# Diffraction Shaders

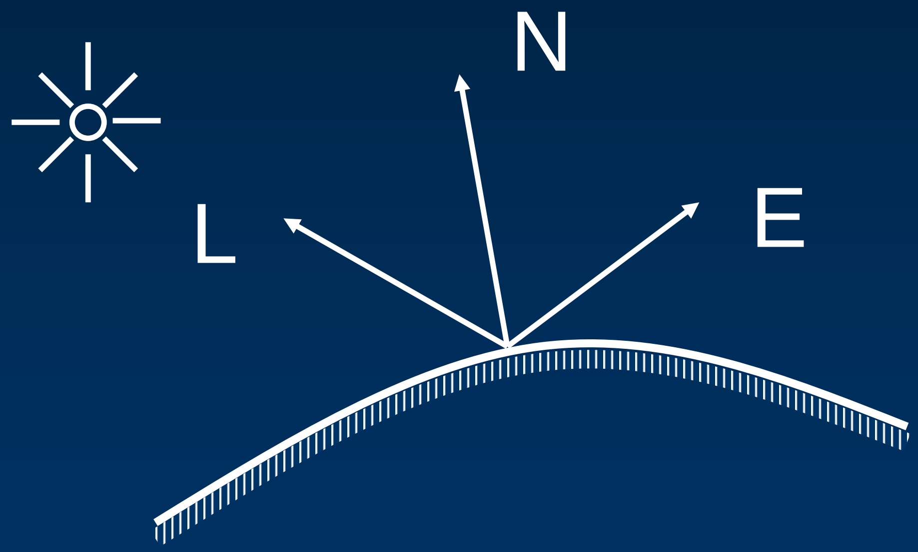
Jos Stam

Alias | wavefront

Seattle, WA USA

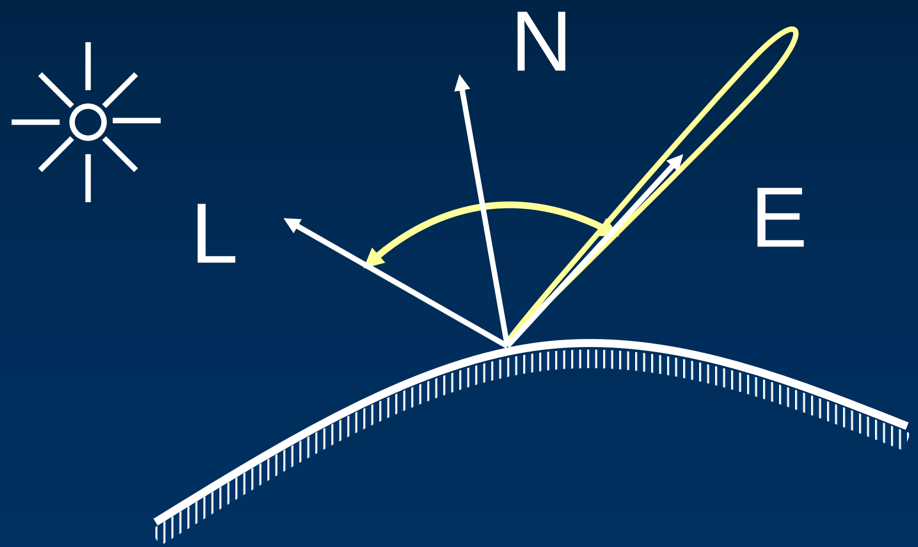
# Shaders

Model reflection from surfaces



# Shaders

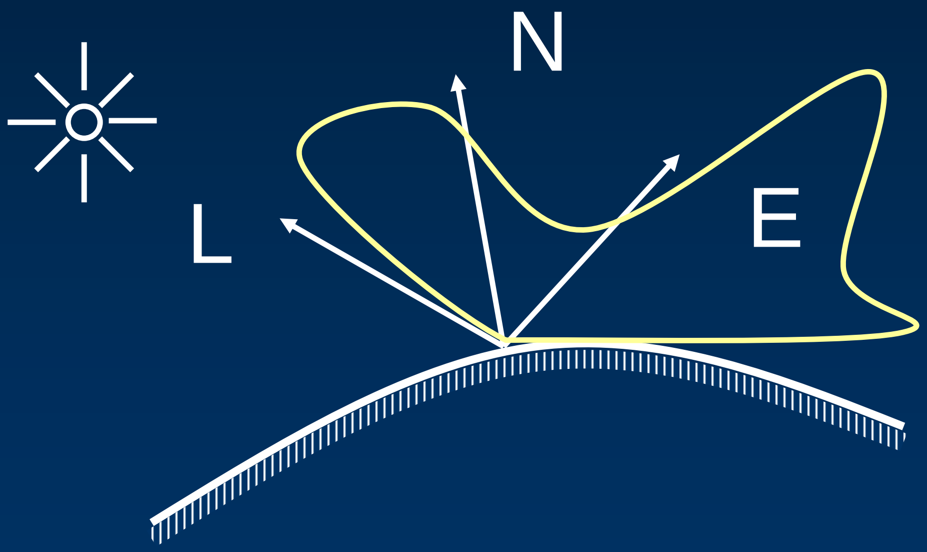
