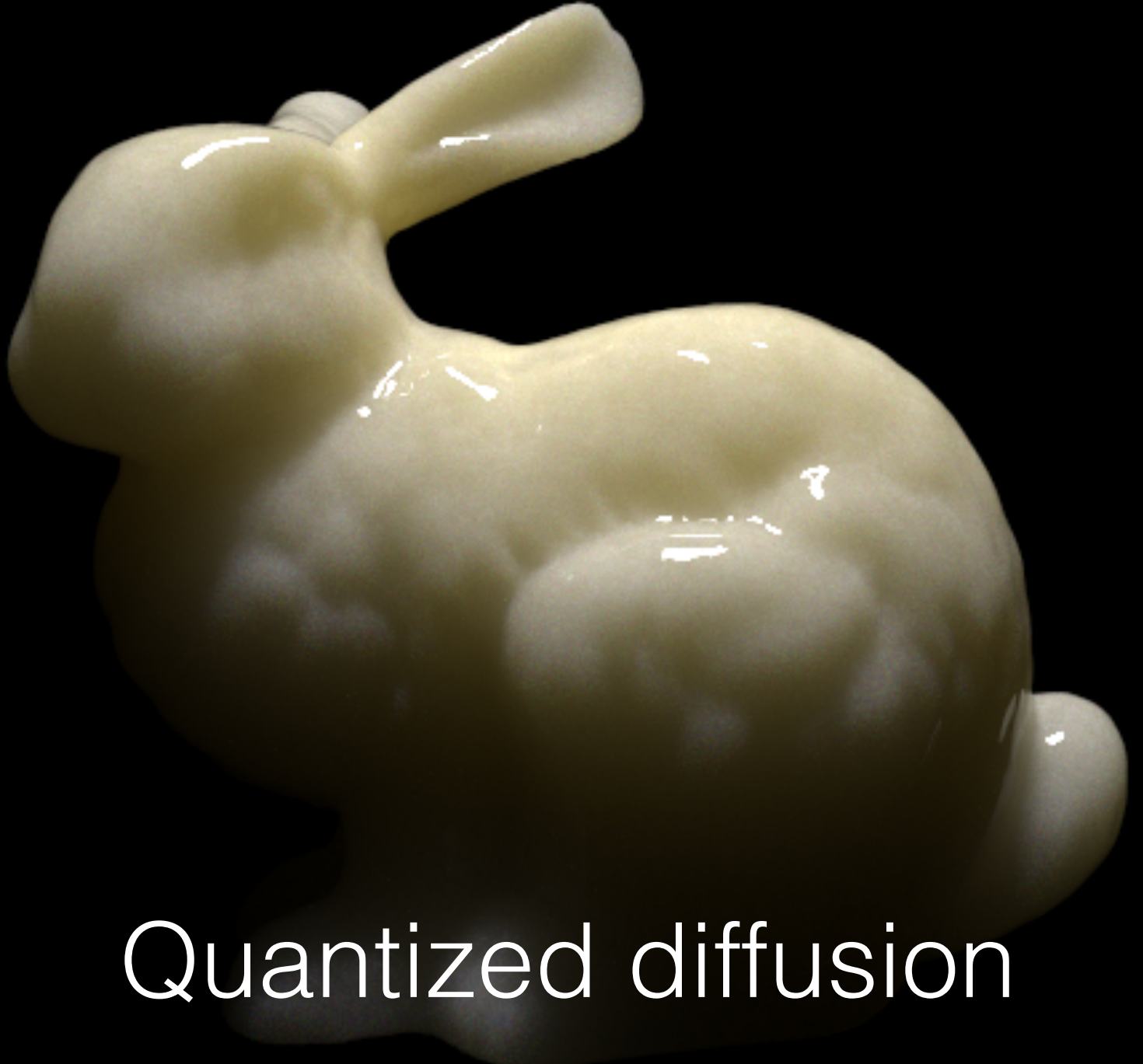
Contributions

Our model is the **first** BSSRDF model which

- Considers incoming light direction
- Requires no precomputation
- Provides fully analytical function



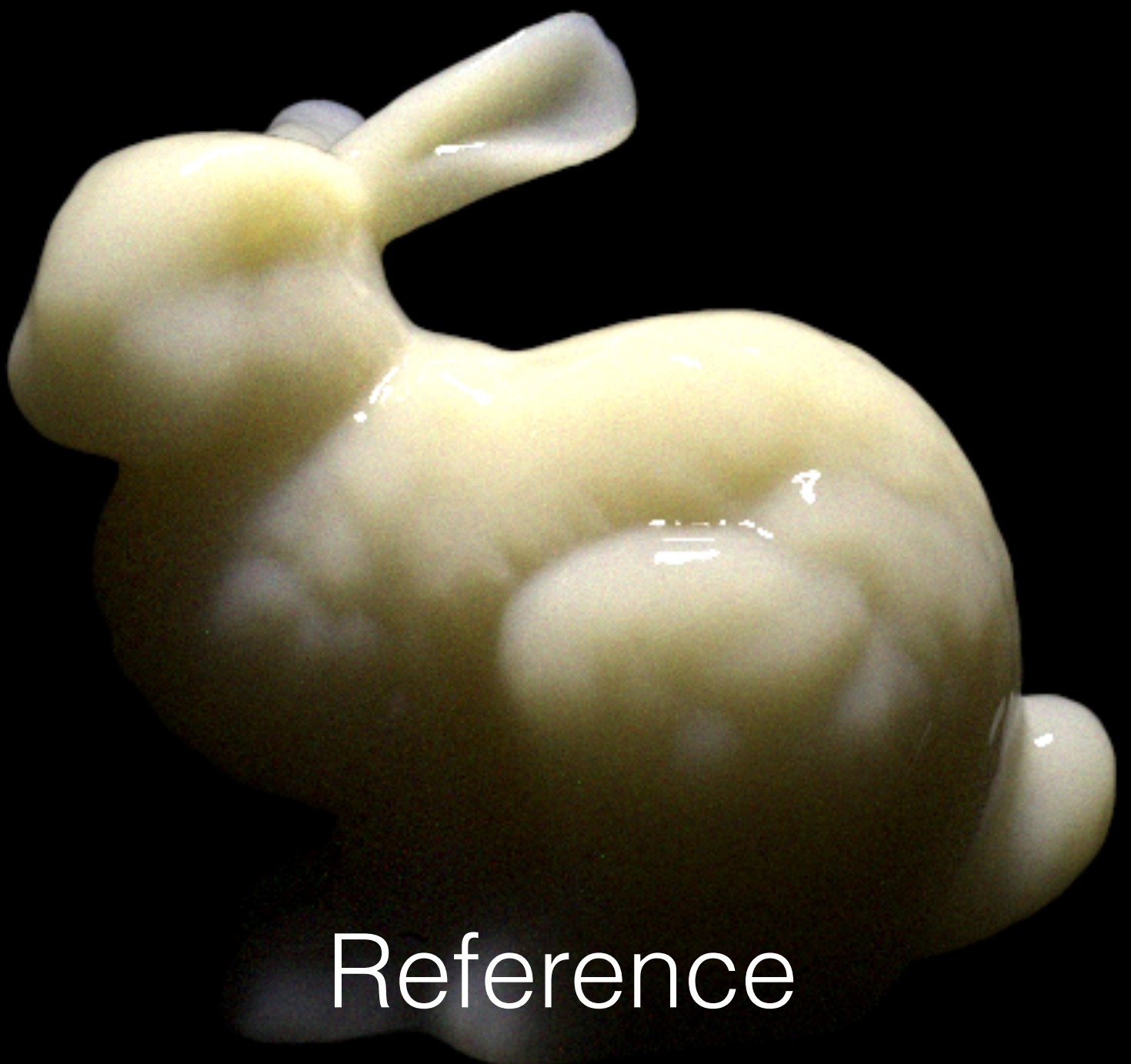
Dipole



Quantized diffusion

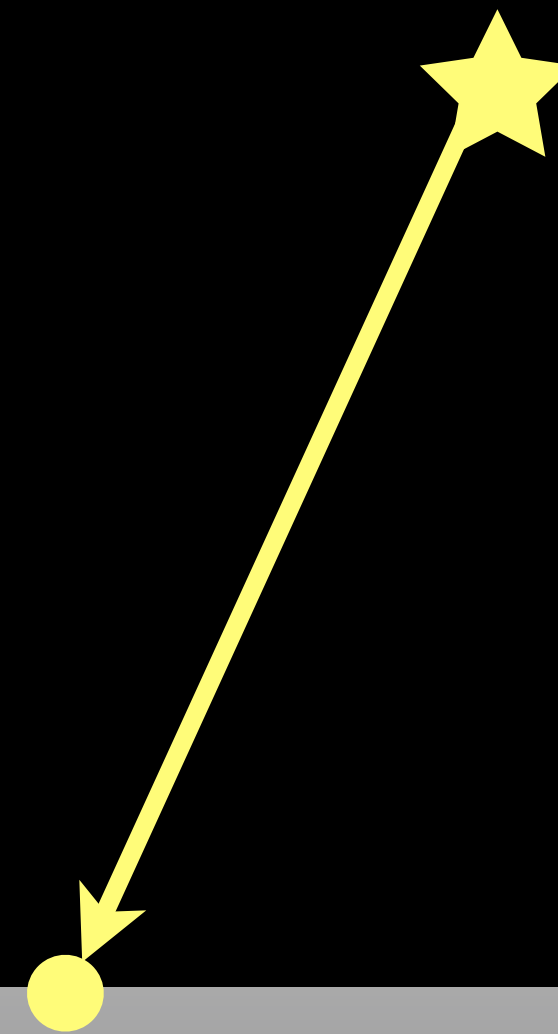
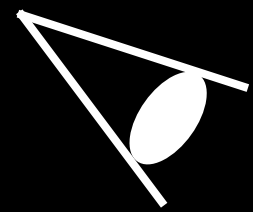


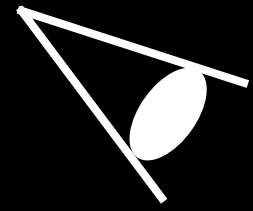
Our model

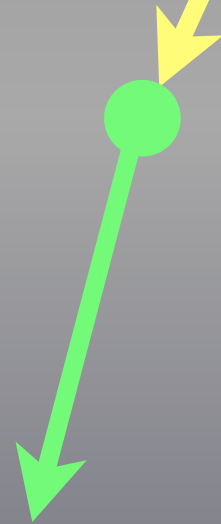
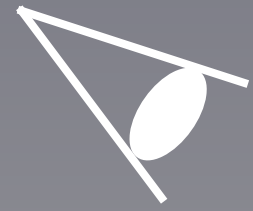


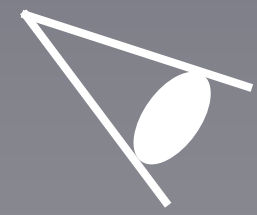
Reference

Idea

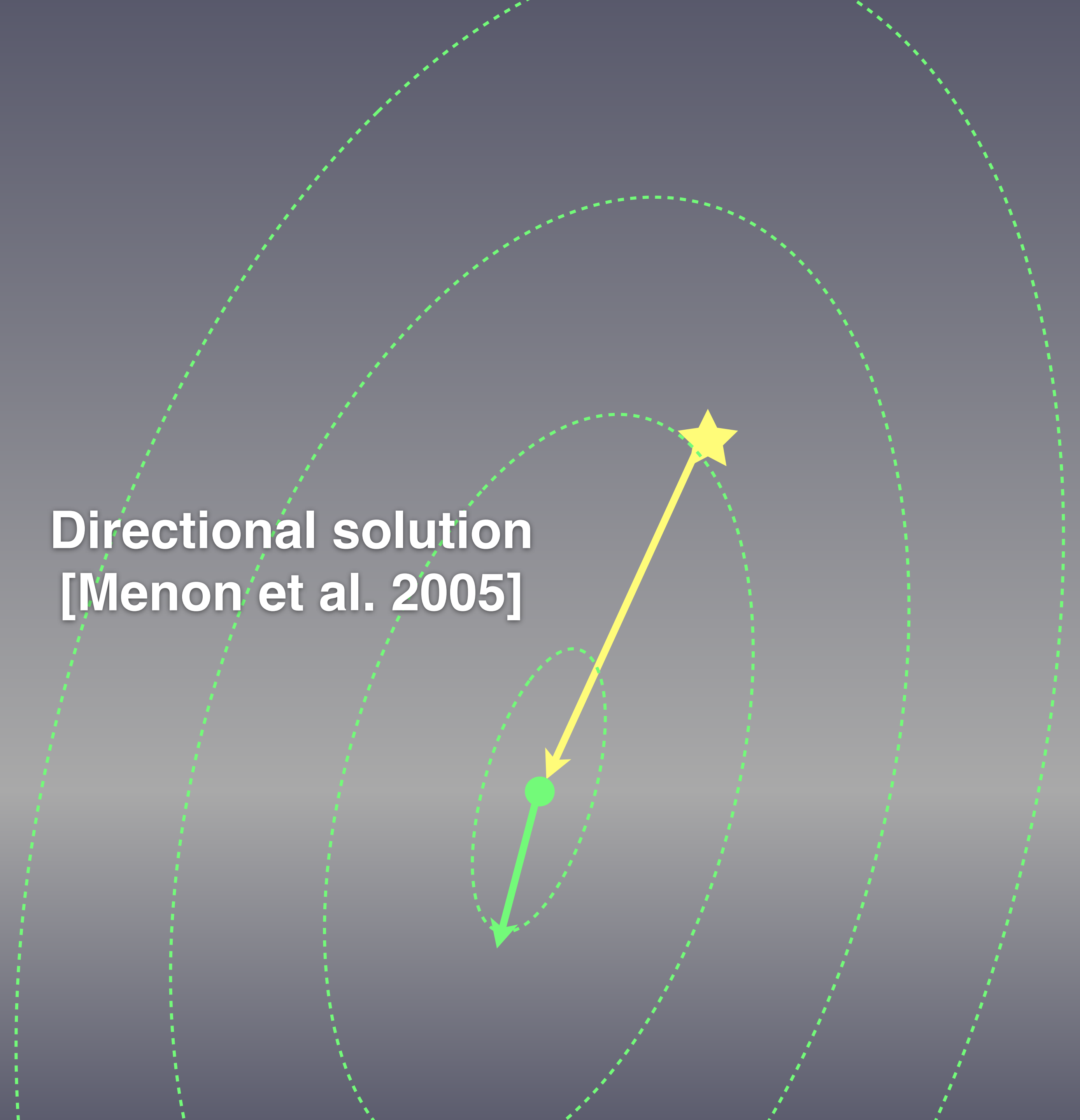


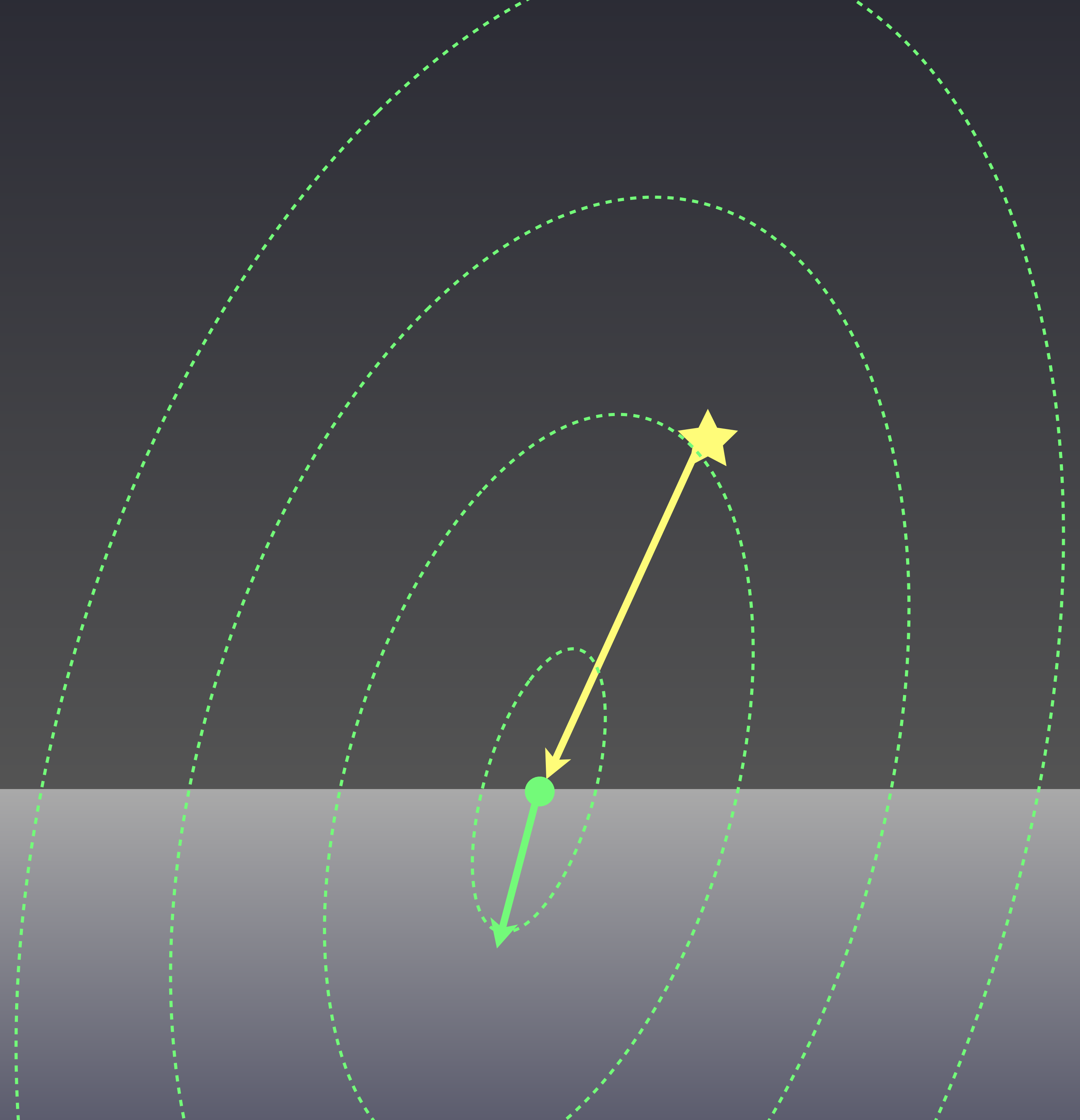
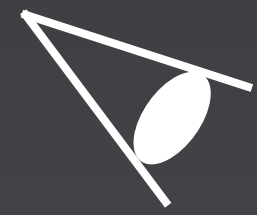




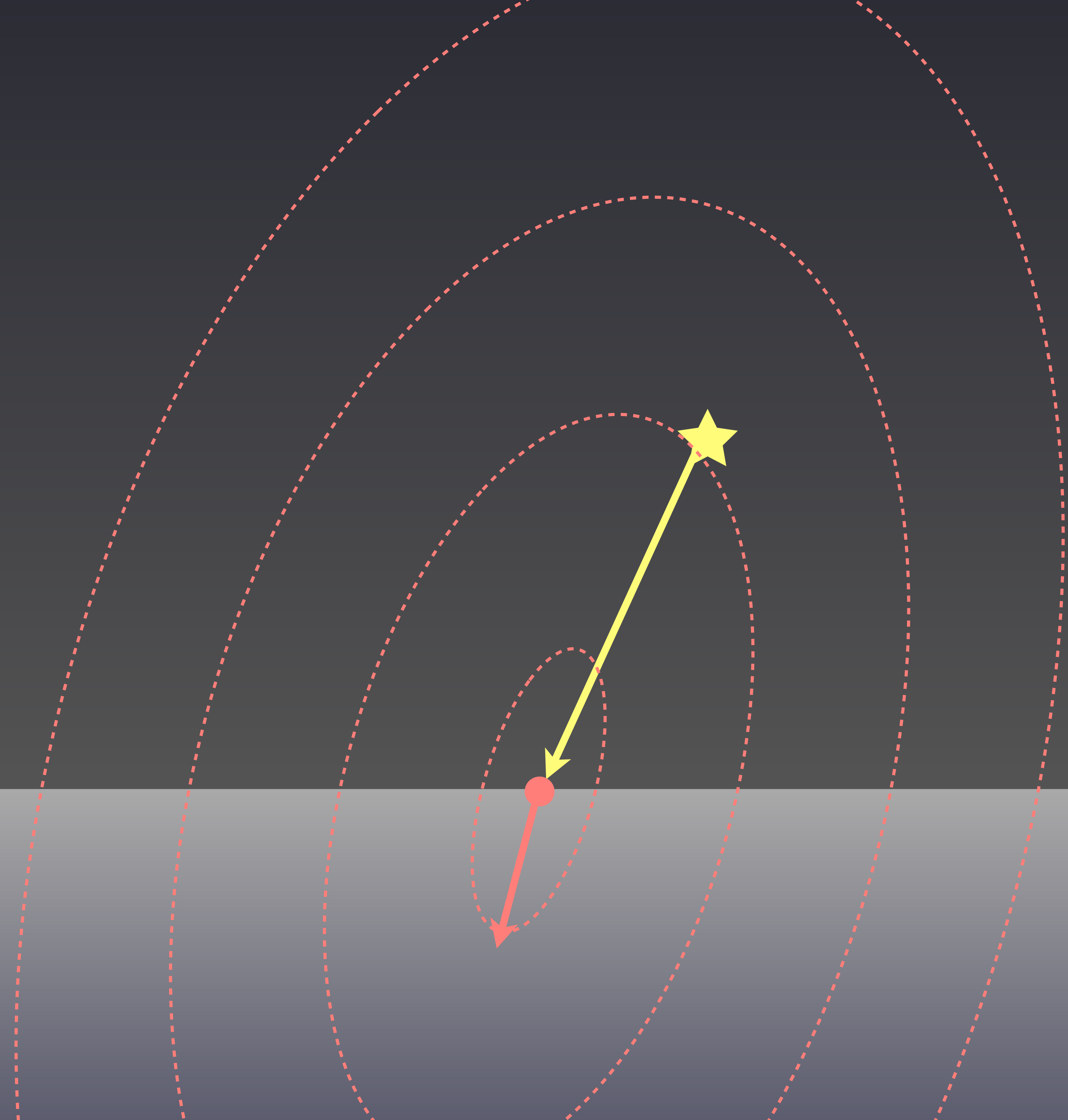
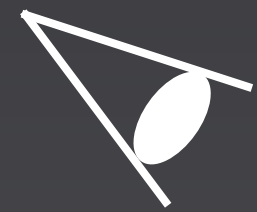