Perfectly smooth surface




Not very interesting

# Shaders

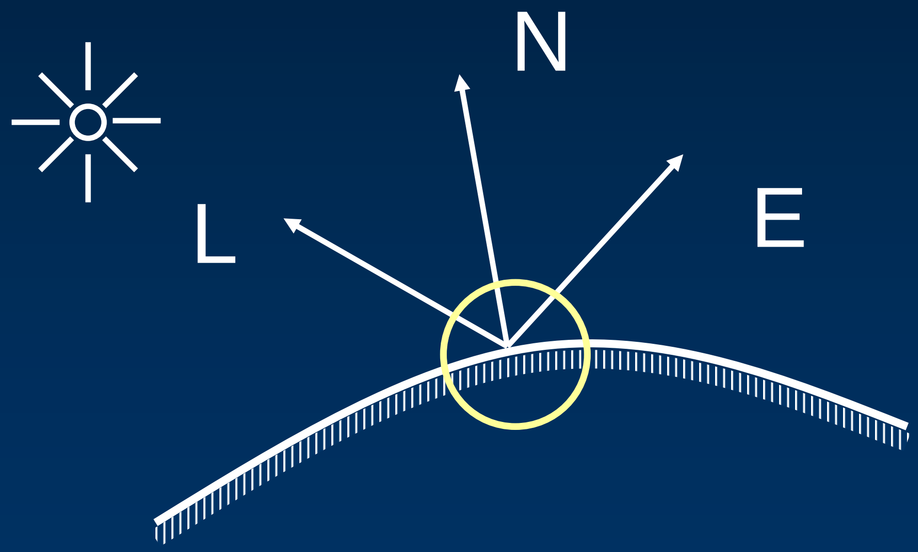
Rough surfaces




More interesting

# Shaders

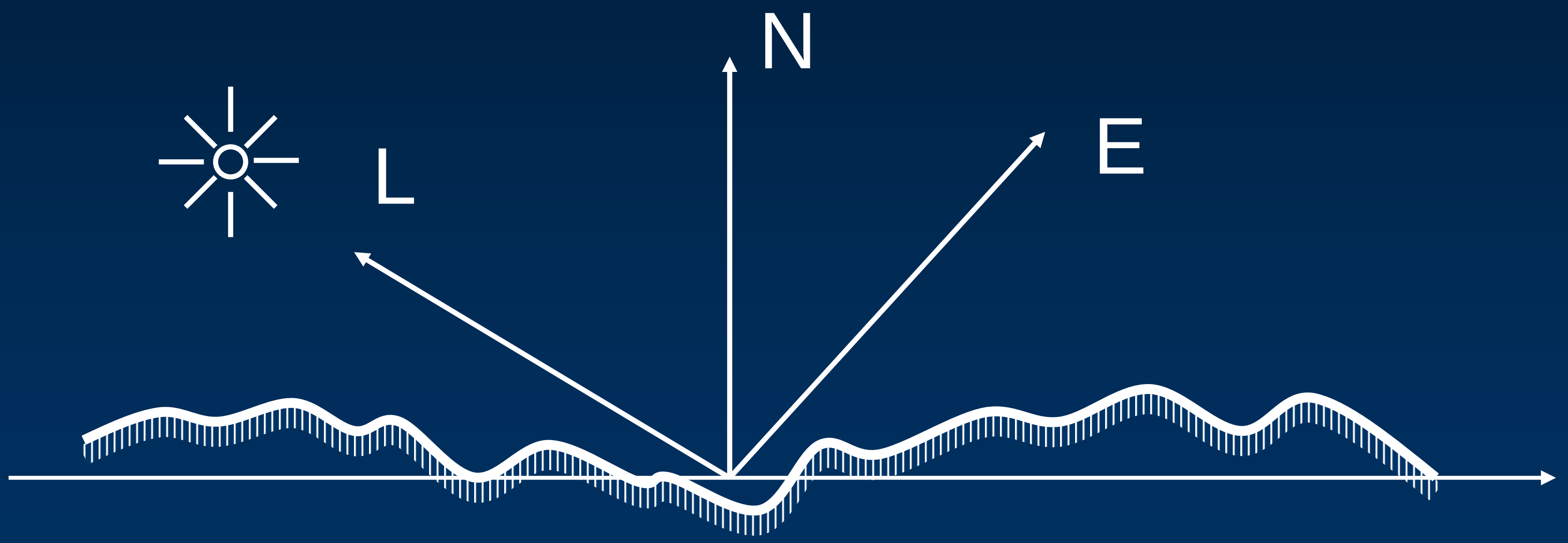
Rough surfaces




Zoom in on microstructure