Directional solution
[Menon et al. 2005]

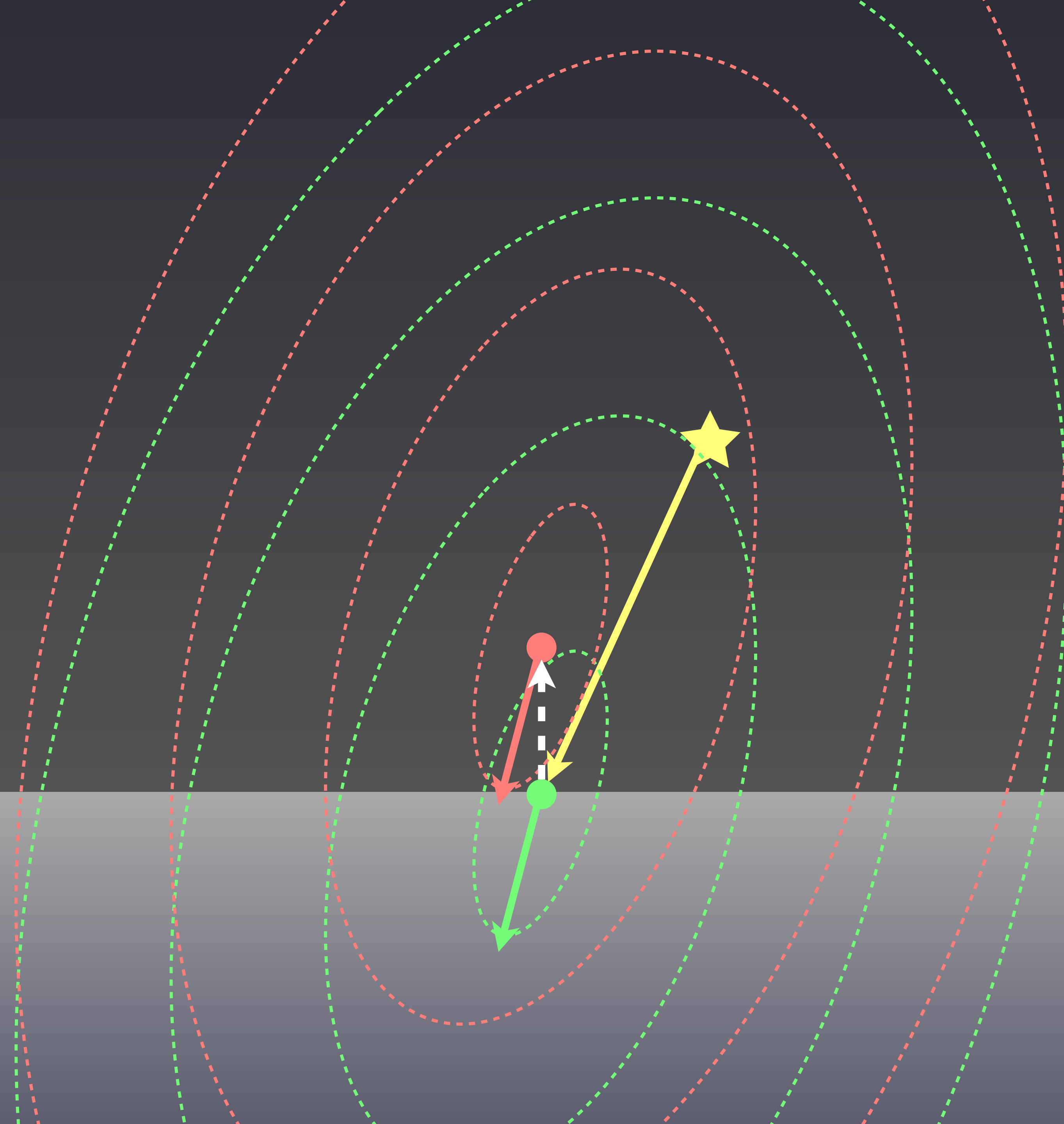


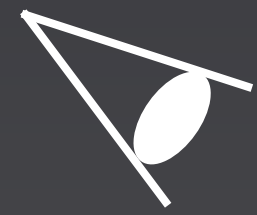


Virtual source

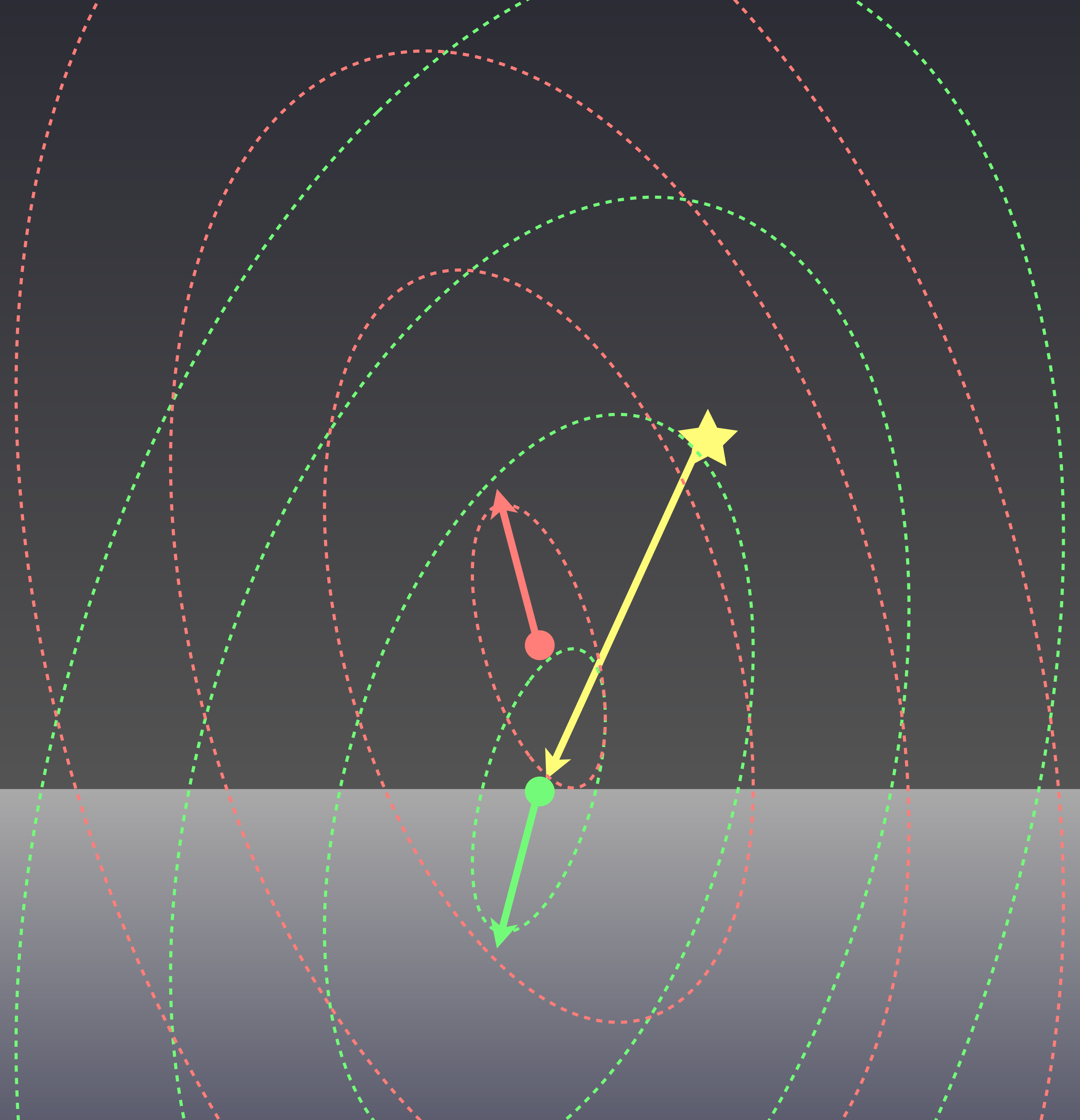


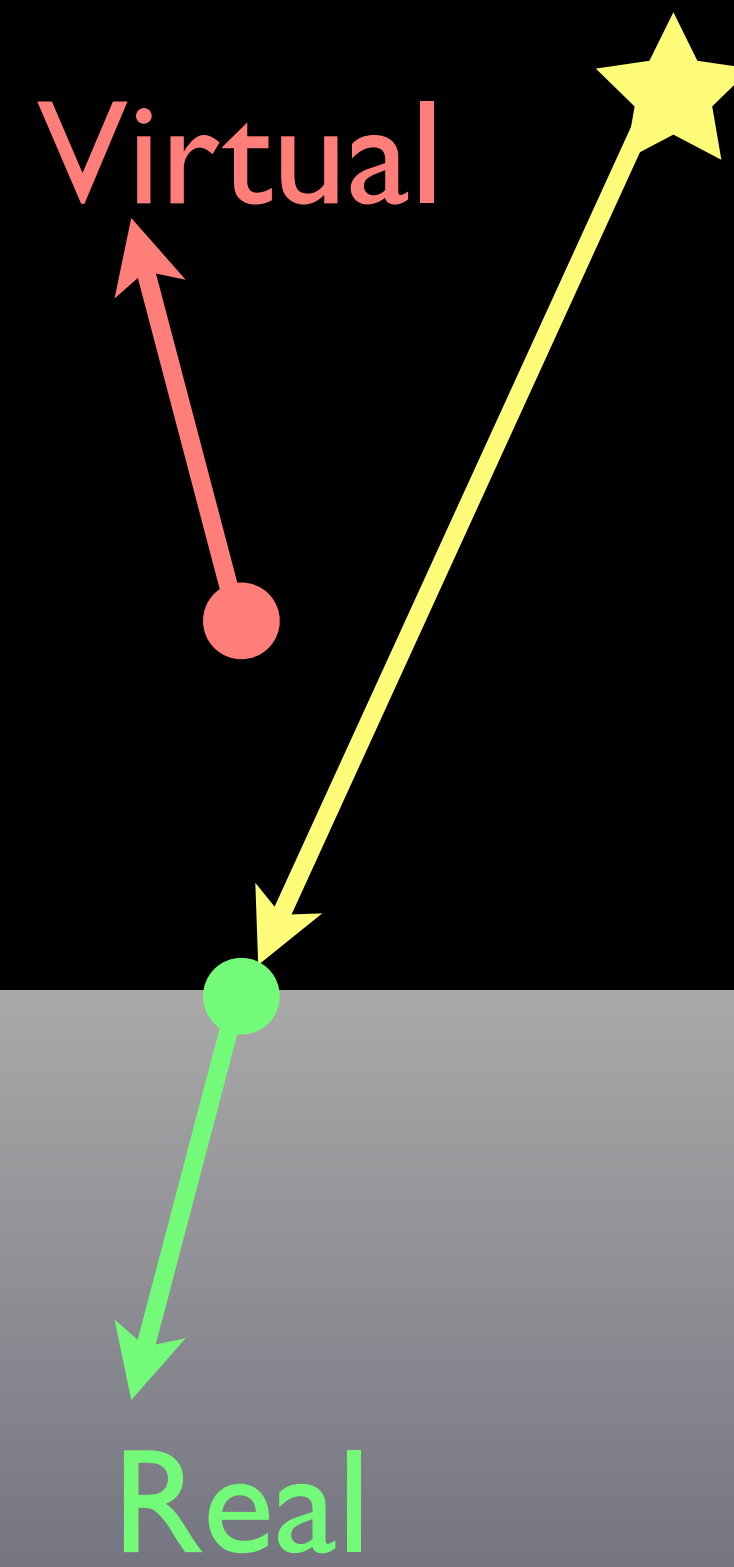
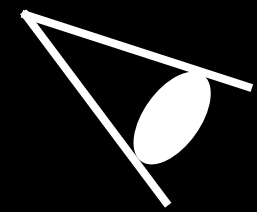
Offset location



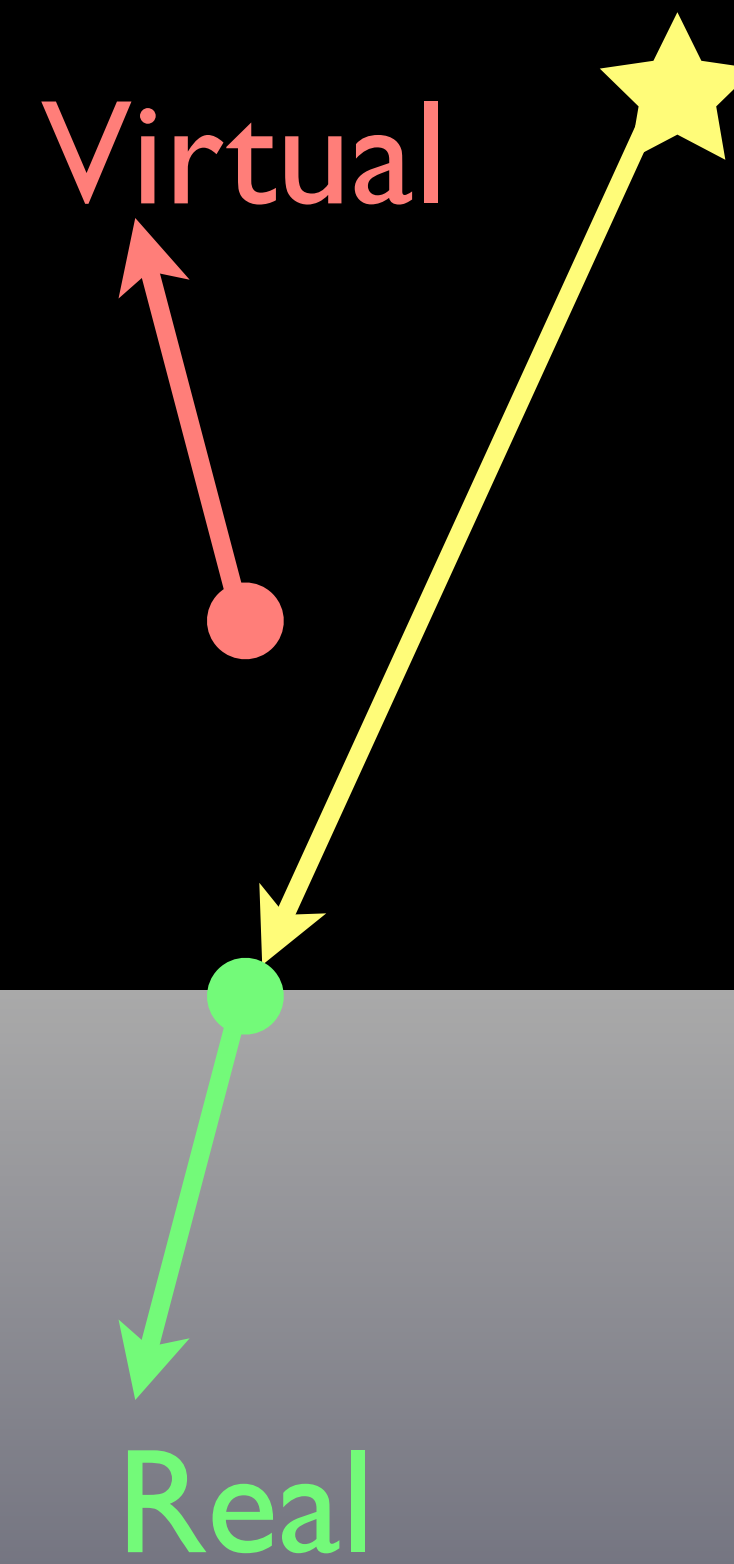
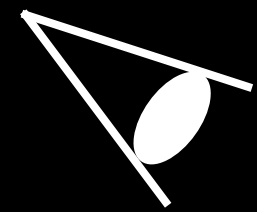


Mirror direction

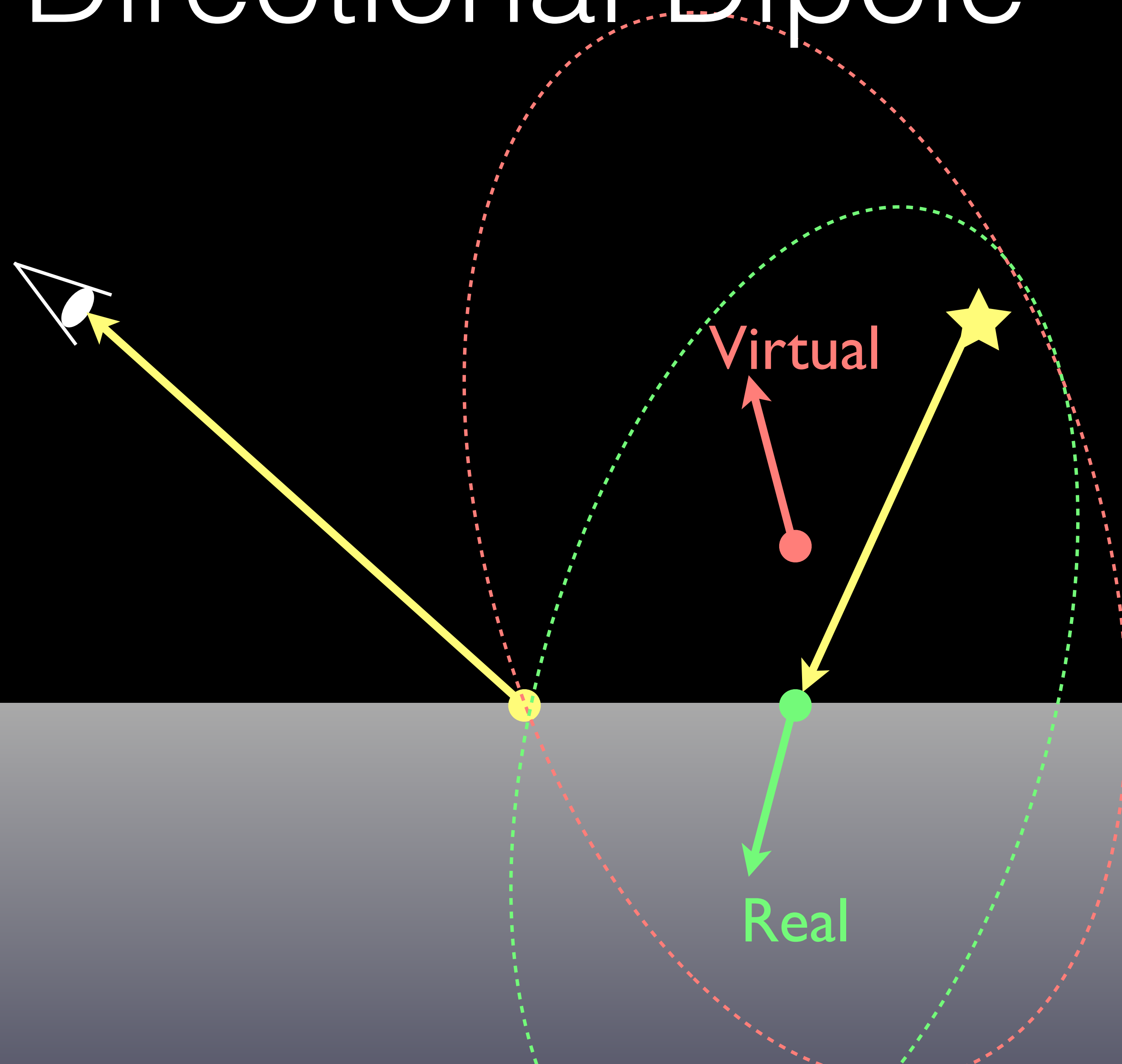




Directional Dipole



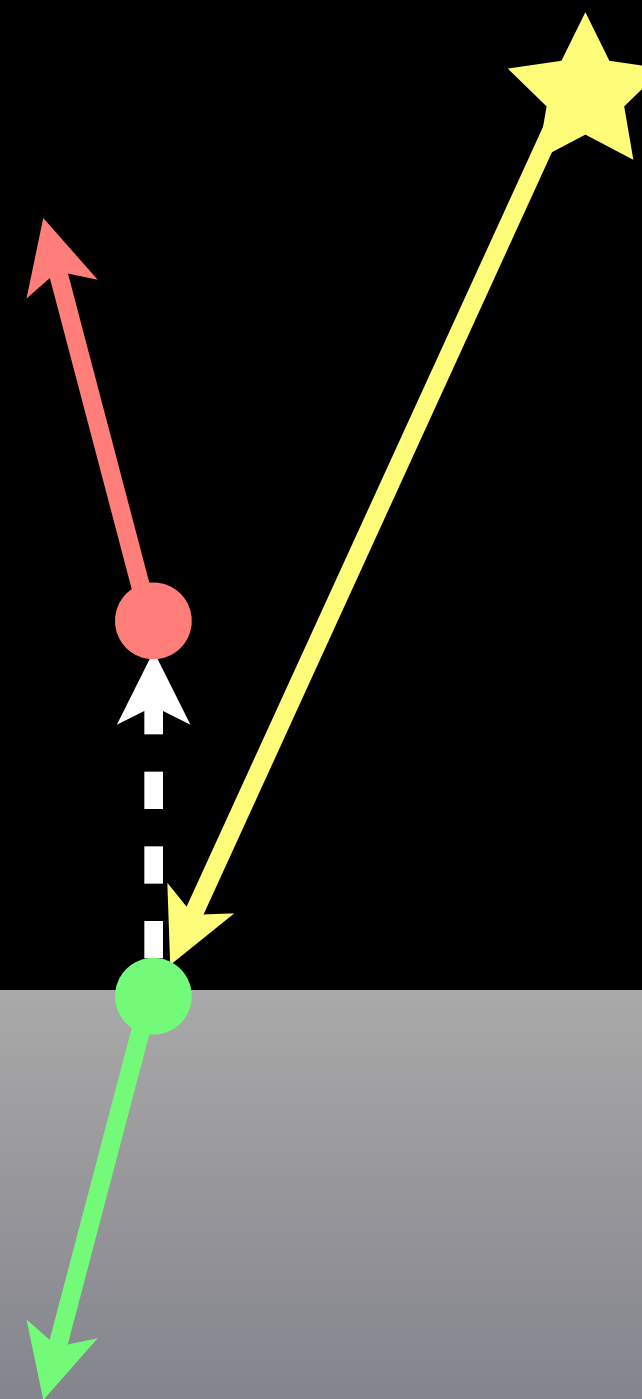
Directional Dipole



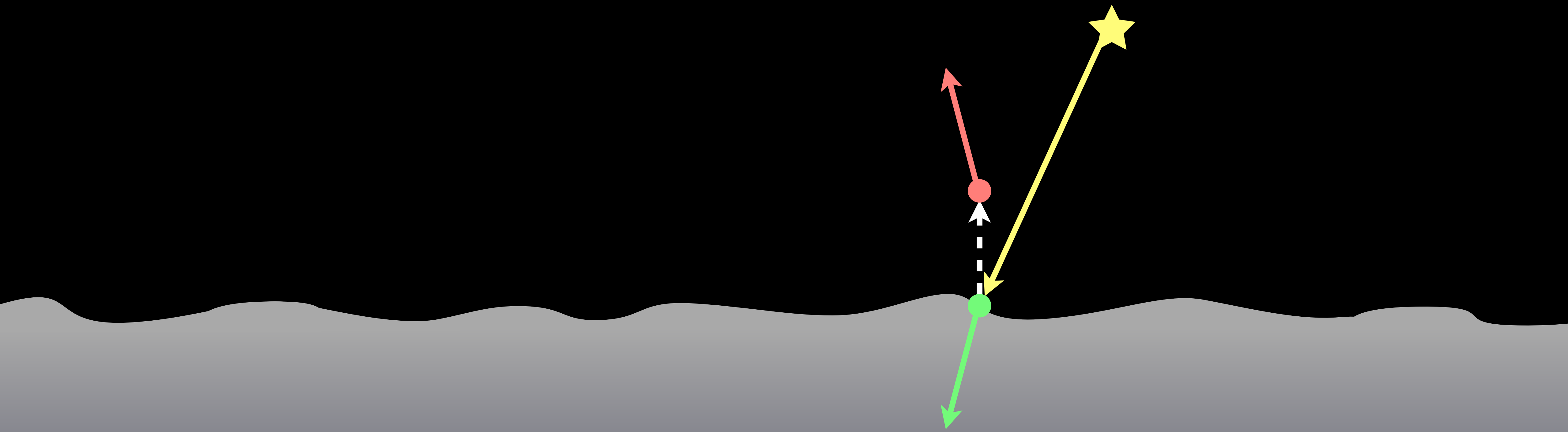
Toward Practical Model

- Need to solve two practical issues
 - Mirroring for the virtual source is unstable
 - Contribution of the real source diverges