# Shaders

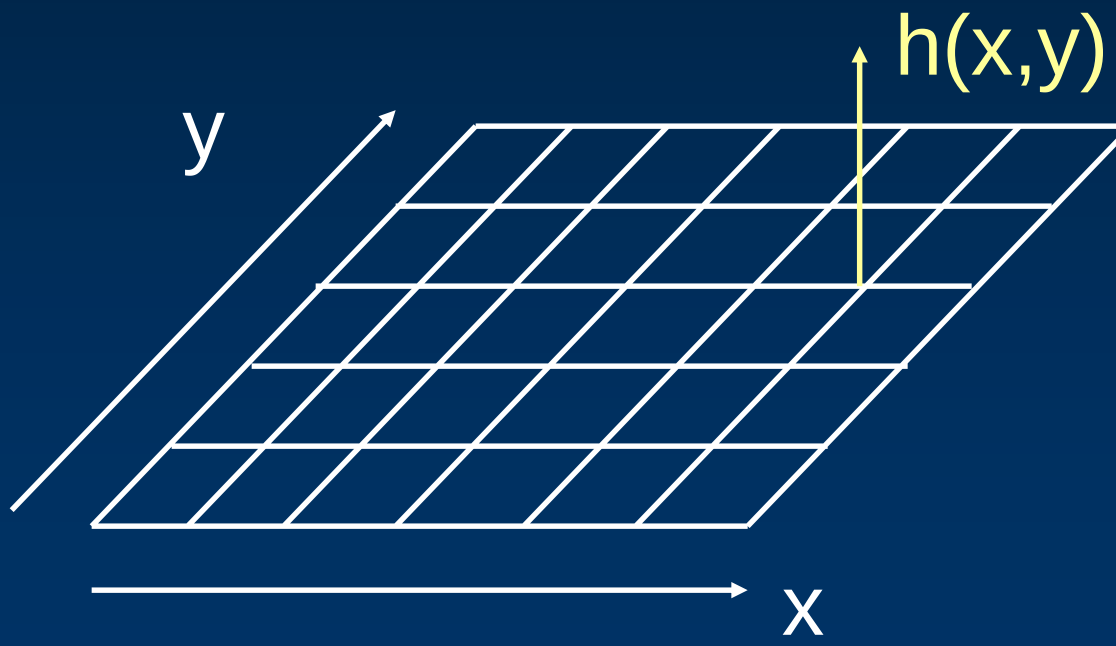
Rough surfaces




Reflection depends on the microsurface

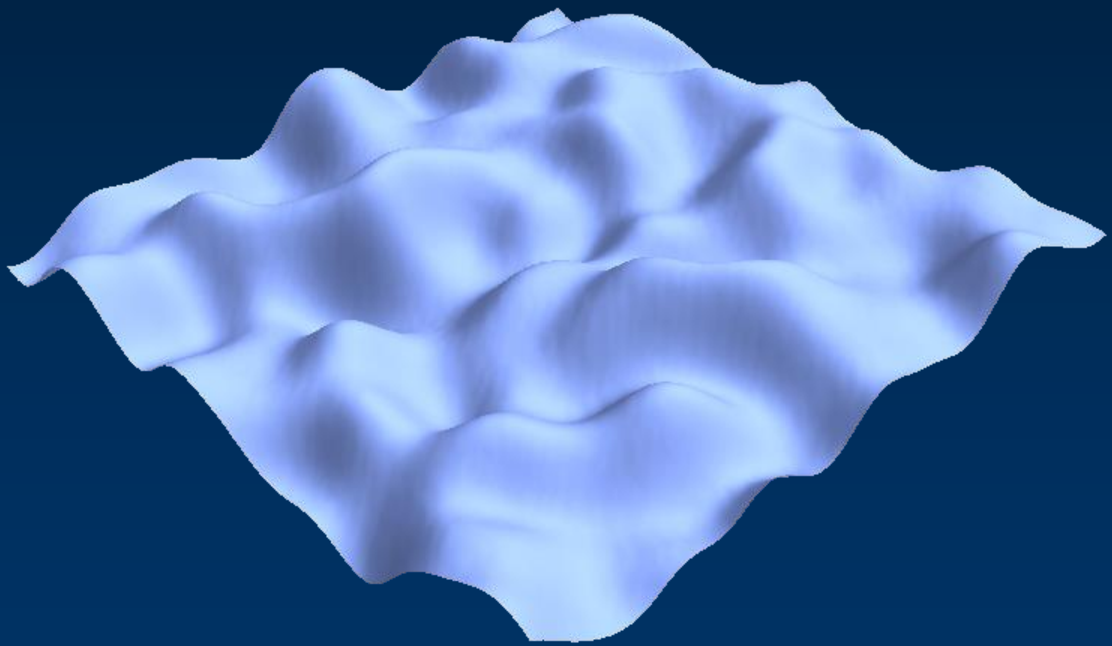
# Microsurface Models

Model surface as a two-dimensional (random) height field



# Microsurface Models

Isotropic Gaussian (smooth)



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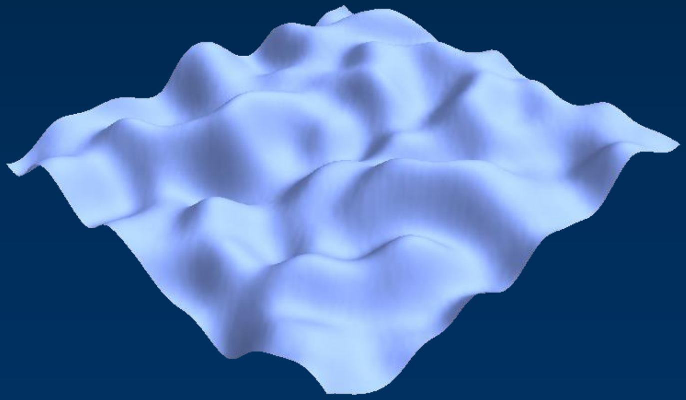
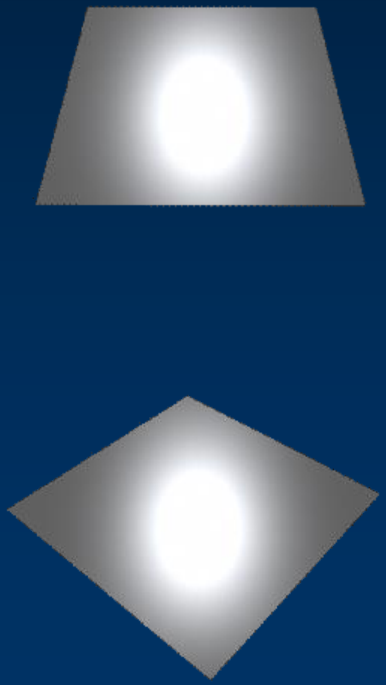
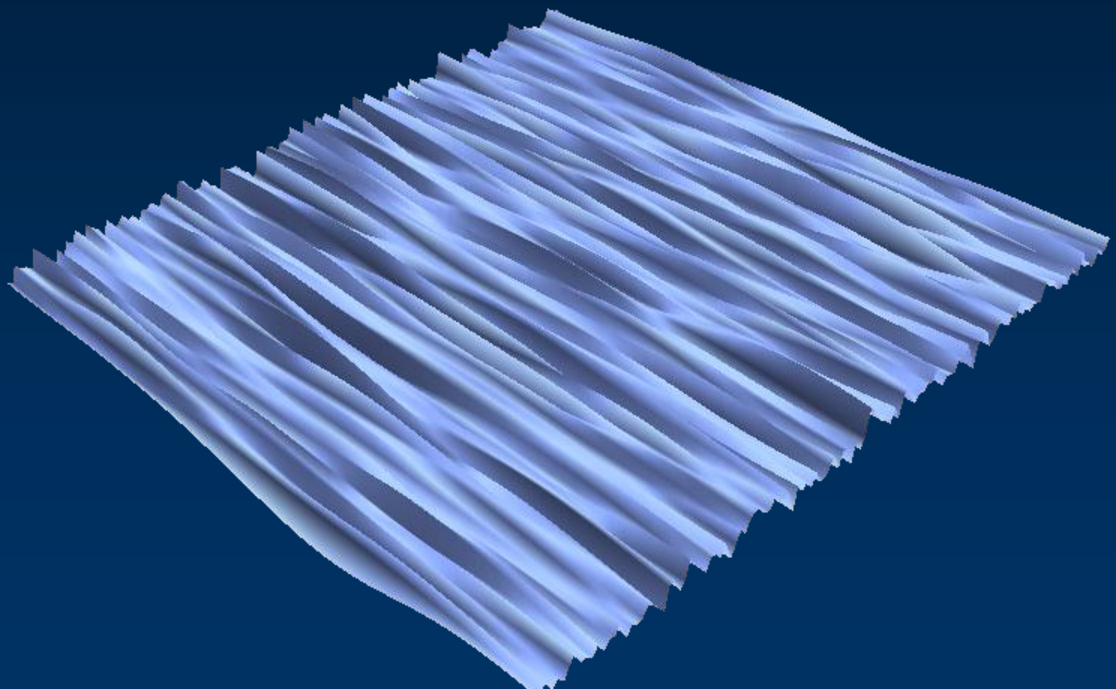