Unstable Mirroring

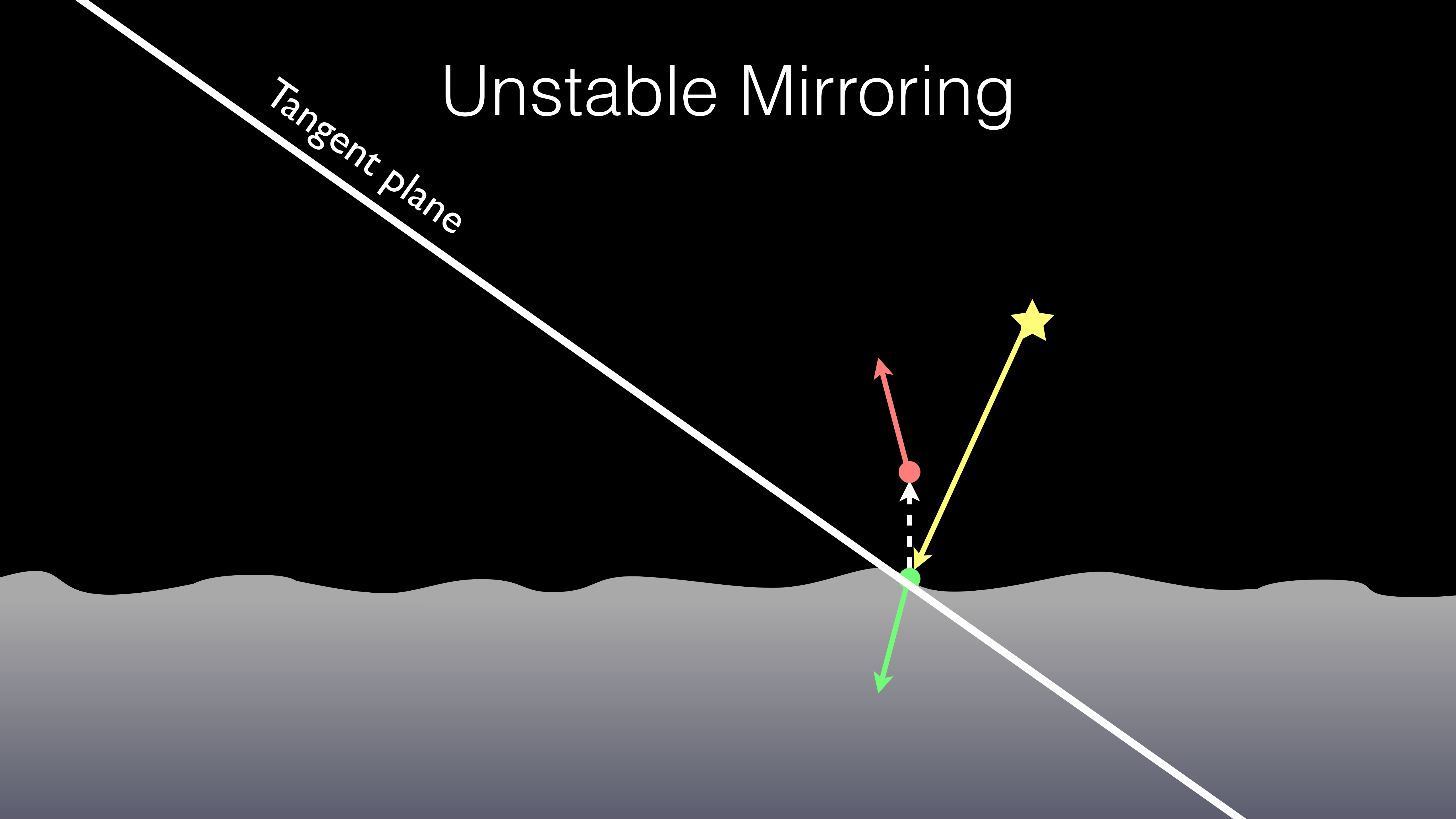


Unstable Mirroring



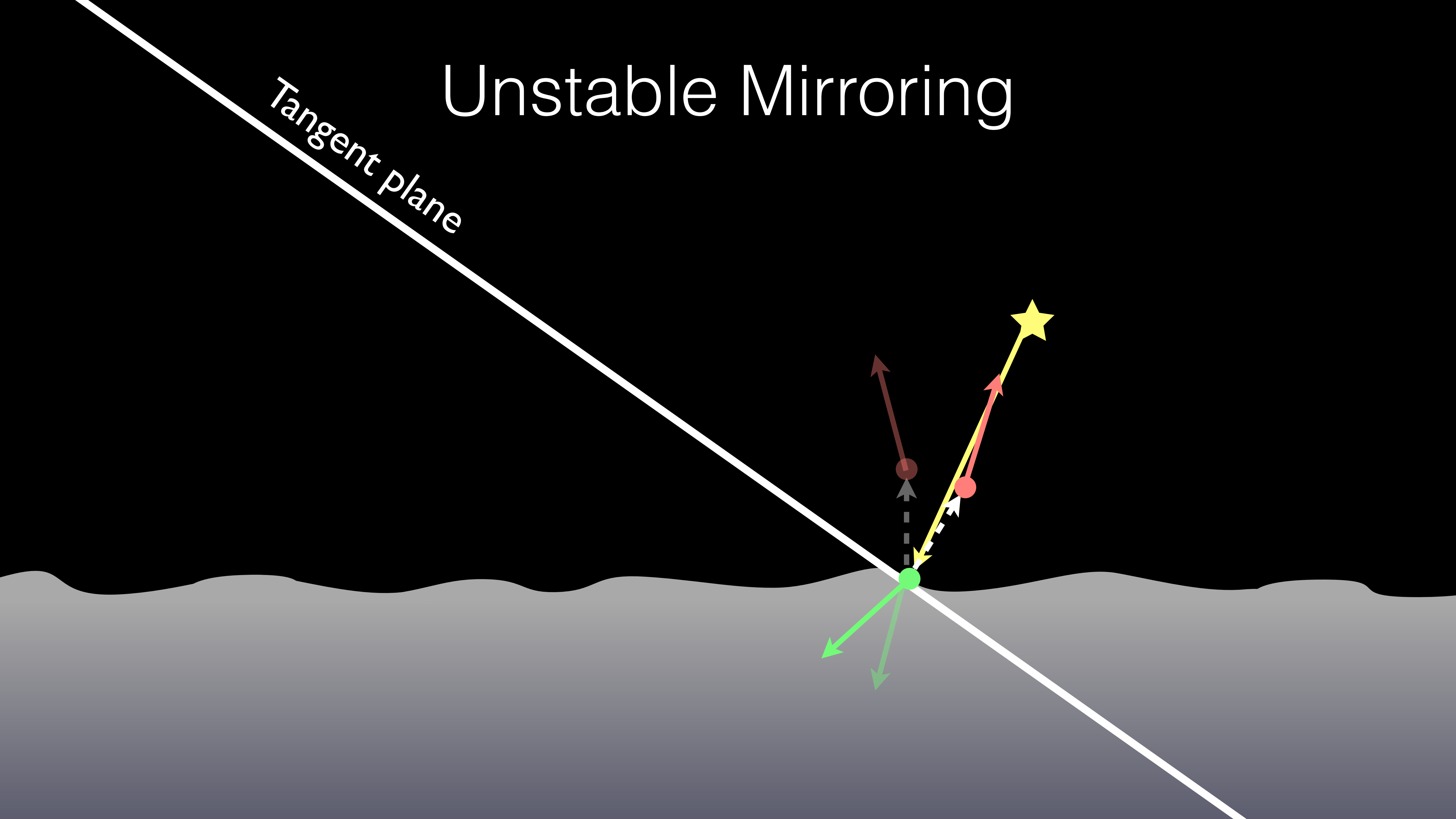
Unstable Mirroring

Tangent plane

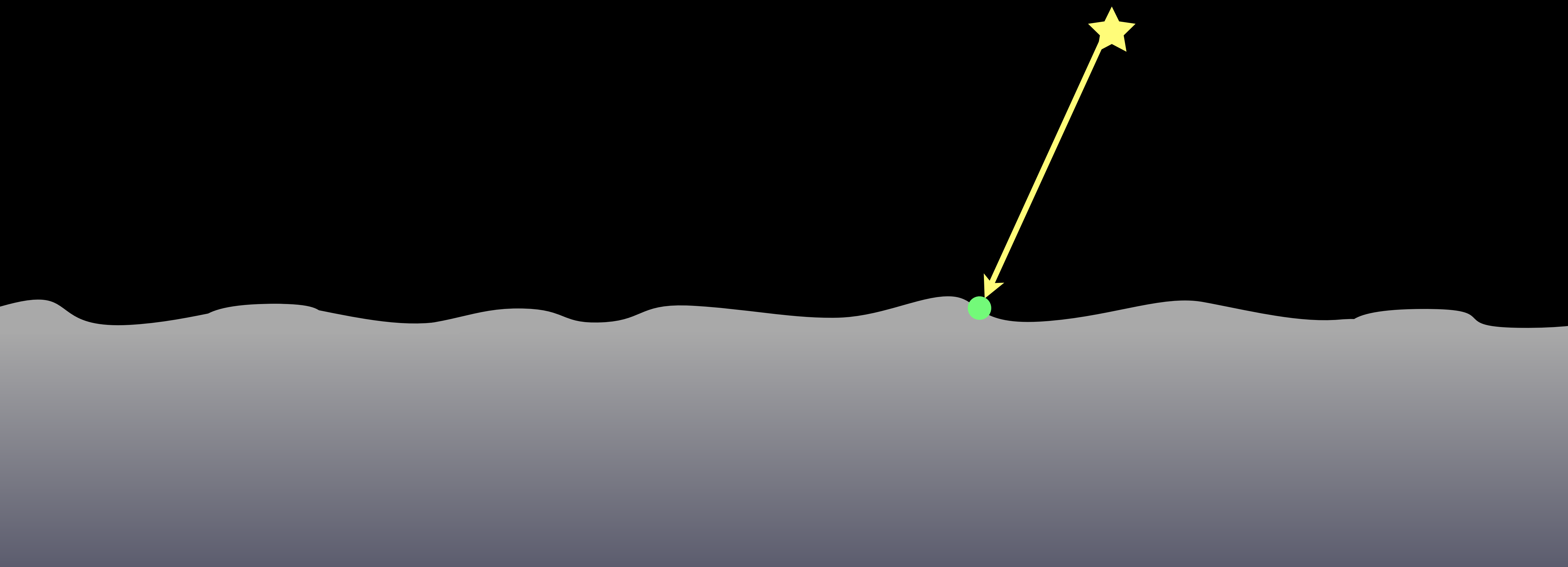


Unstable Mirroring

Tangent plane

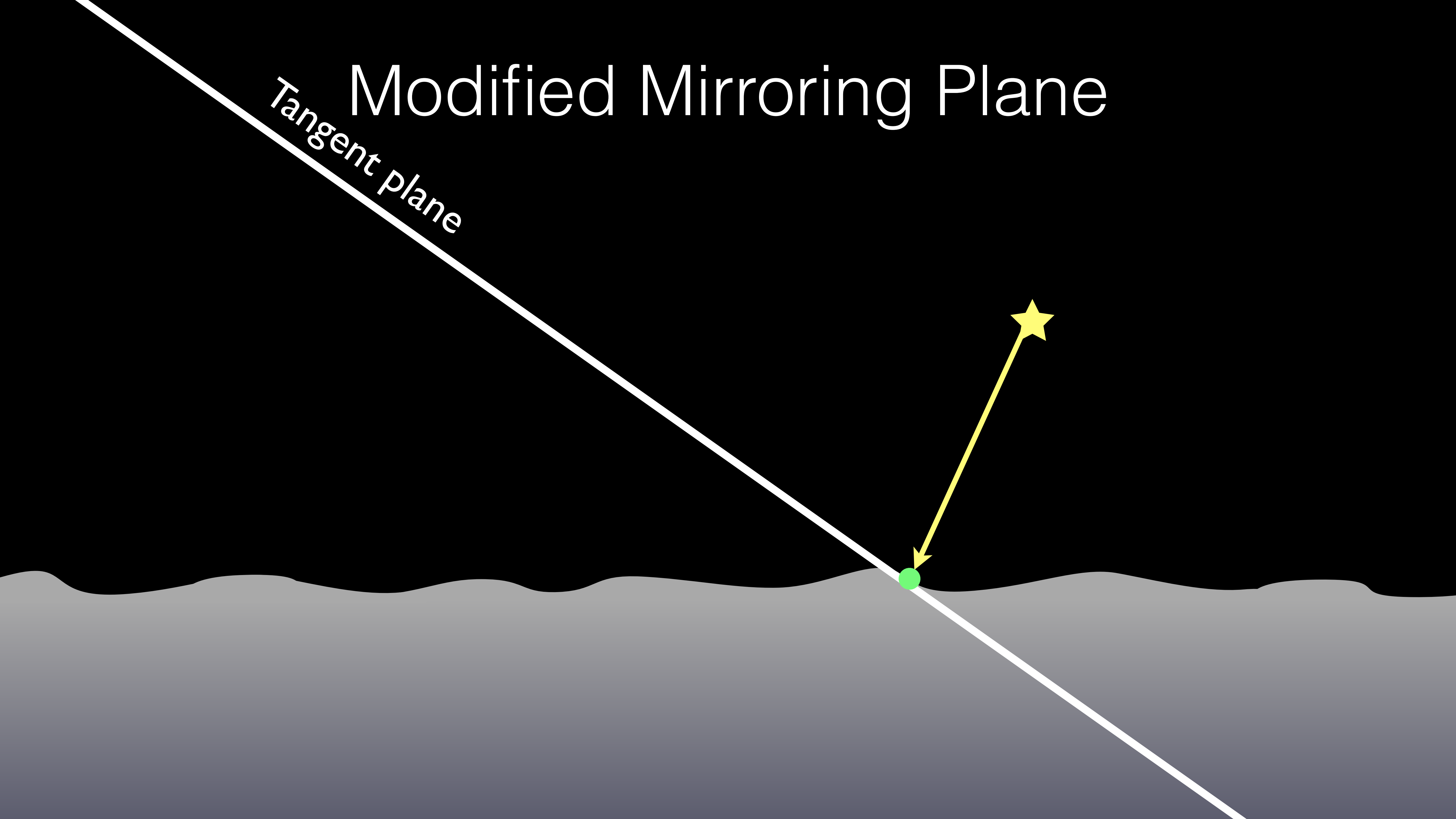


Modified Mirroring Plane



Modified Mirroring Plane

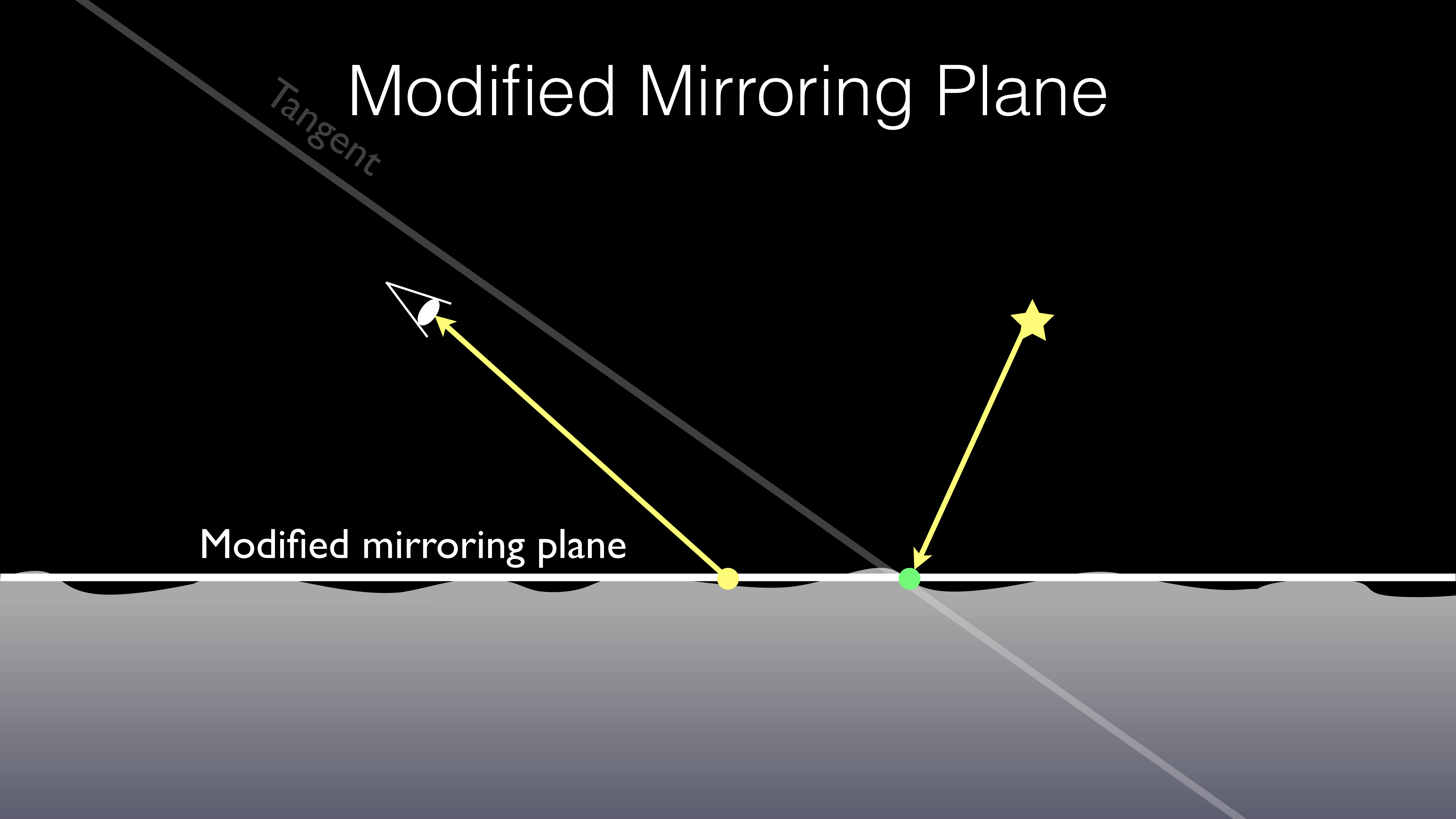
Tangent plane



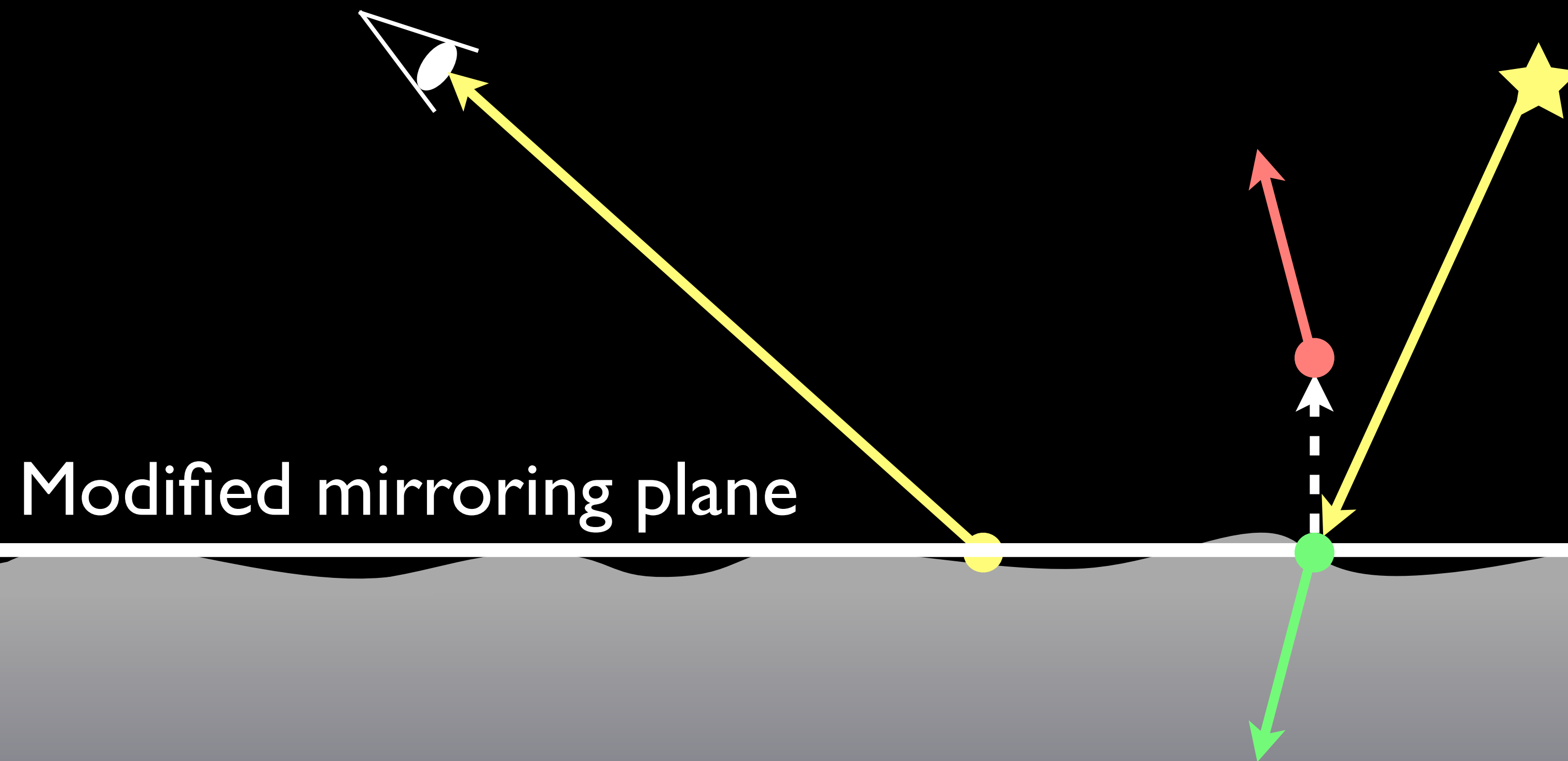
Modified Mirroring Plane

Tangent

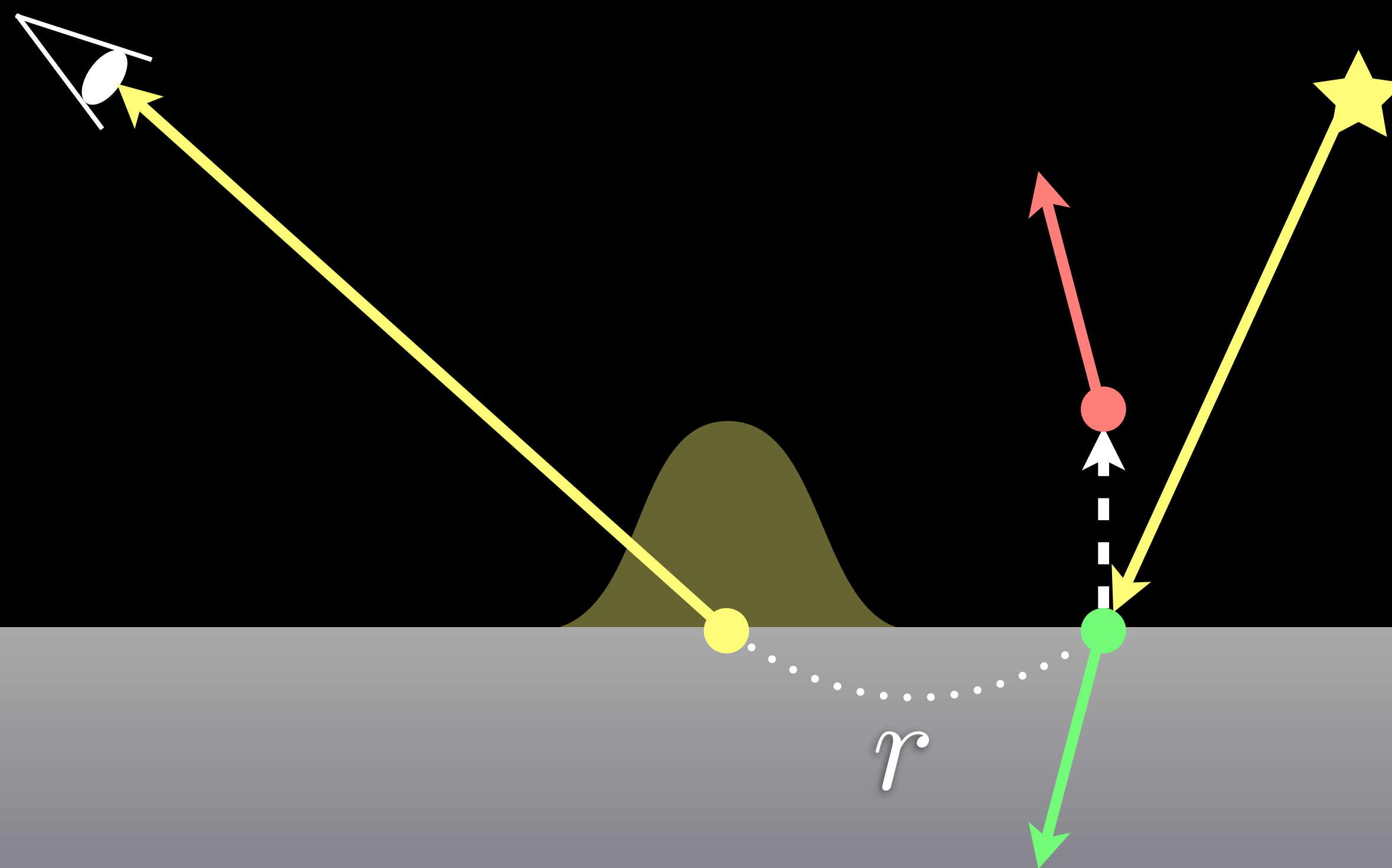
Modified mirroring plane



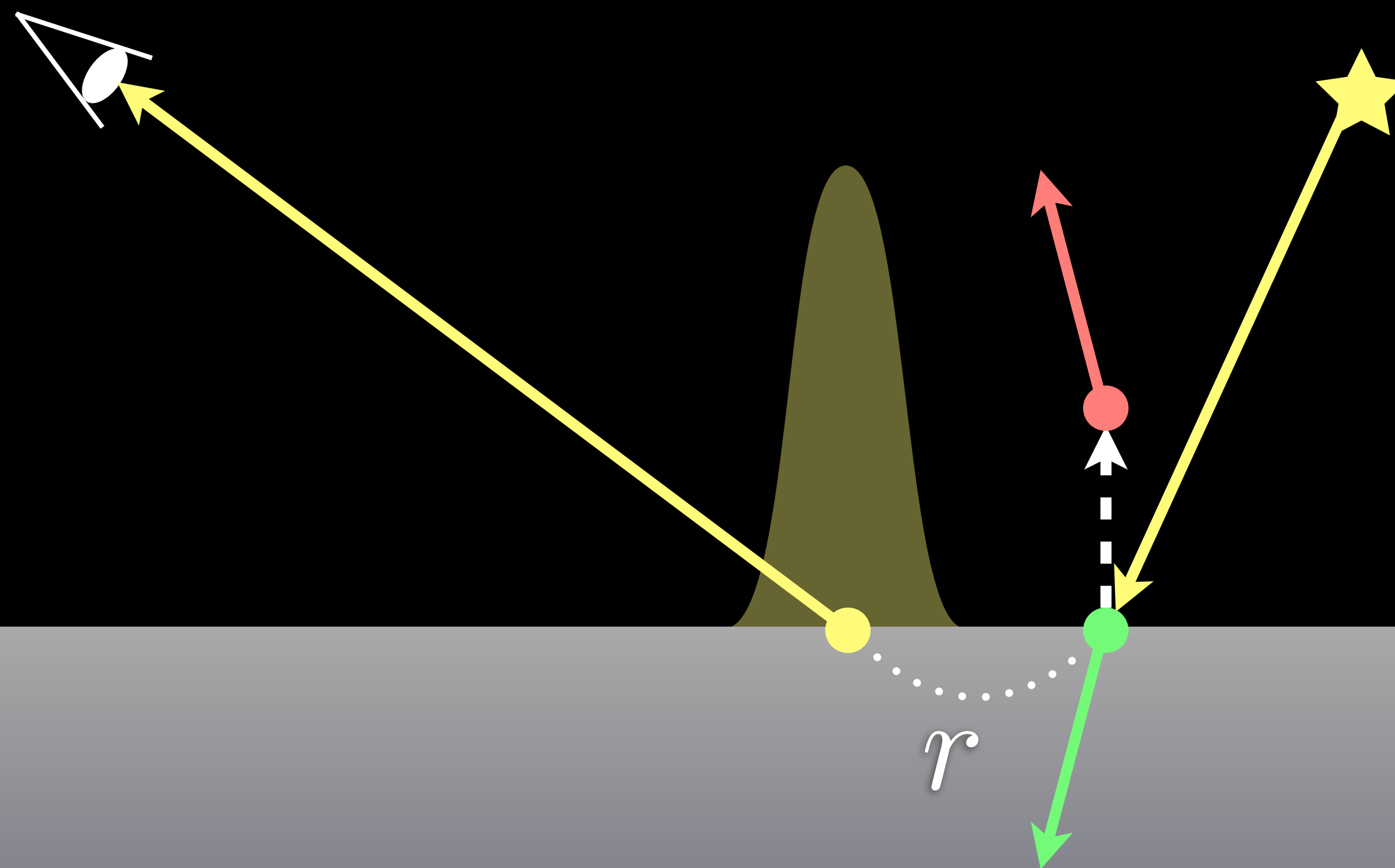
Modified Mirroring Plane



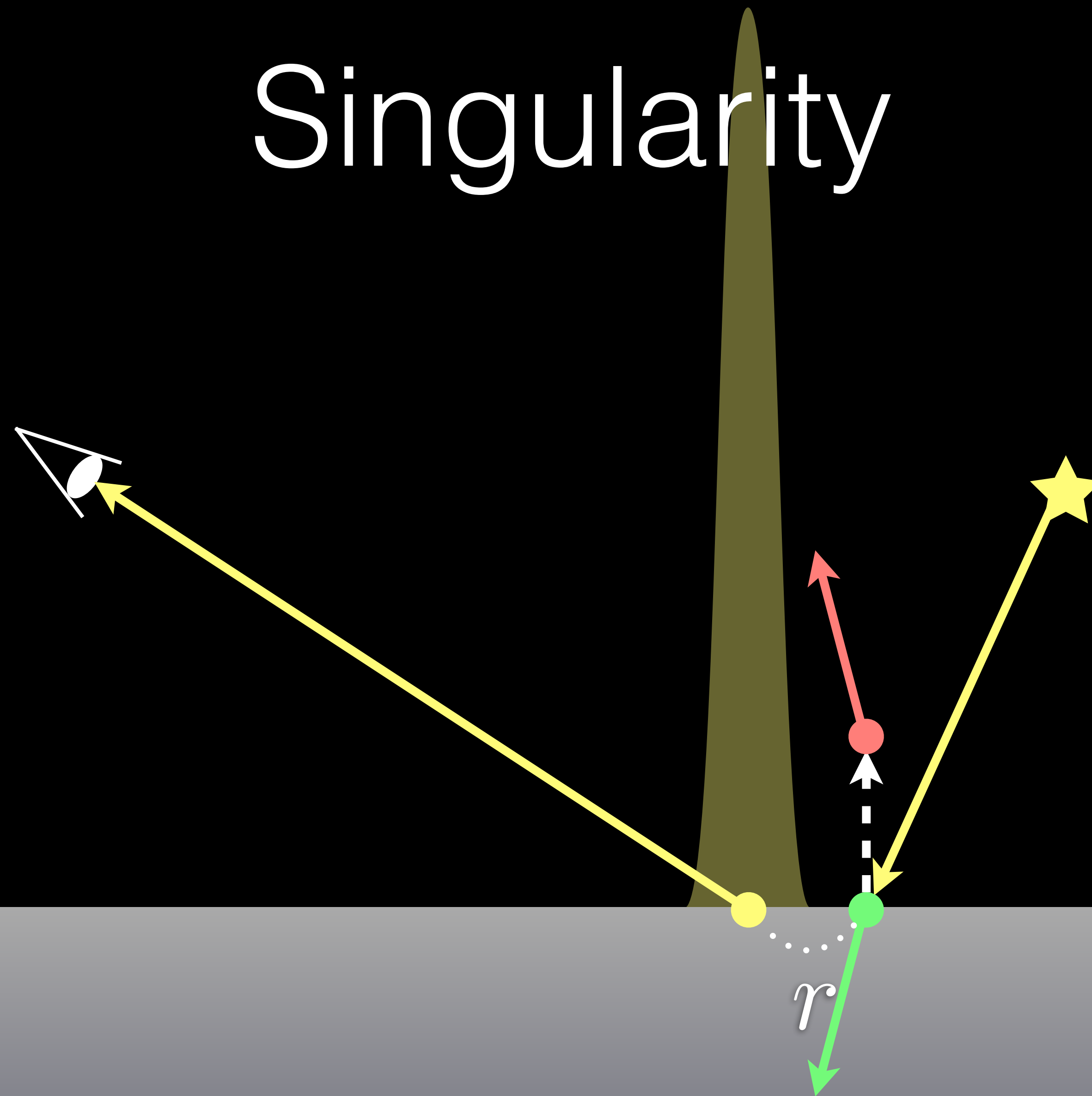
Singularity



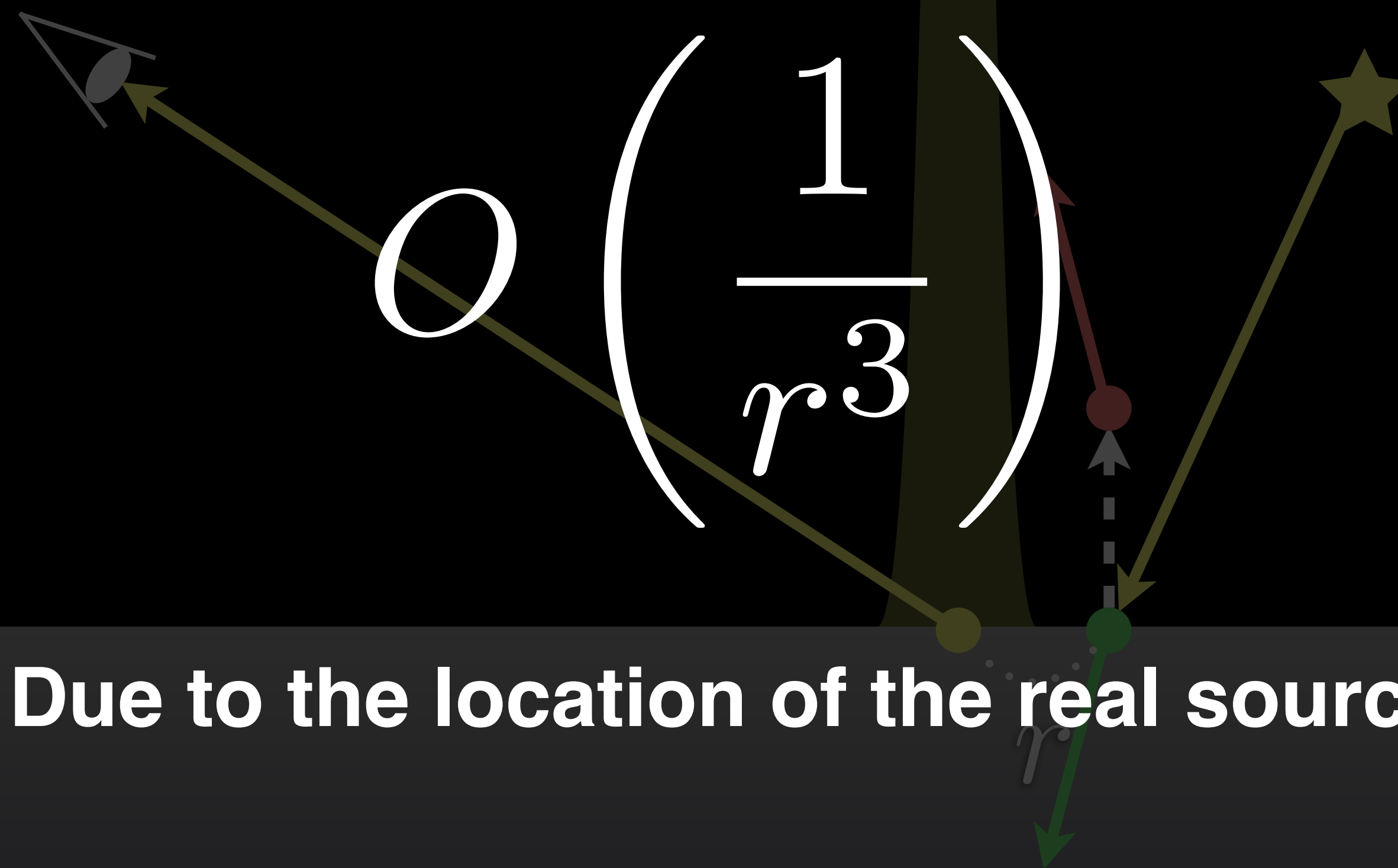
Singularity



Singularity



Singularity



Due to the location of the real source

Distance Correction

$$r'^2 = \begin{cases} r^2 + D\mu_0(D\mu_0 - 2d_e \cos \beta) & \text{(front lit)} \\ r^2 + (3\sigma_t)^{-2} & \text{(back lit)} \end{cases}$$

The diagram illustrates the relationship between the corrected distance (r'^2), the distance (r^2), and the correction factor. The corrected distance is shown as a green box, and the distance is shown as a red box. The correction factor is shown as a yellow box. The equation is presented as a piecewise function with two cases: front lit and back lit. The front lit case is $r^2 + D\mu_0(D\mu_0 - 2d_e \cos \beta)$ and the back lit case is $r^2 + (3\sigma_t)^{-2}$. Arrows indicate the flow of information: a green arrow points from the corrected distance box to the r'^2 term; a red arrow points from the distance box to the r^2 terms; and yellow arrows point from the correction factor box to the correction terms in both cases.

corrected distance

distance

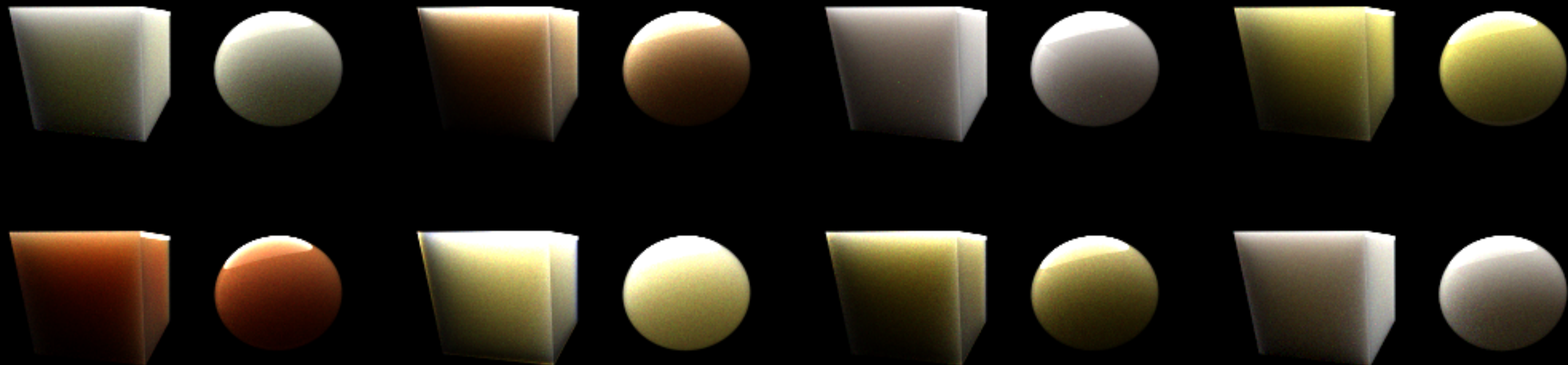
correction factor

Inspired by more exact solutions of the transport theory

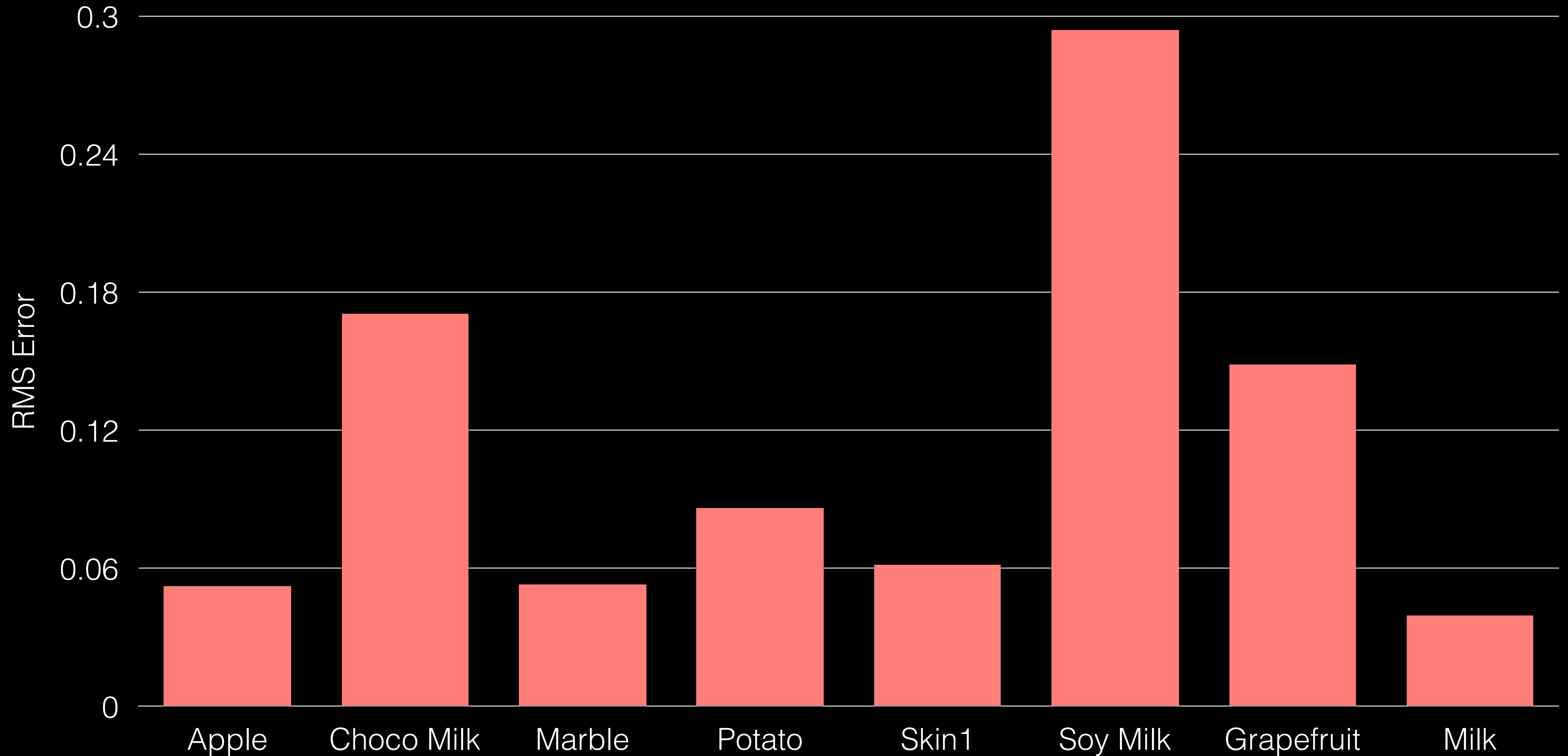
Results

Simple Test Cases

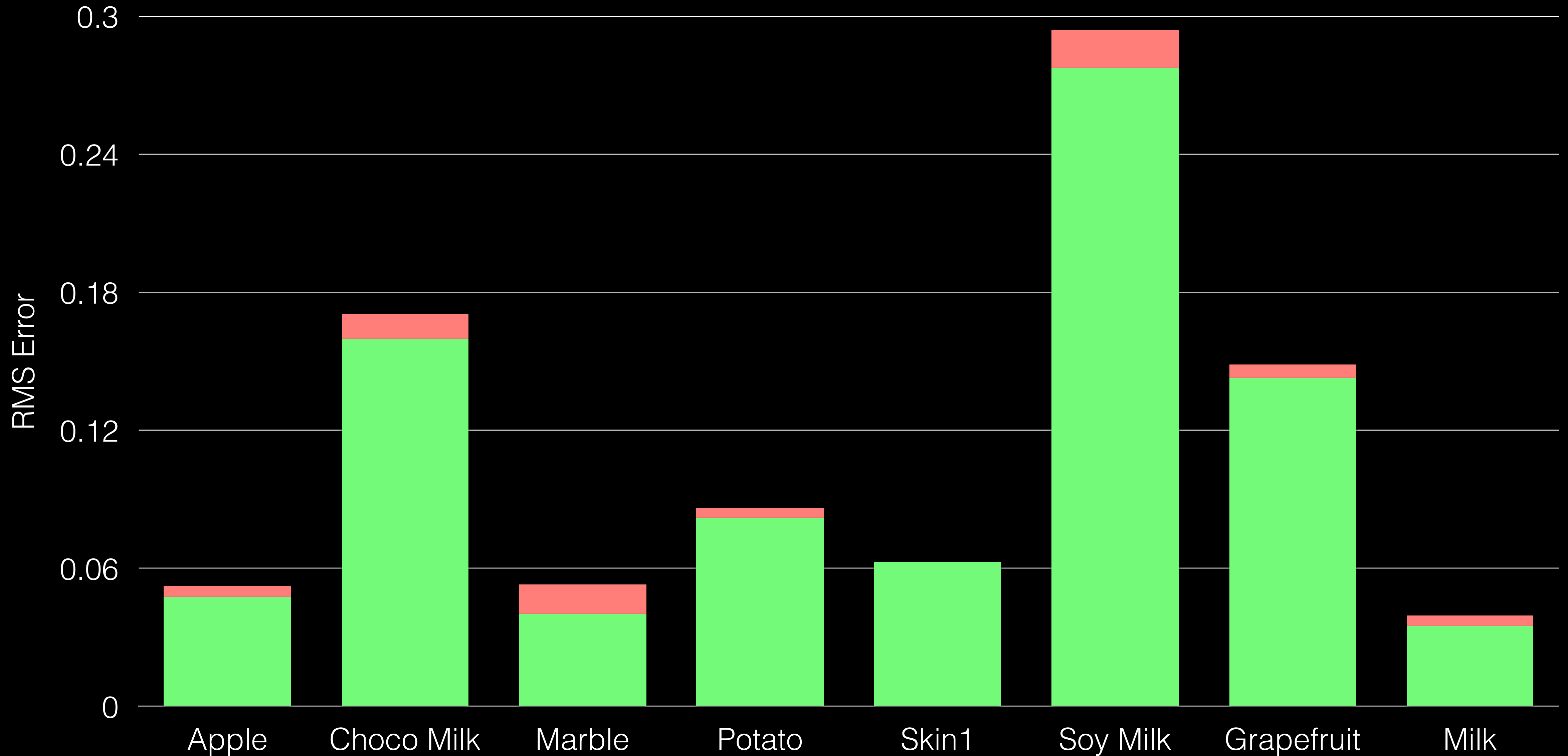
- Measured materials [Jensen et al. 2001] [Narasimhan et a. 2006]
- Comparisons with Monte Carlo simulation
- Highly directional lighting



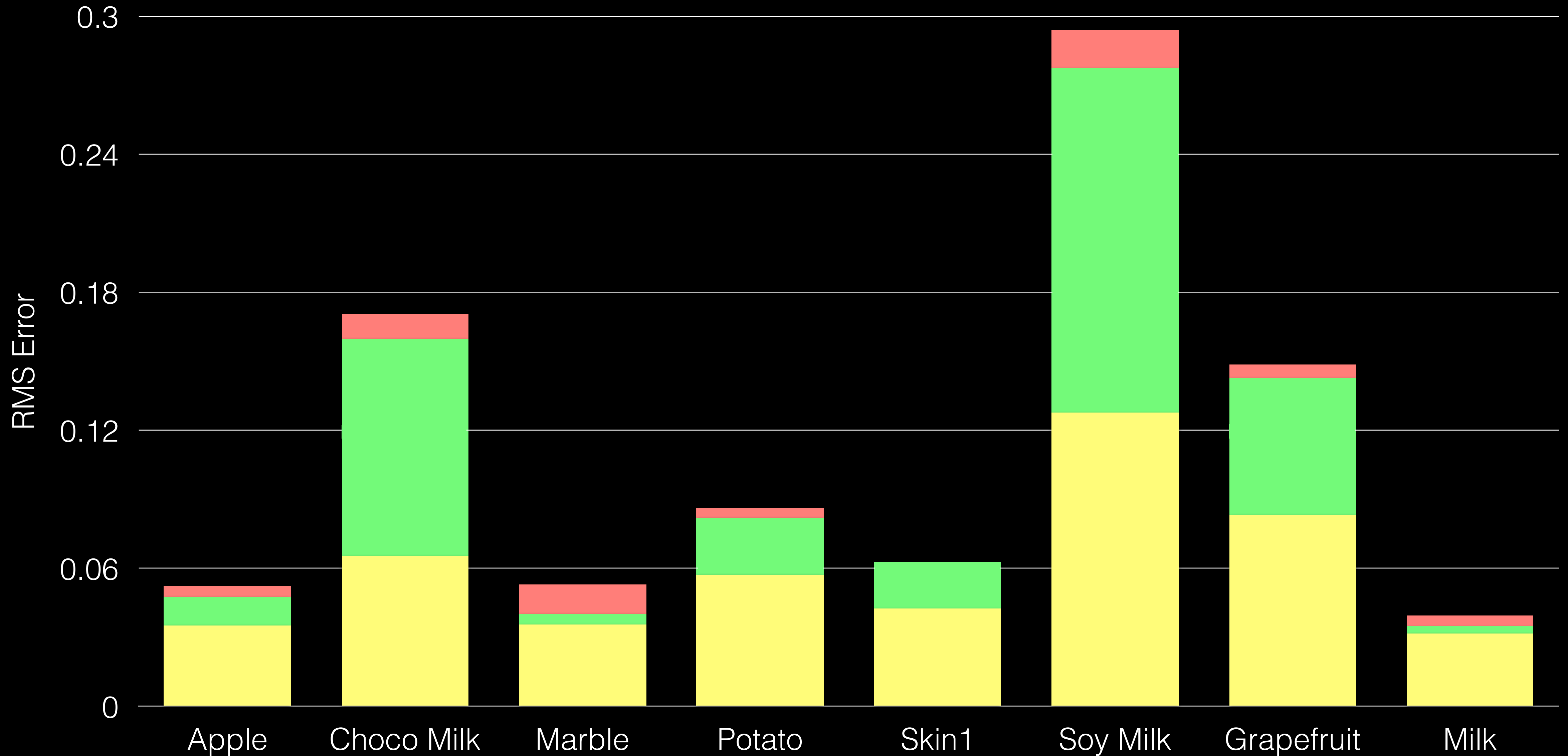
Simple Test Cases: Dipole



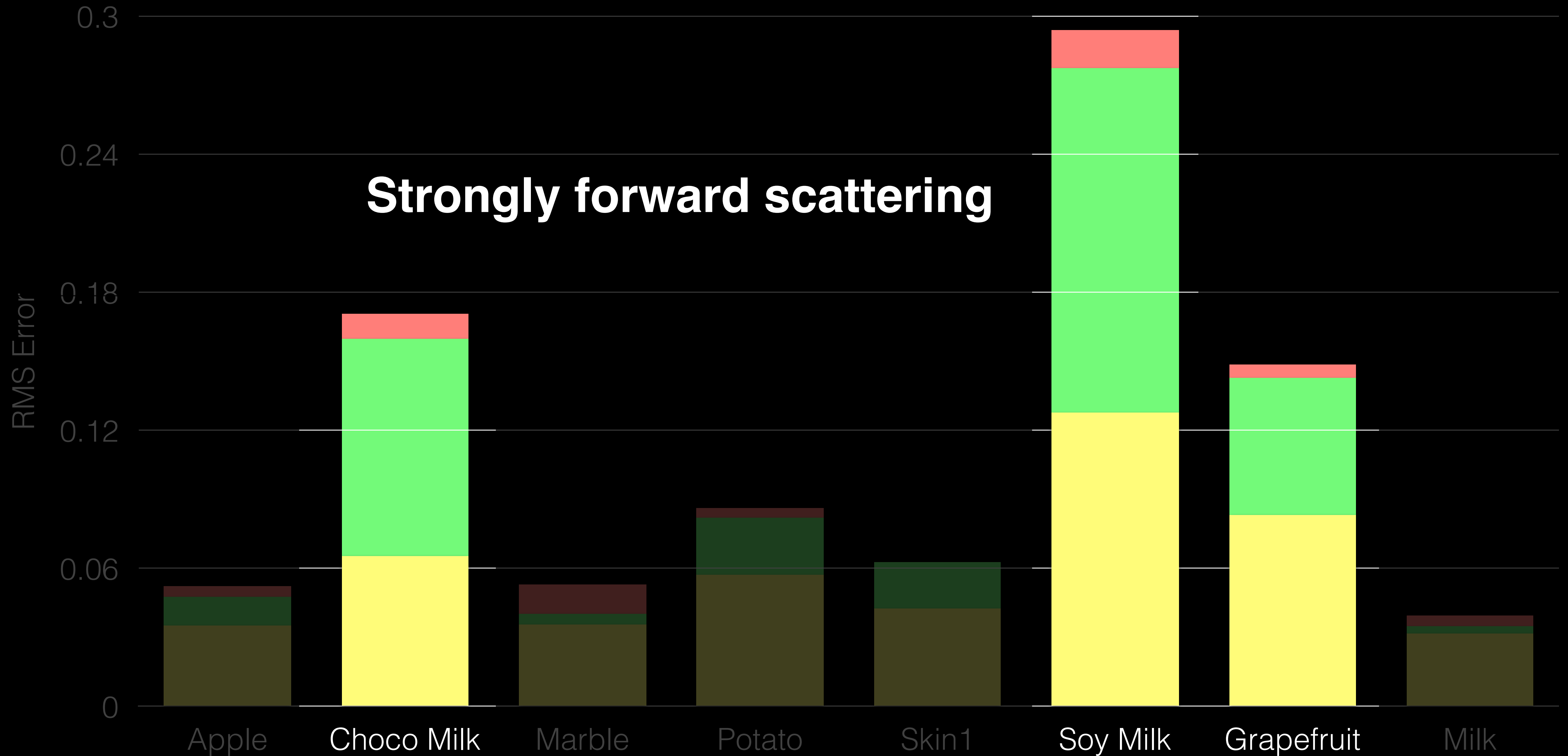
Simple Test Cases: Quantized



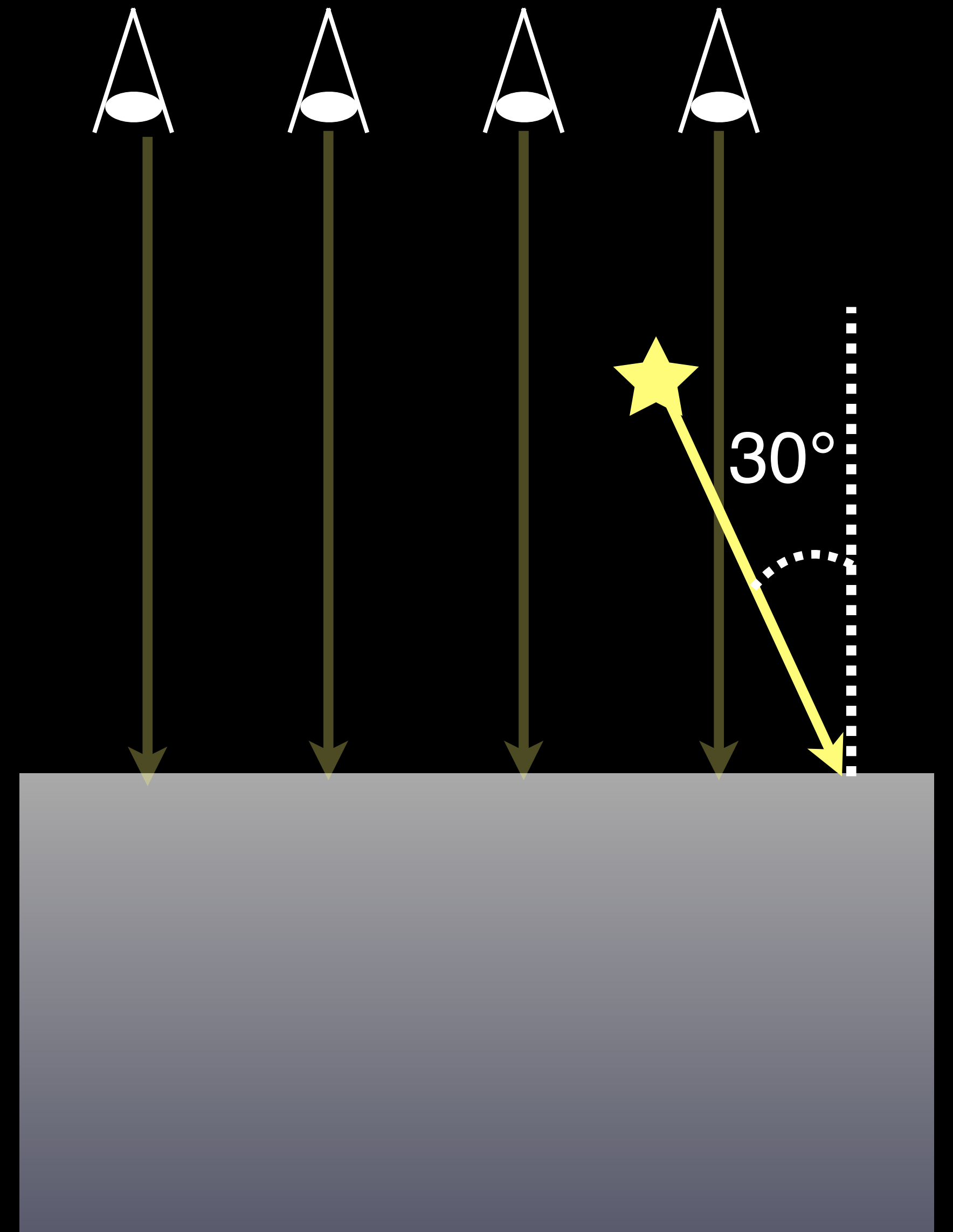
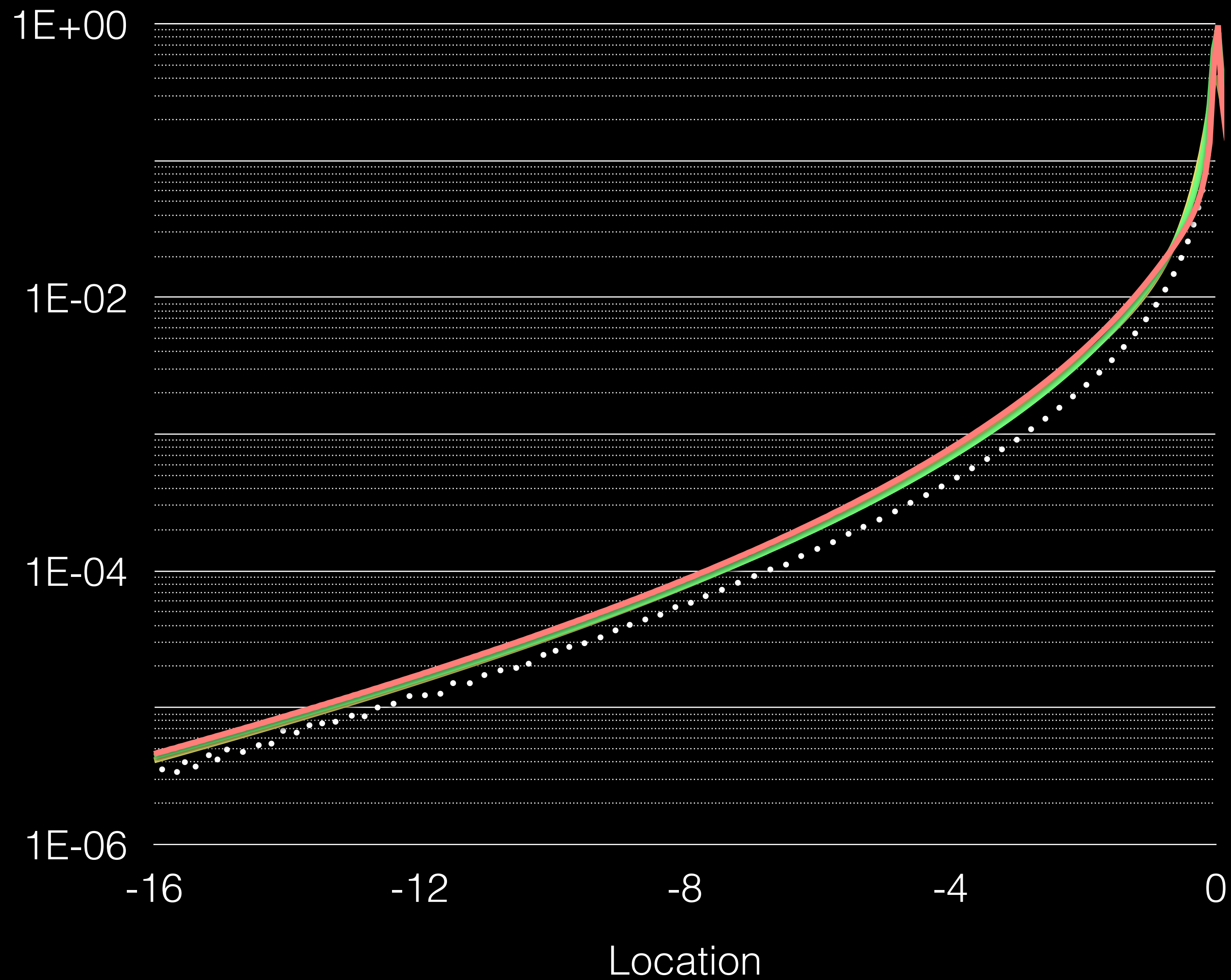
Simple Test Cases: Directional