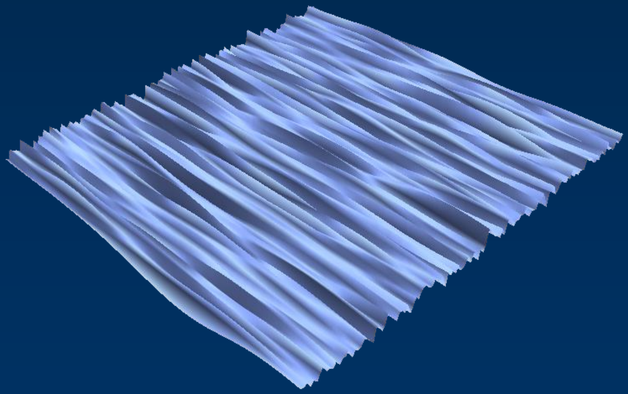
# Microsurface Models

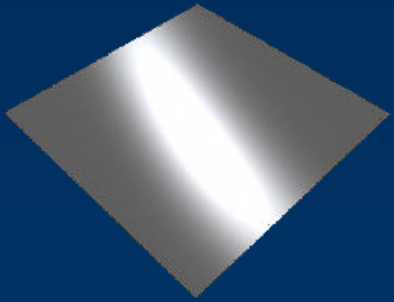
Anisotropic Gaussian (brushed metal)



# Microsurface Models

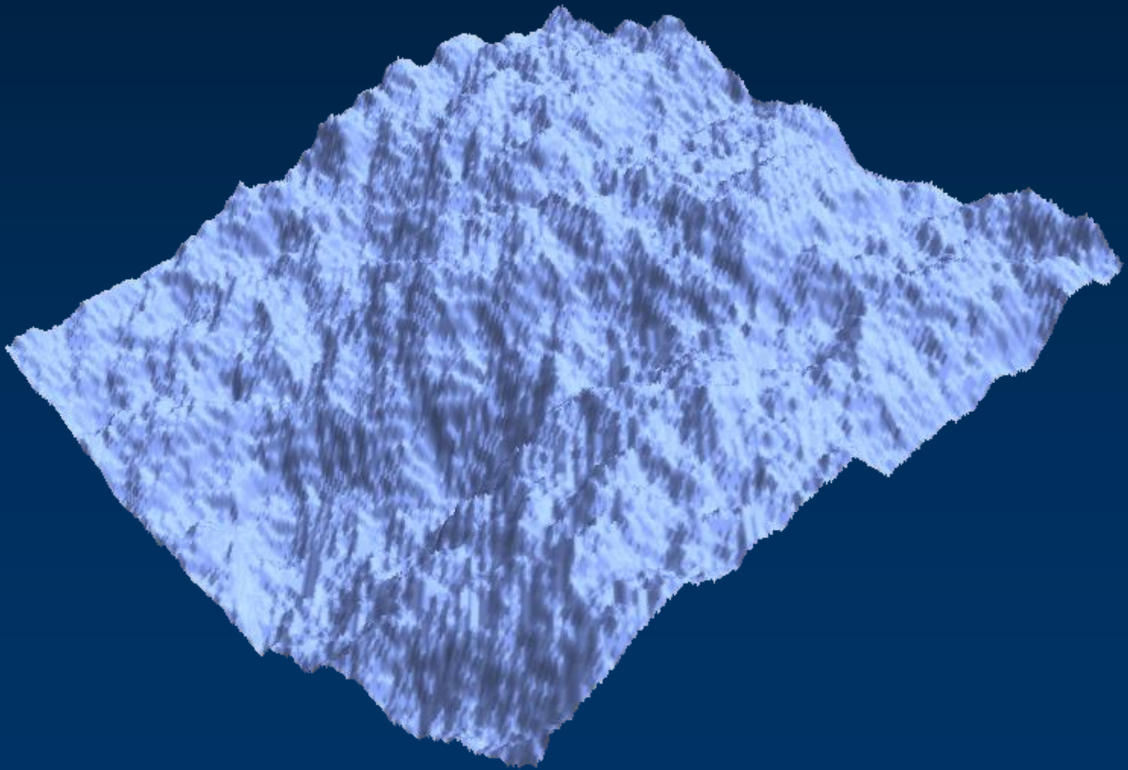
Anisotropic Gaussian (brushed metal)