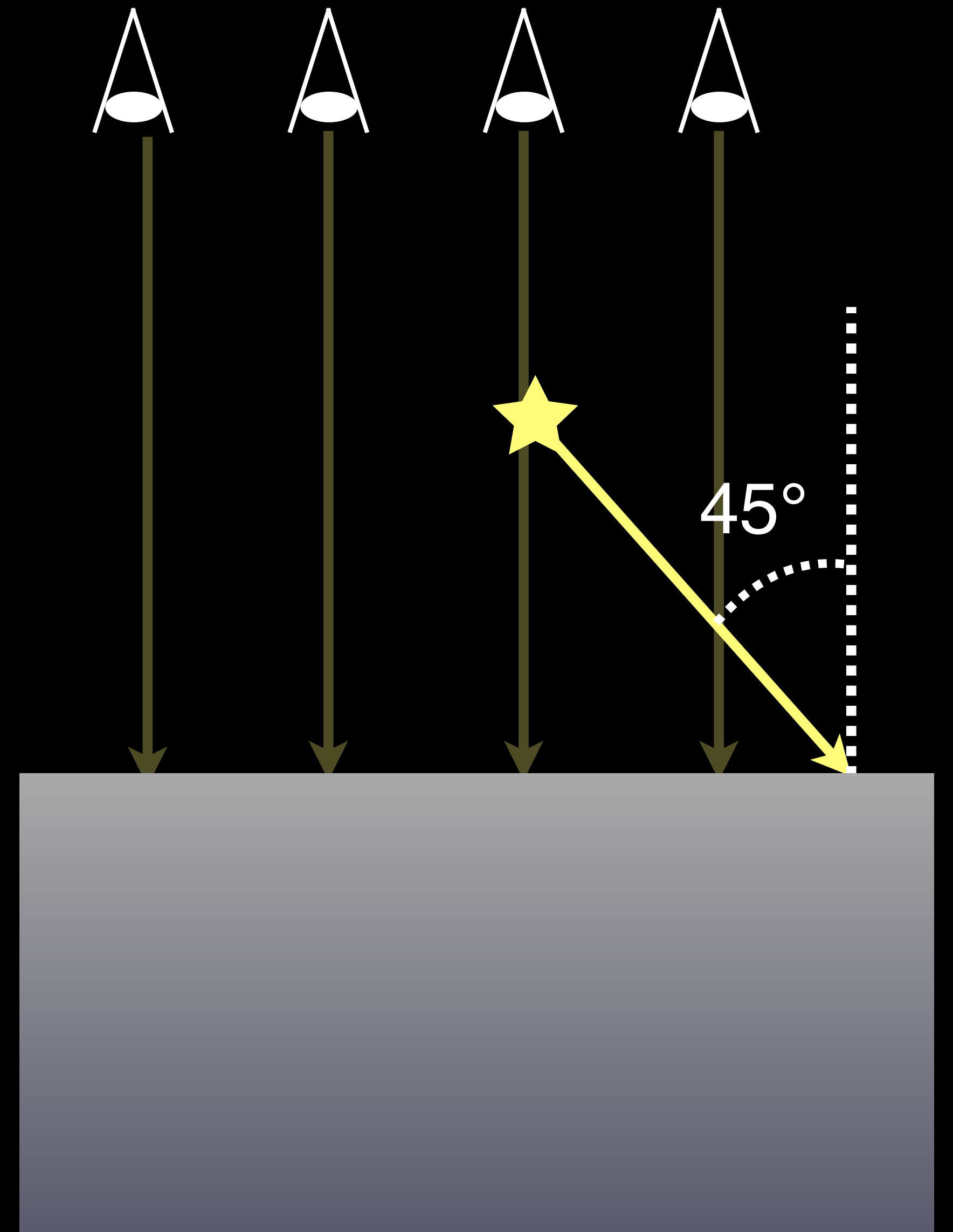
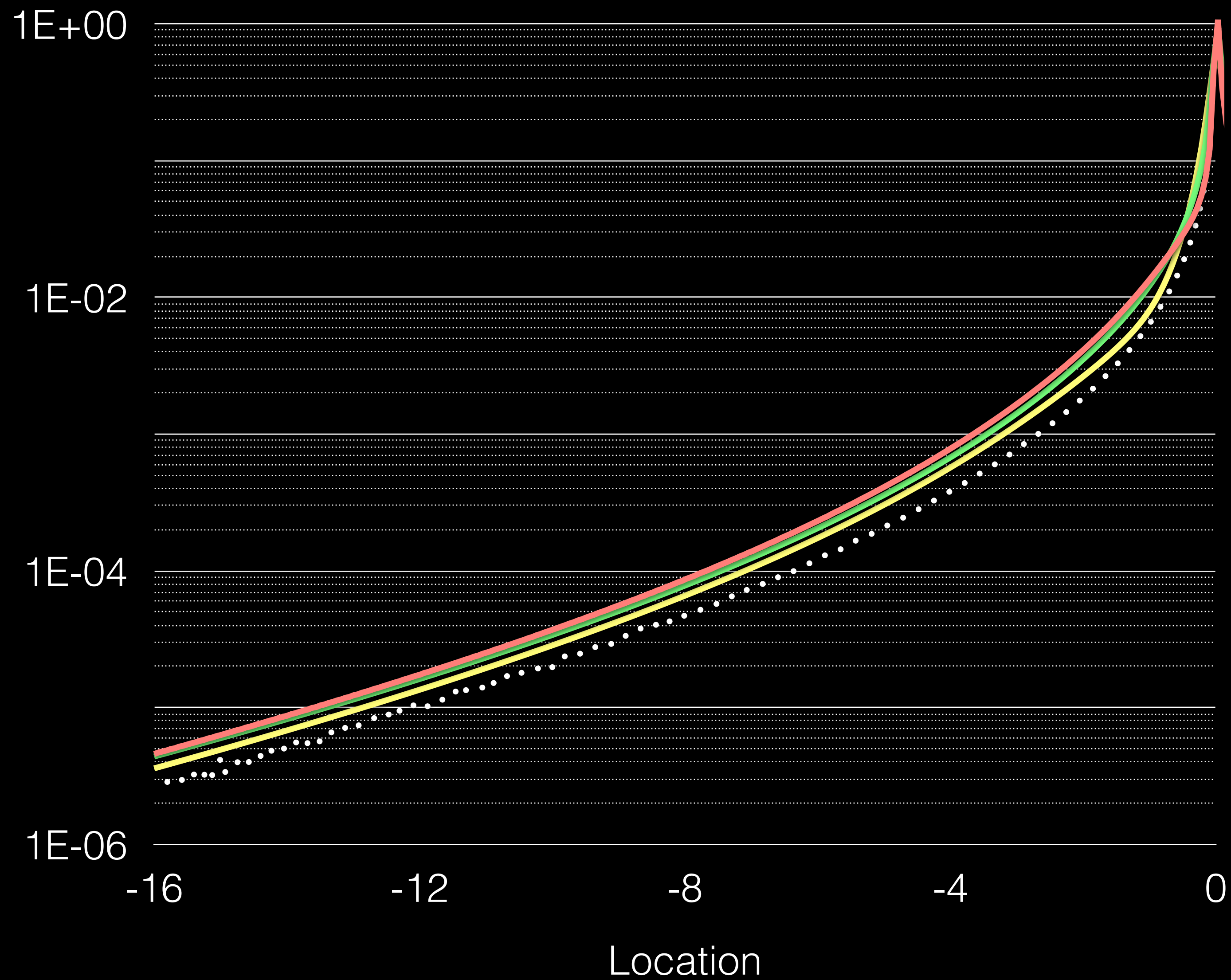
Simple Test Cases: Directional



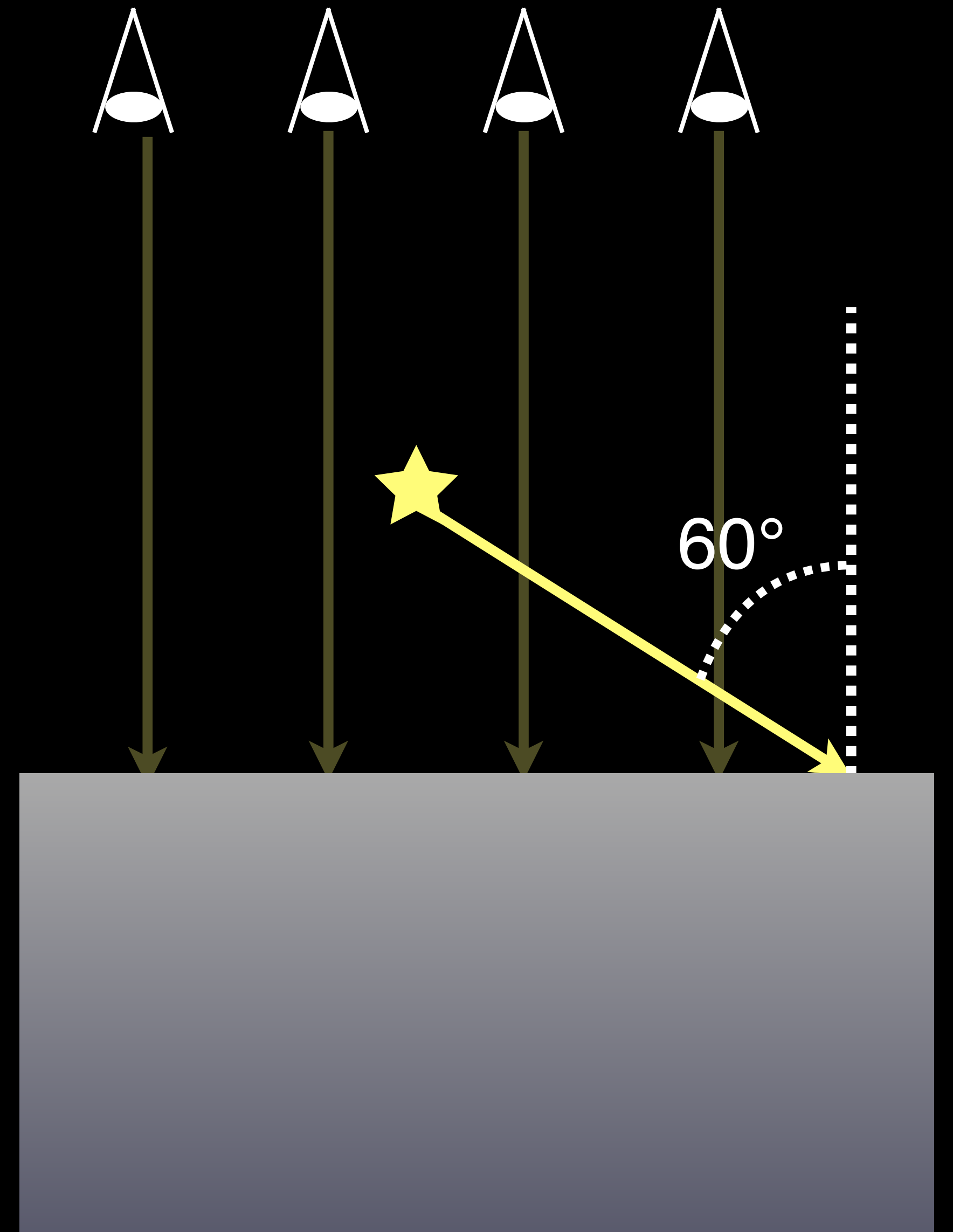
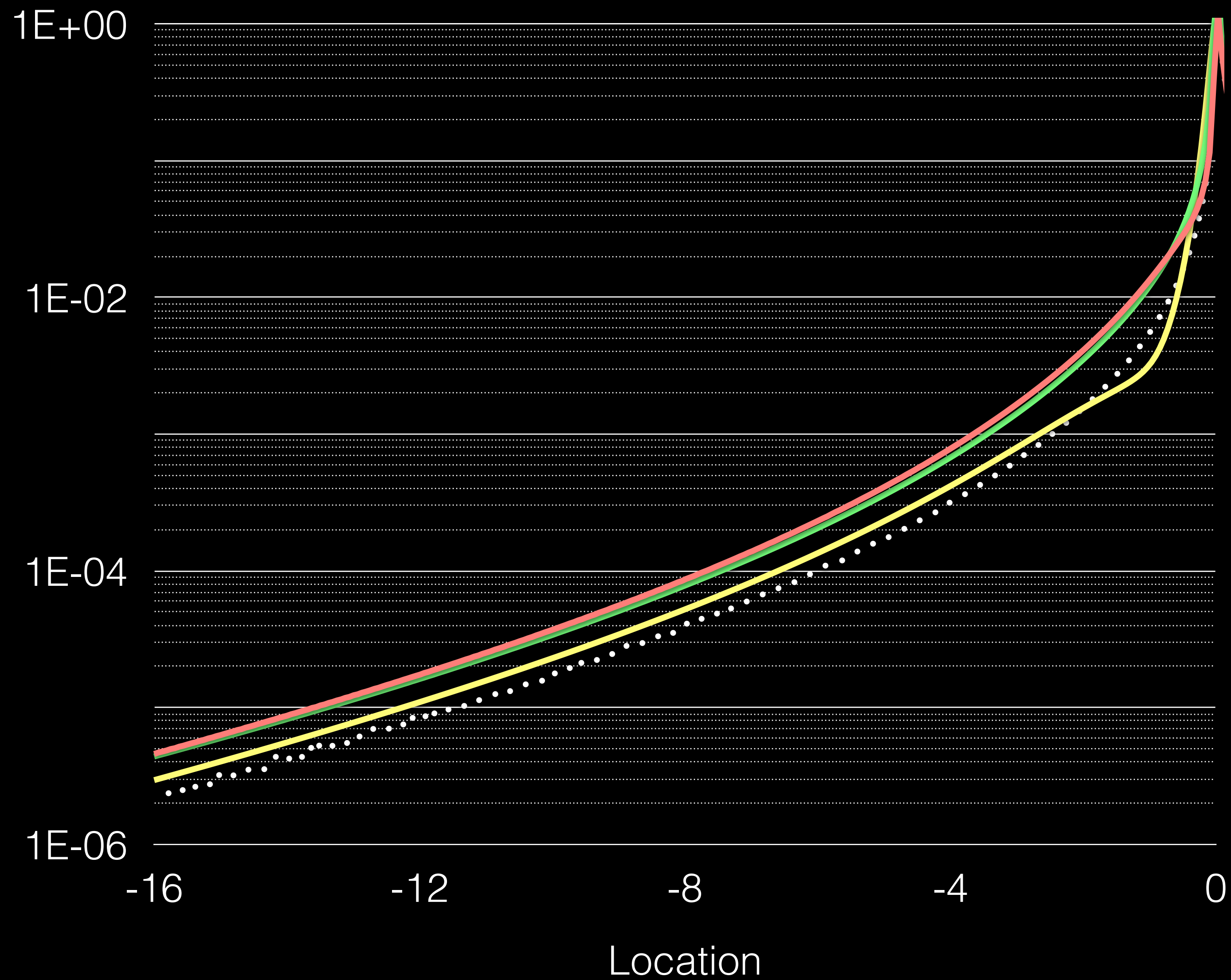
Directional Effect: 30°