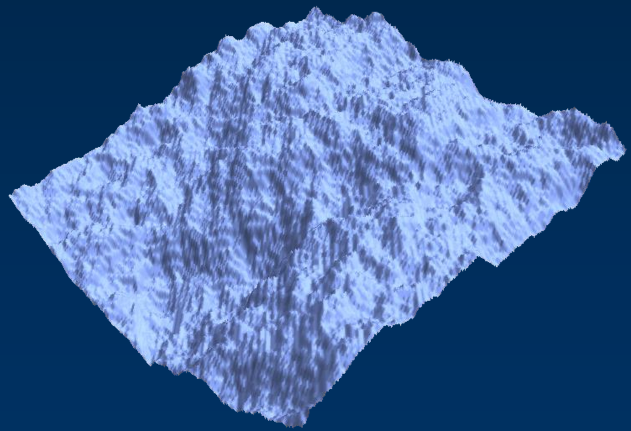
# Microsurface Models

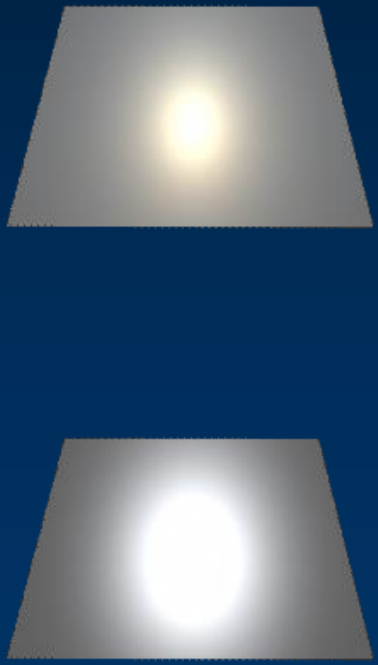
Fractal



# Microsurface Models

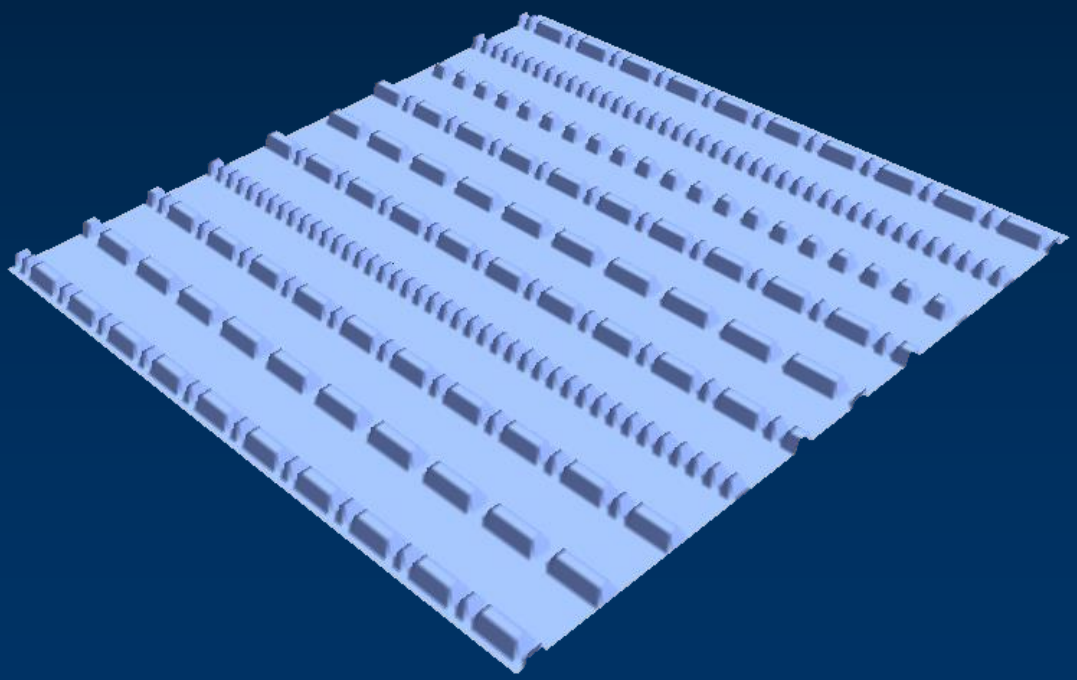
Fractal





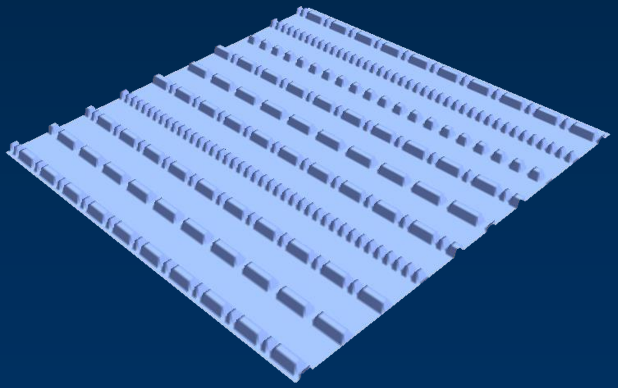
# Microsurface Models

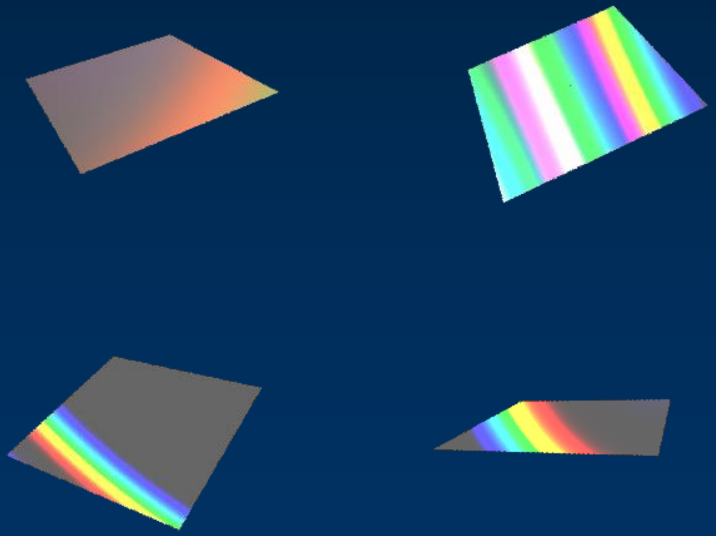
Periodic (compact disk)



# Microsurface Models

Periodic (compact disk)





# Previous Work

| | Ray theory | Wave Theory |
|---|---|---|
| Isotropic (smooth) | Torrance-Sparrow 67<br>Blinn 77<br>Cook-Torrance 81 | Beckmann 63<br>He-Torrance 91<br>Nayar 91<br>Bahar-Chakrabarti 87 |
| Anisotropic | Tomiyasu 88<br>Poulin-Fournier 90<br>Ward 92 | |
| Fractal | N/A | |
| Periodic | N/A | |

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| Anisotropic | Tomiyasu 88<br>Poulin-Fournier 90<br>Ward 92 | ✓ |
| Fractal | N/A | ✓ |
| Periodic | N/A | ✓ |