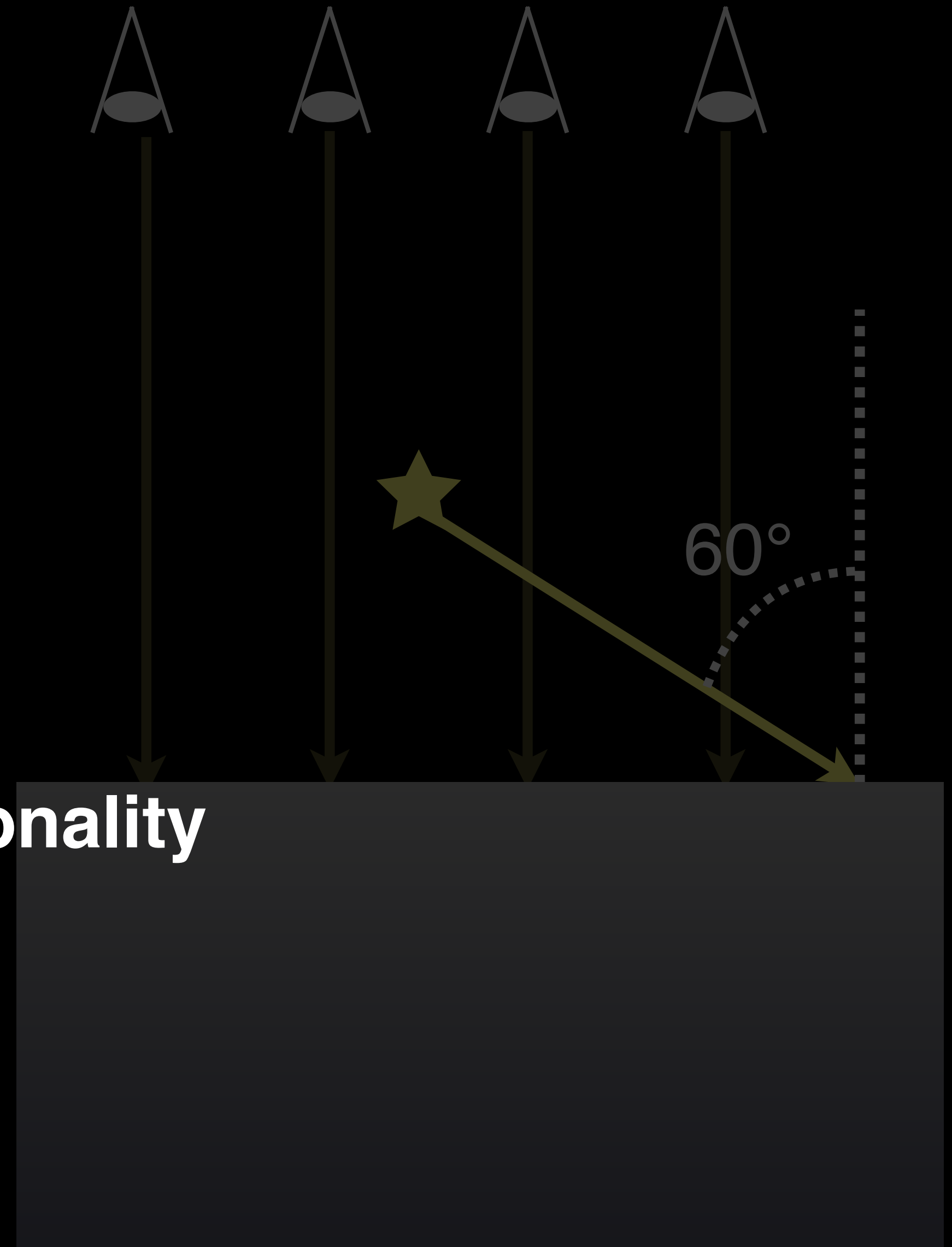
Directional Effect: 45°



Directional Effect: 60°

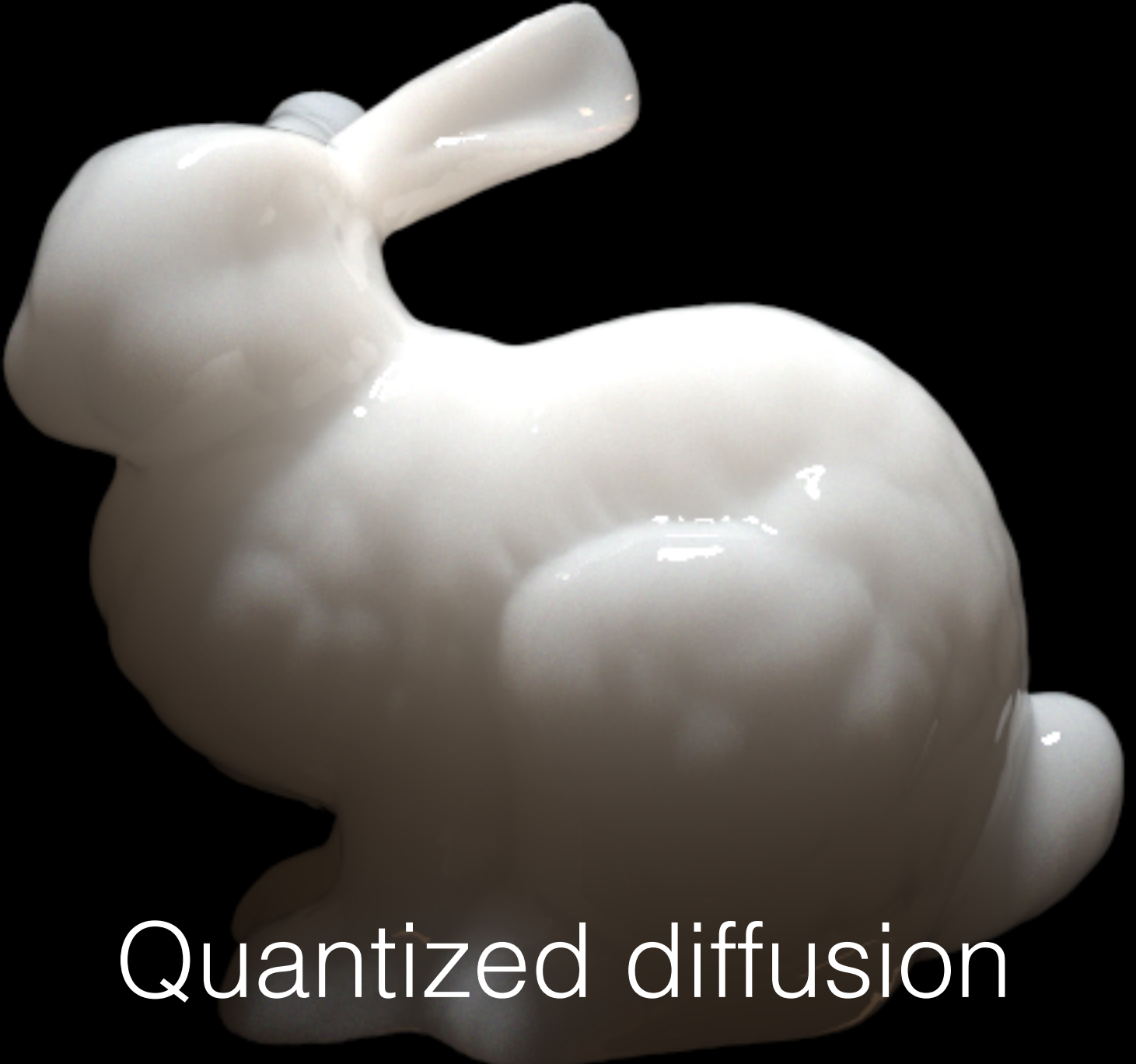


Directional Effect: 60°





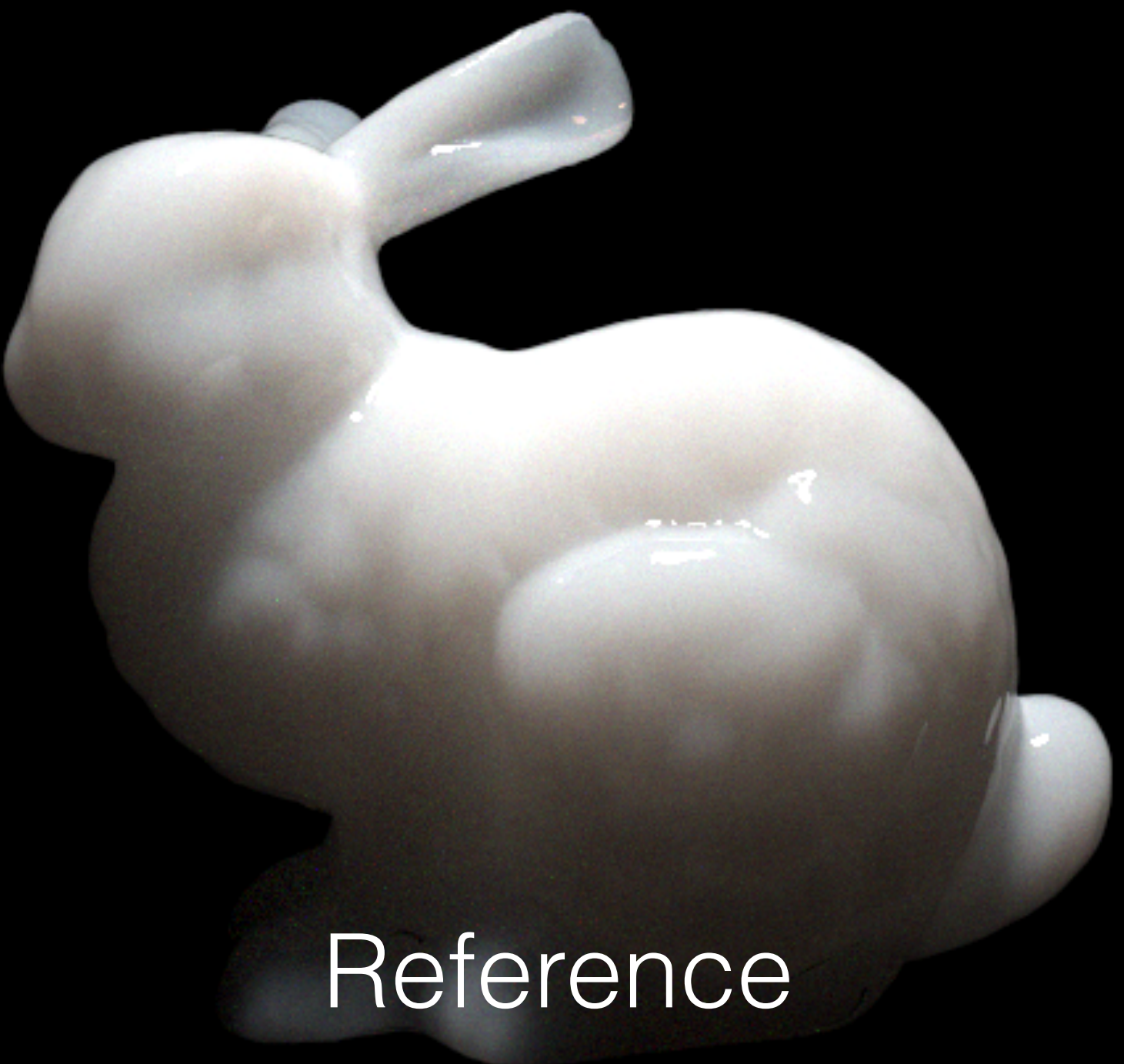
Dipole



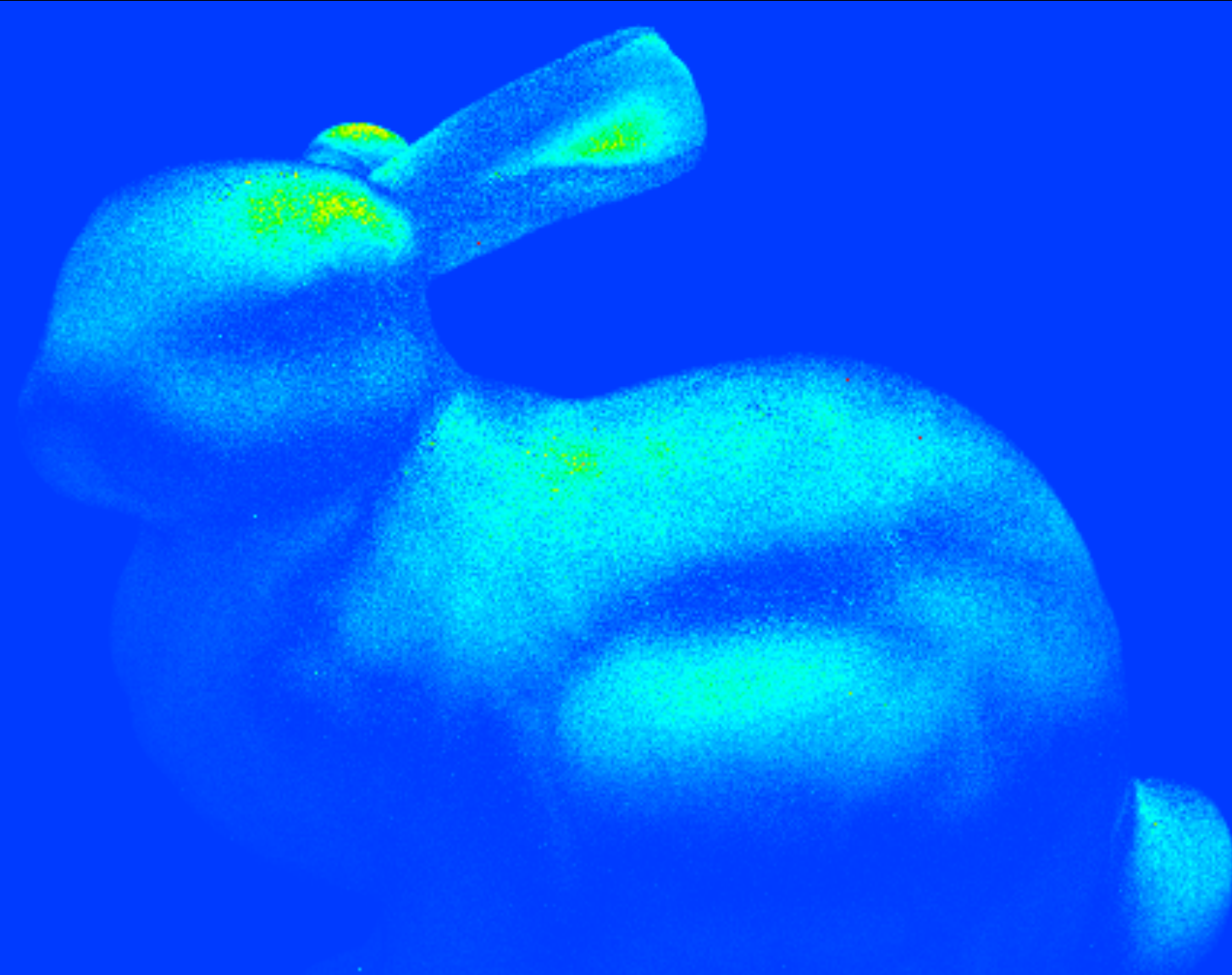
Quantized diffusion



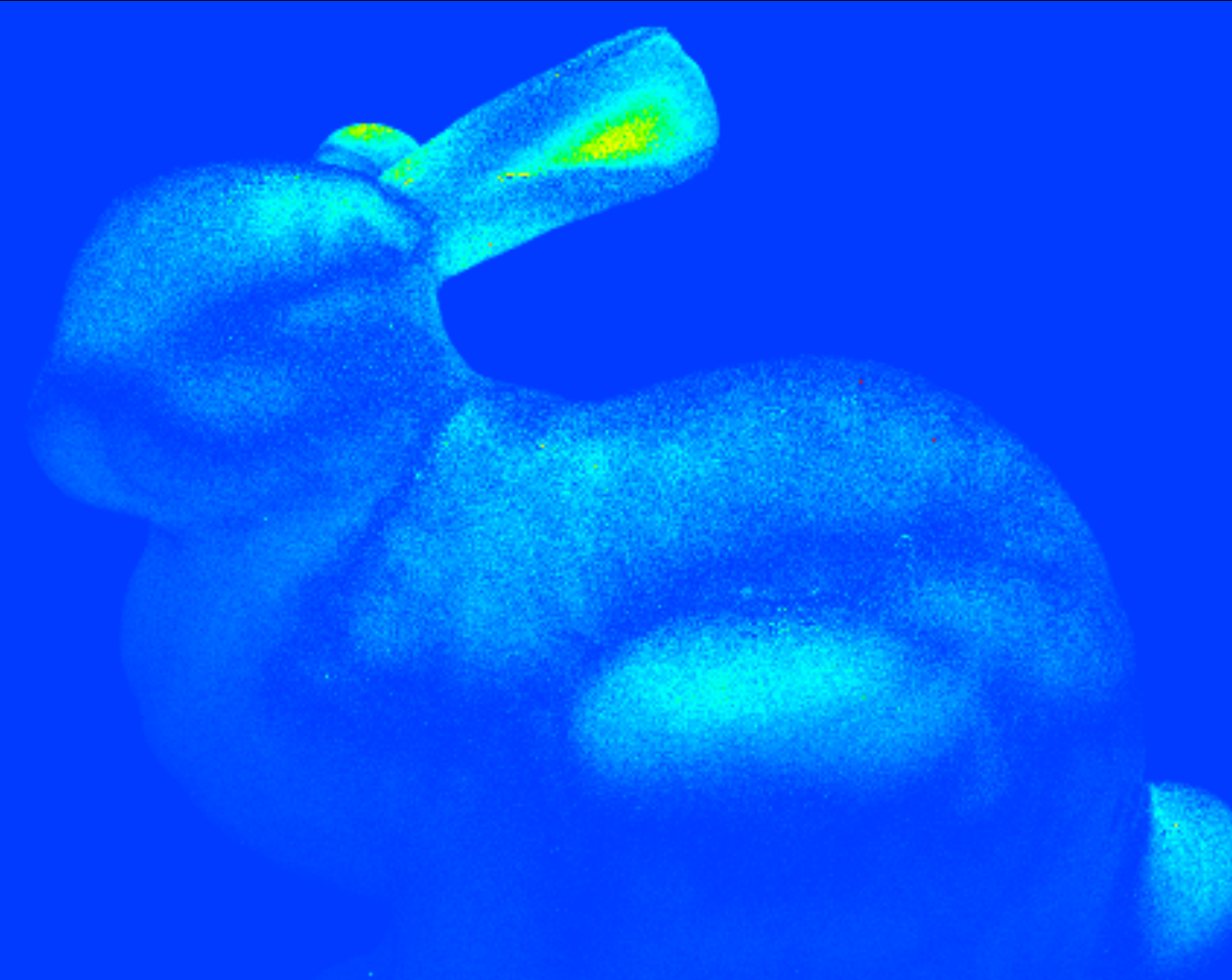
Our model



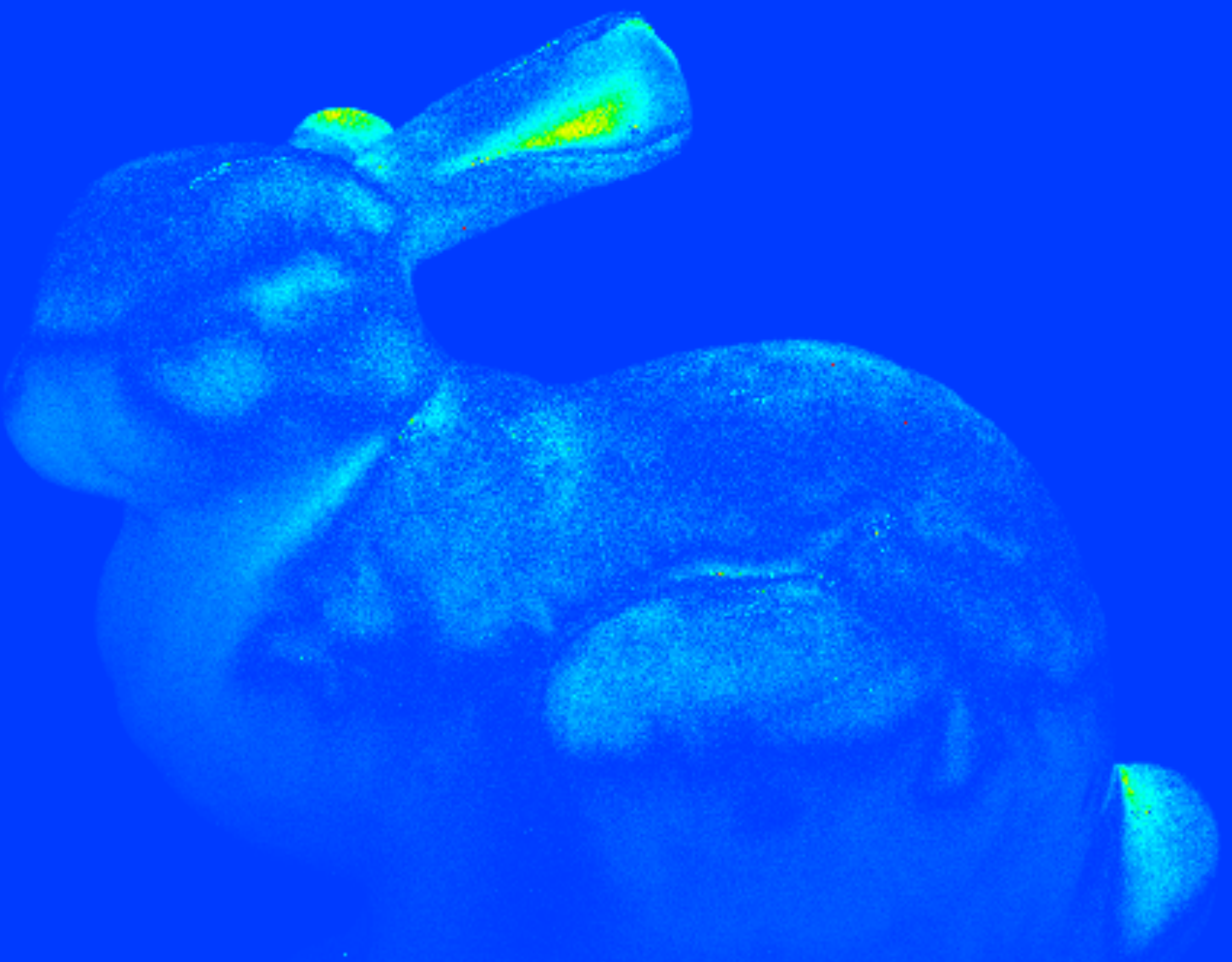
Reference



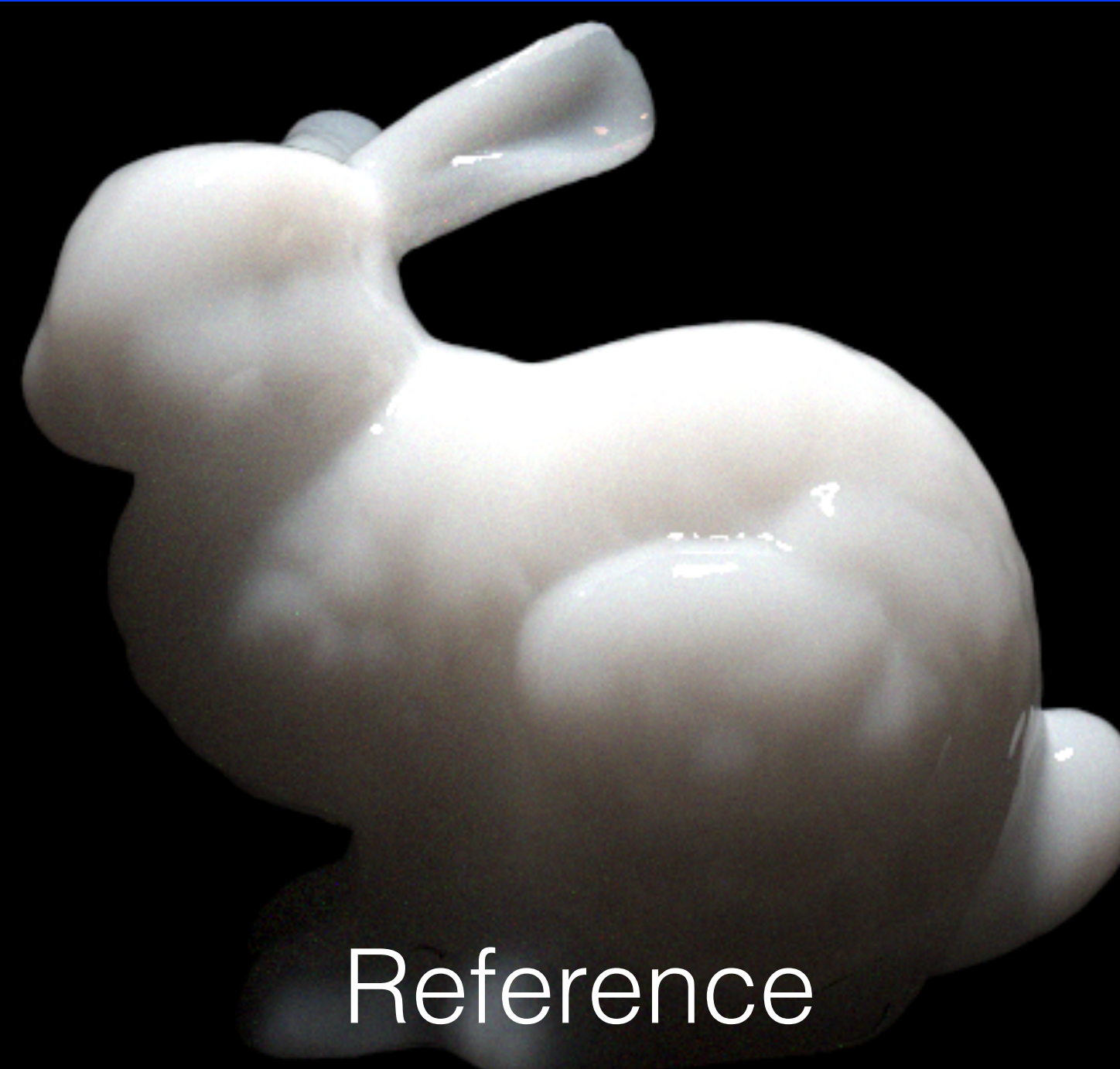
Dipole



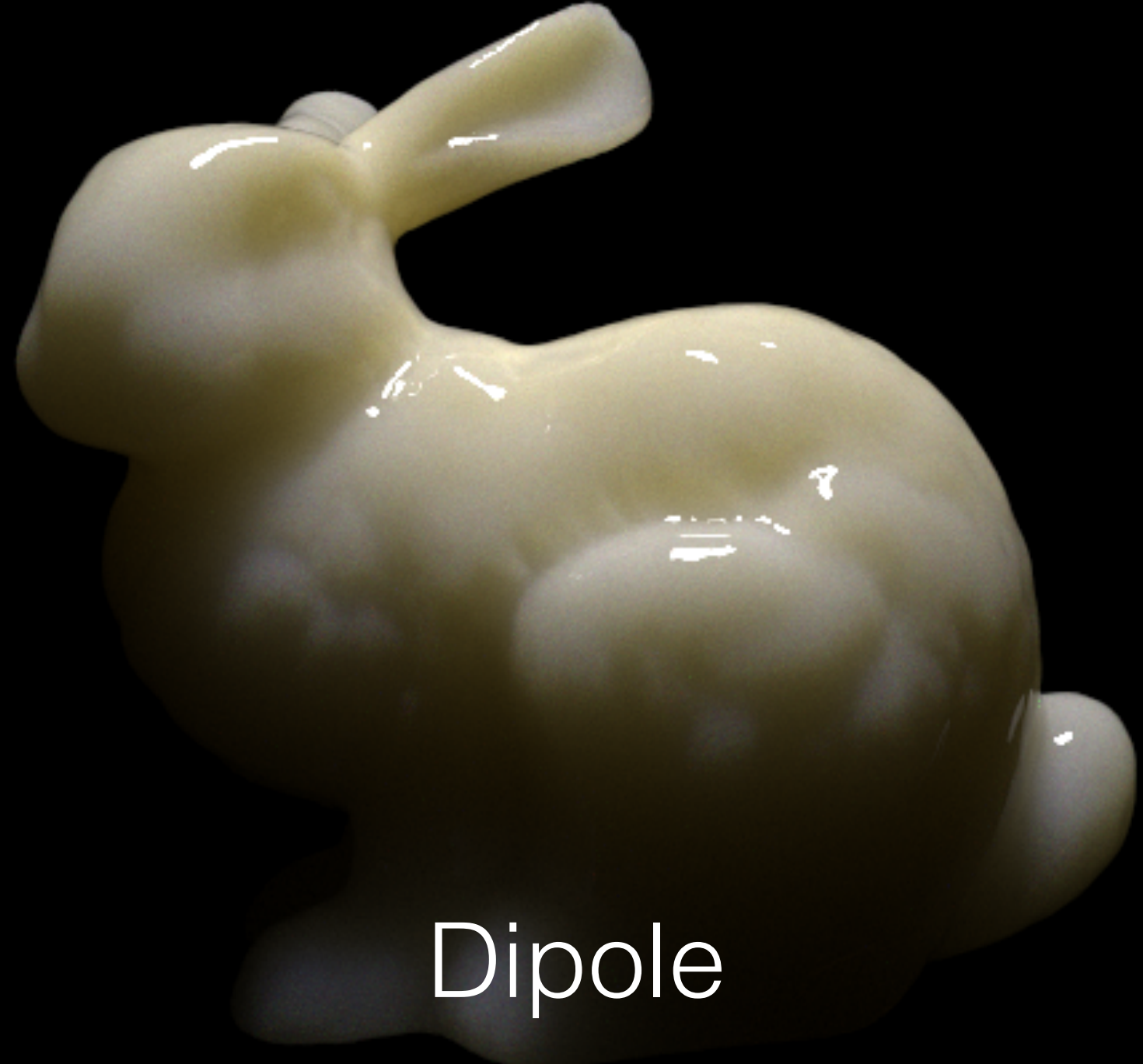
Quantized diffusion



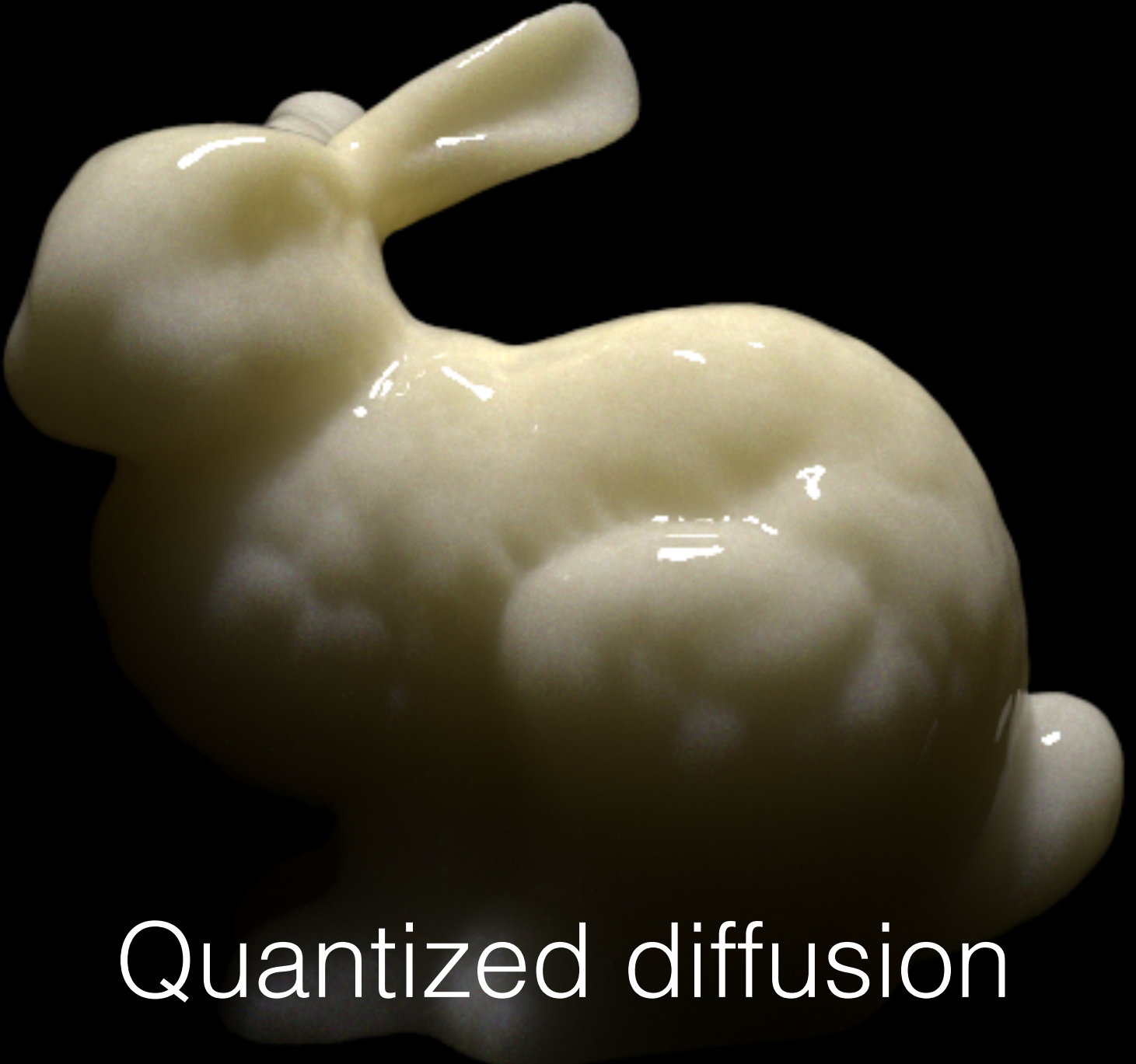
Our model



Reference



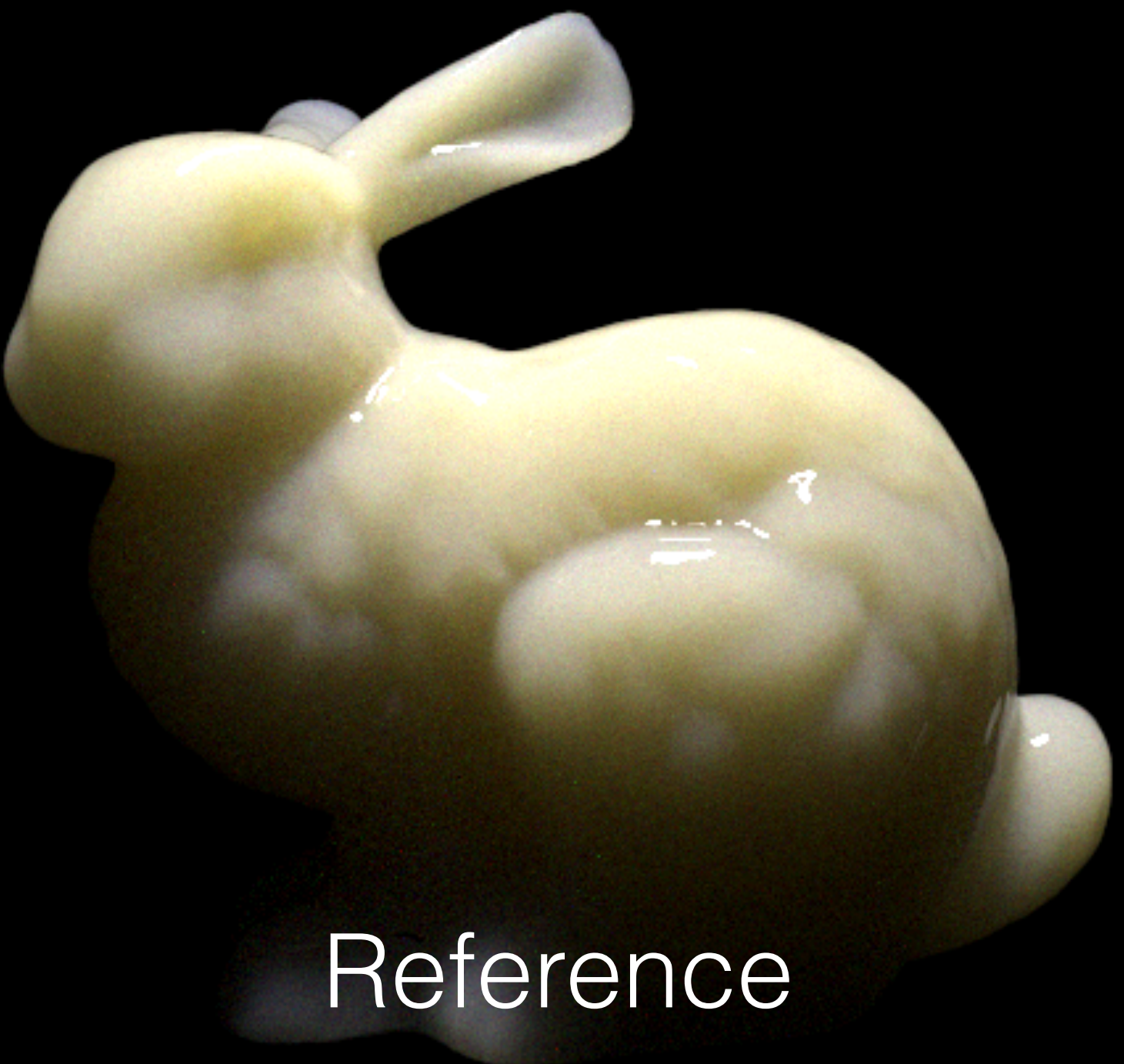
Dipole



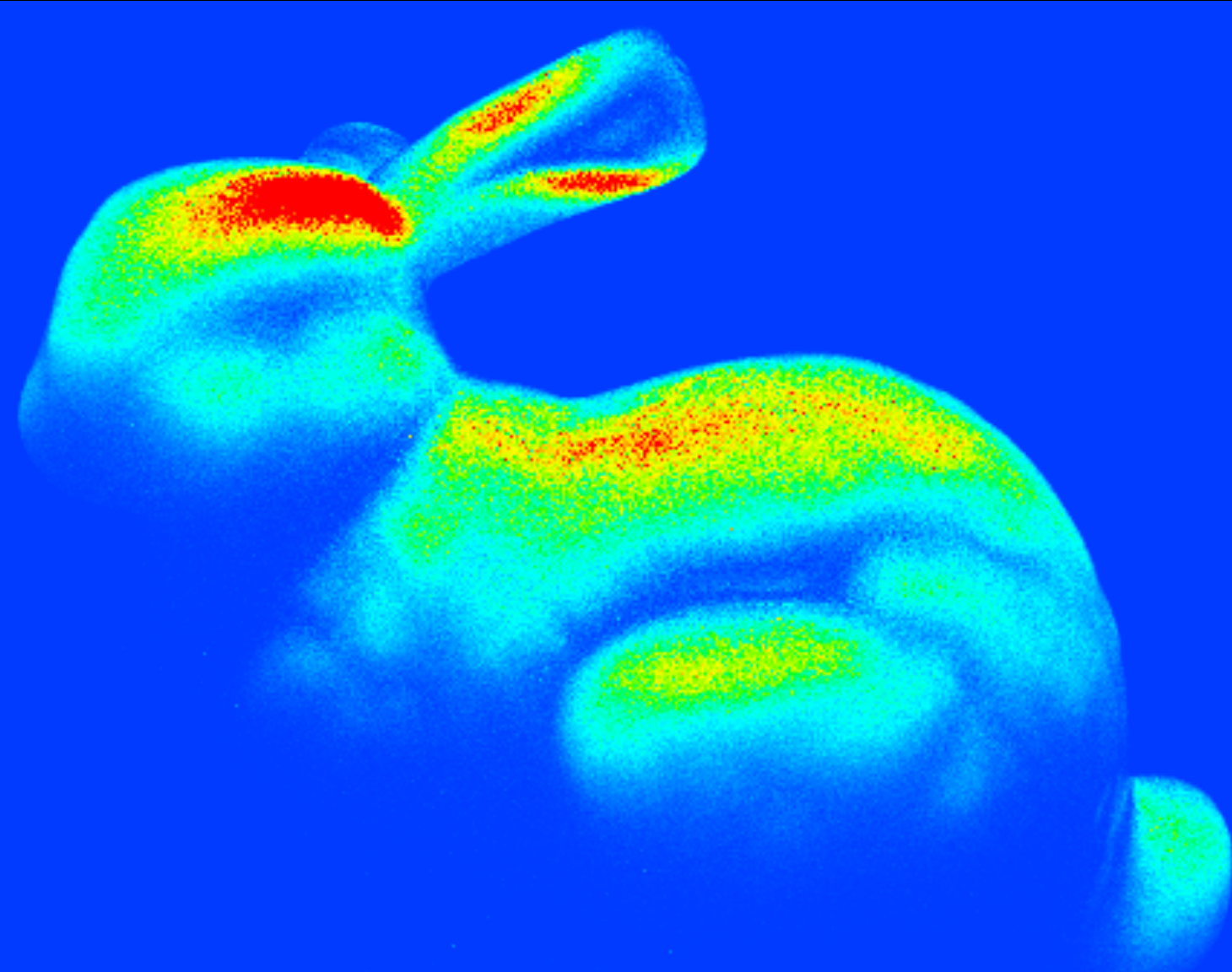
Quantized diffusion



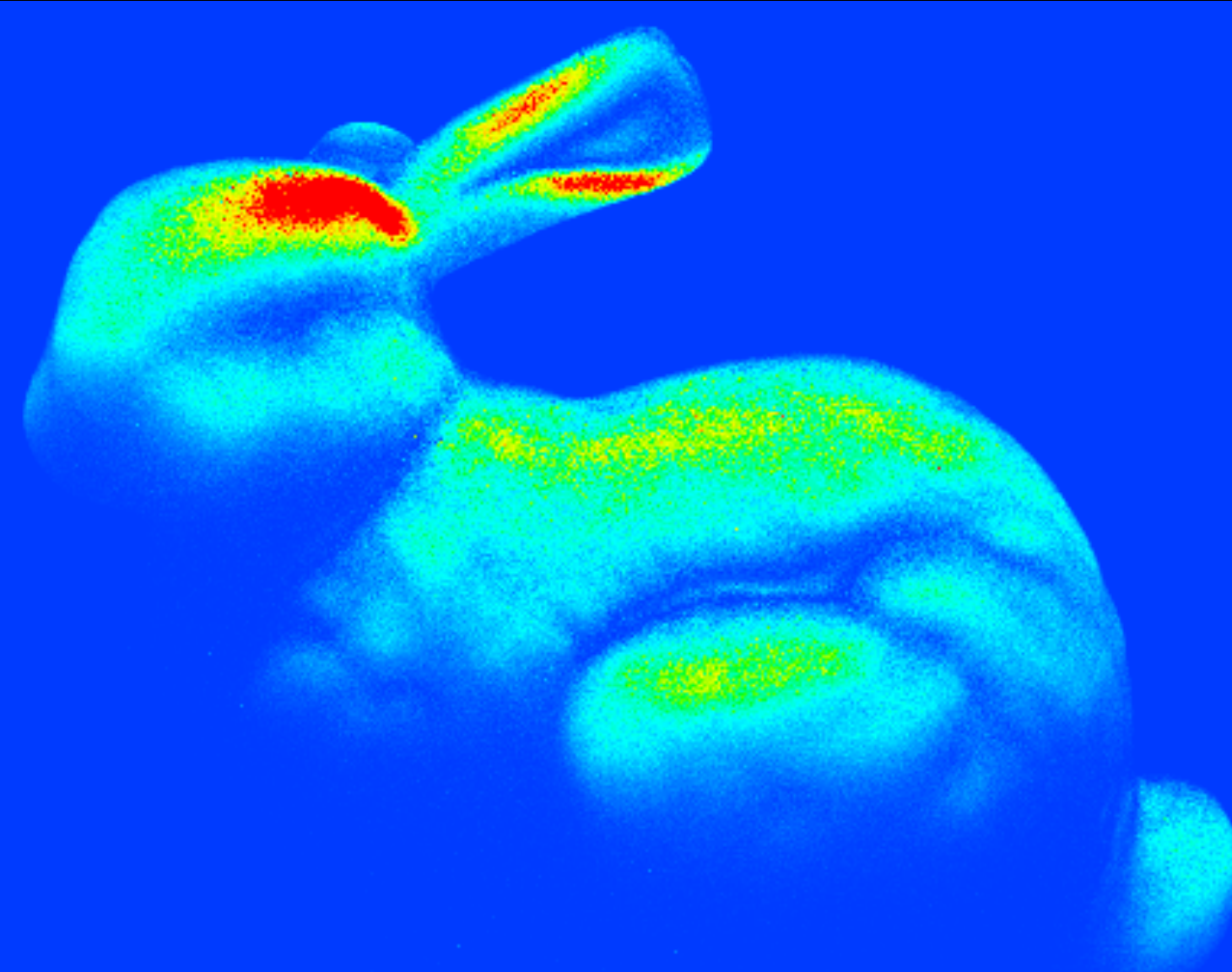
Our model



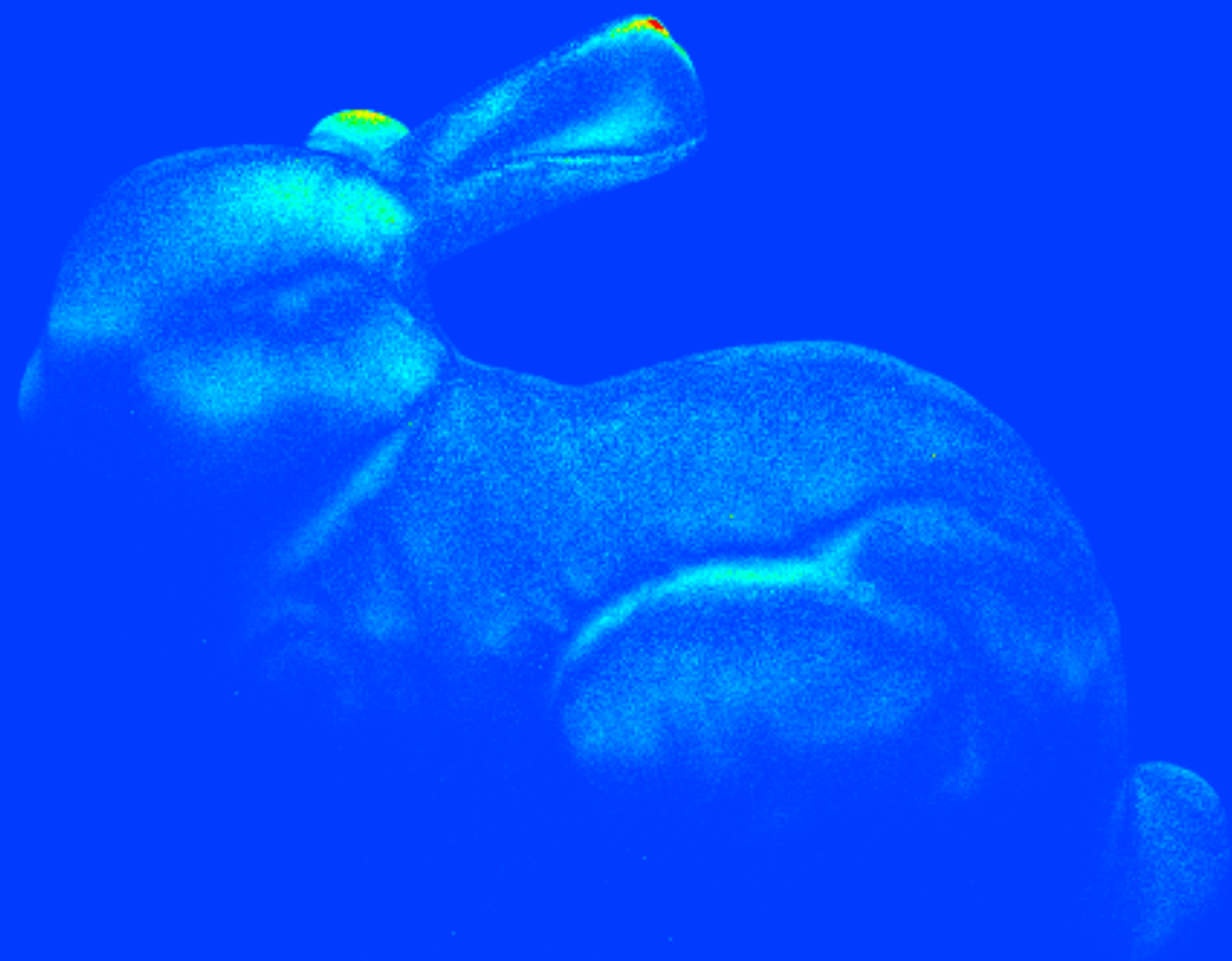
Reference



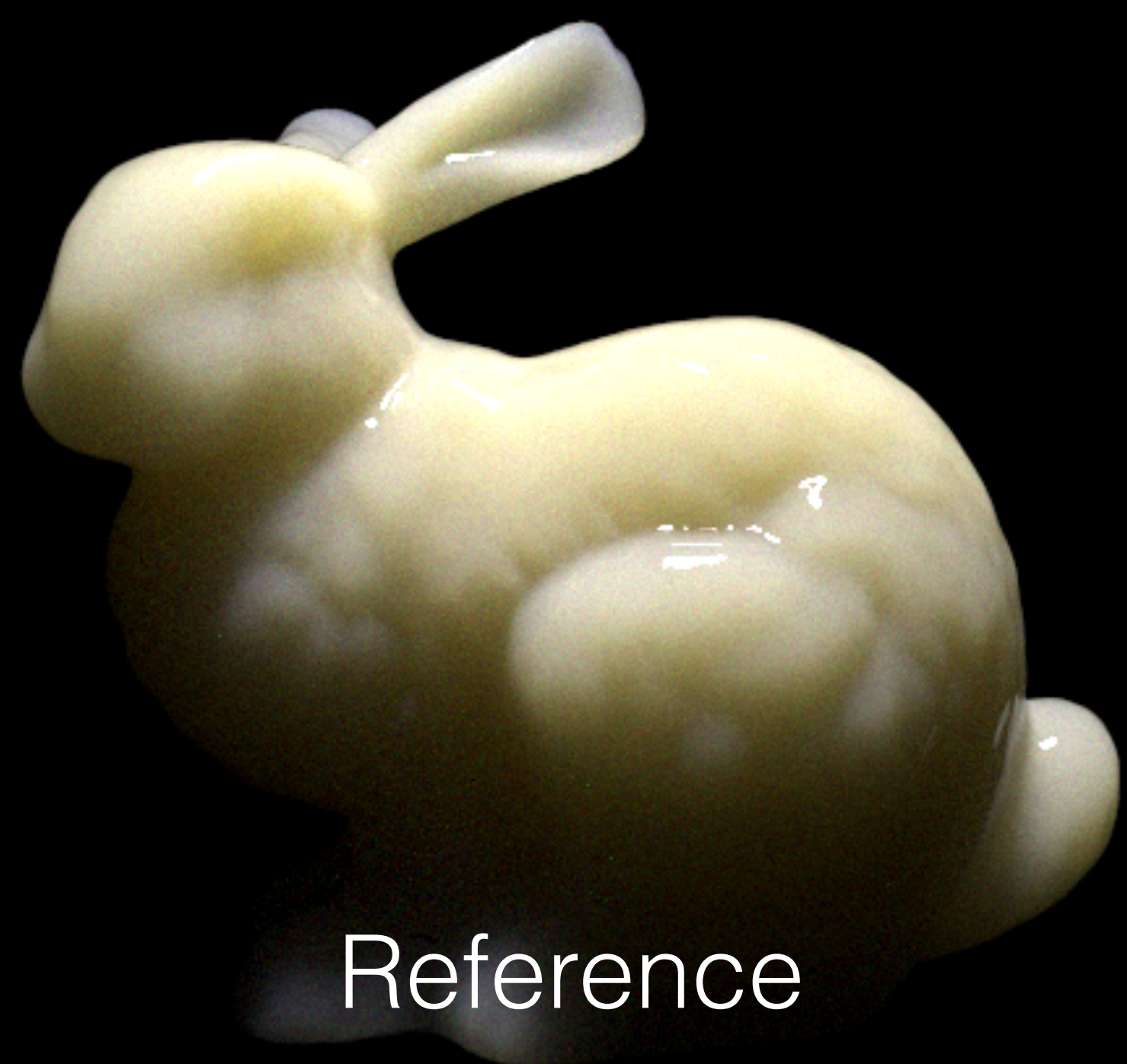
Dipole



Quantized diffusion



Our model



Reference

Our model - 18 min



Quantized diffusion + Single scattering - 13 min



Limitations

- Similar to other models, our model is an **approximation**
 - Many assumptions such as a semi-infinite medium are invalid
 - Cannot distinguish certain combinations of scattering and asymmetry
 - Not reciprocal (please refer to the paper for a heuristic solution)

Future Work

- **All kinds** of extensions available for the original dipole are possible!
 - Real-time rendering via filtering
 - Multipole extension
 - Anisotropic media
 - ...

Take-home Message

- Directional dipole is the **first** BSSRDF which
 - Considers incoming light direction
 - Requires no precomputation
 - Provides fully analytical equation

Example code is available at <http://www.ci.i.u-tokyo.ac.jp/~hachisuka/dirpole.cpp>