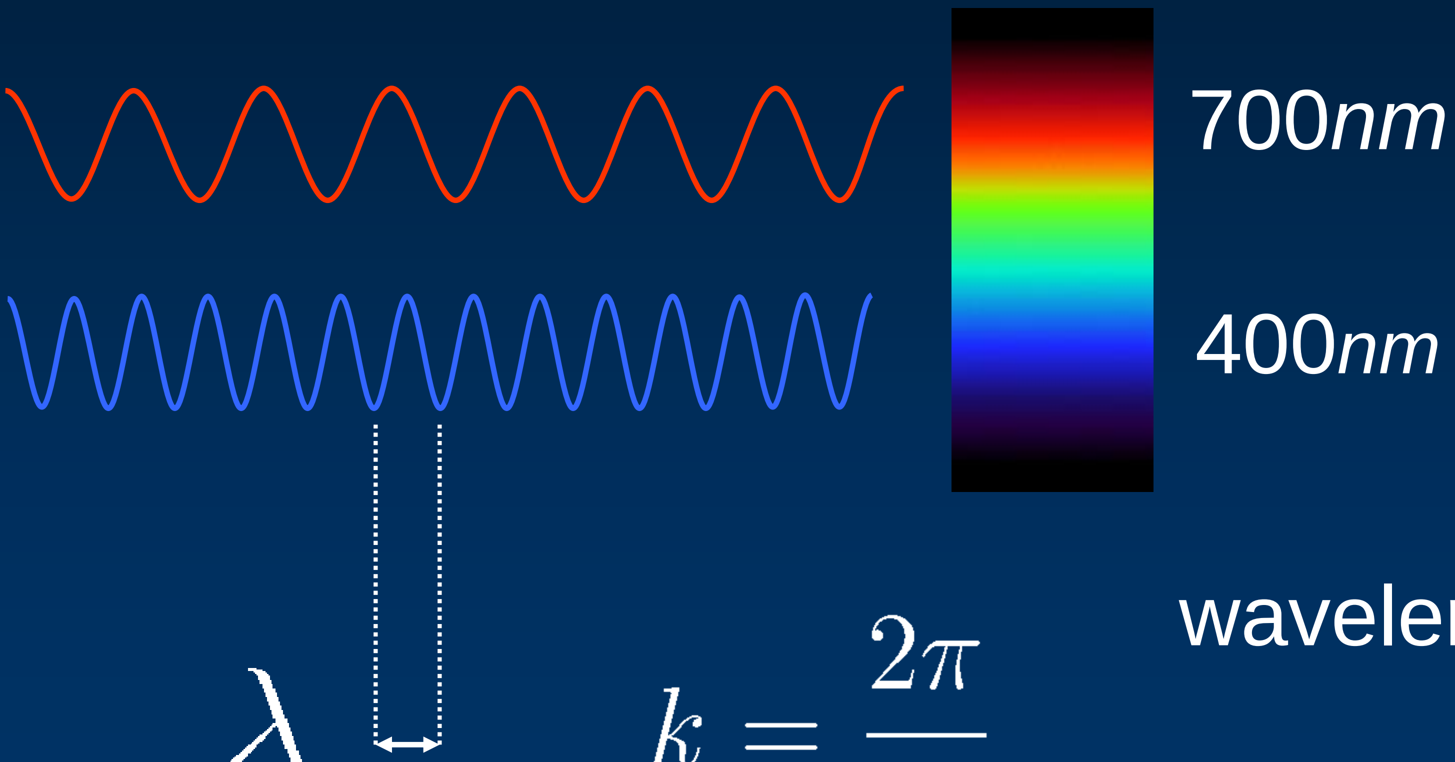
# Our Approach

Use waves to model both

- the propagation of light
- the microsurface (Fourier Analysis)

Generalization of previous models

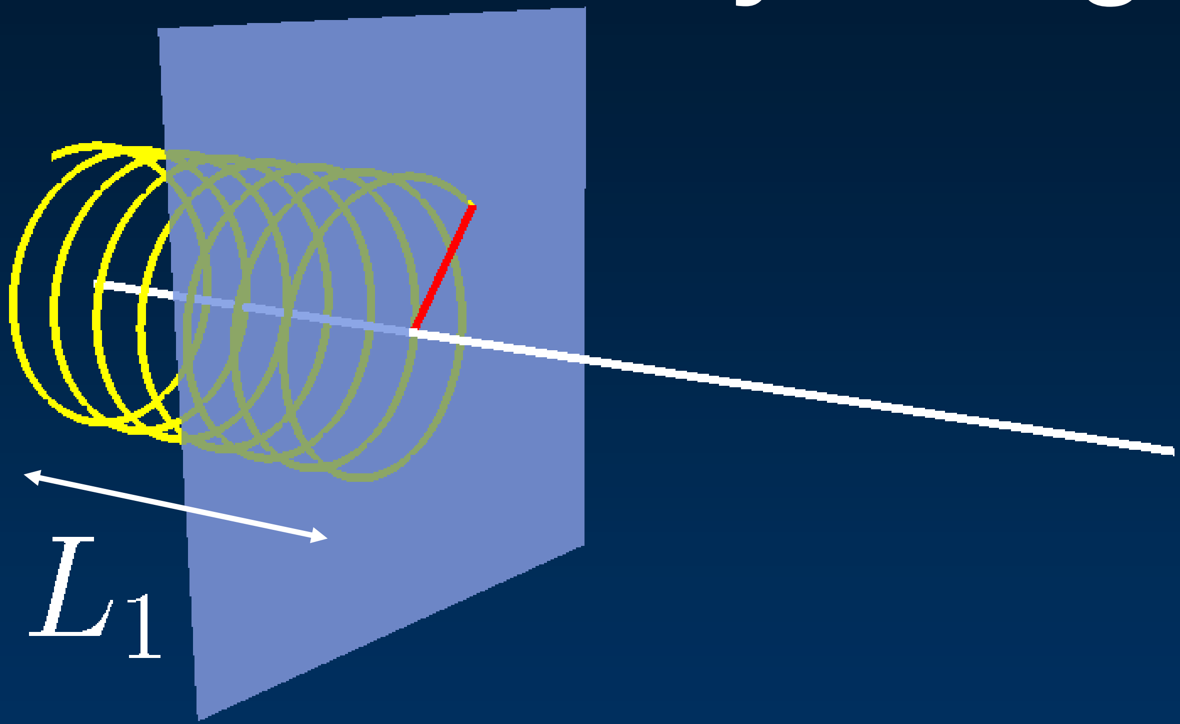
# Wave Theory of Light




wavelength

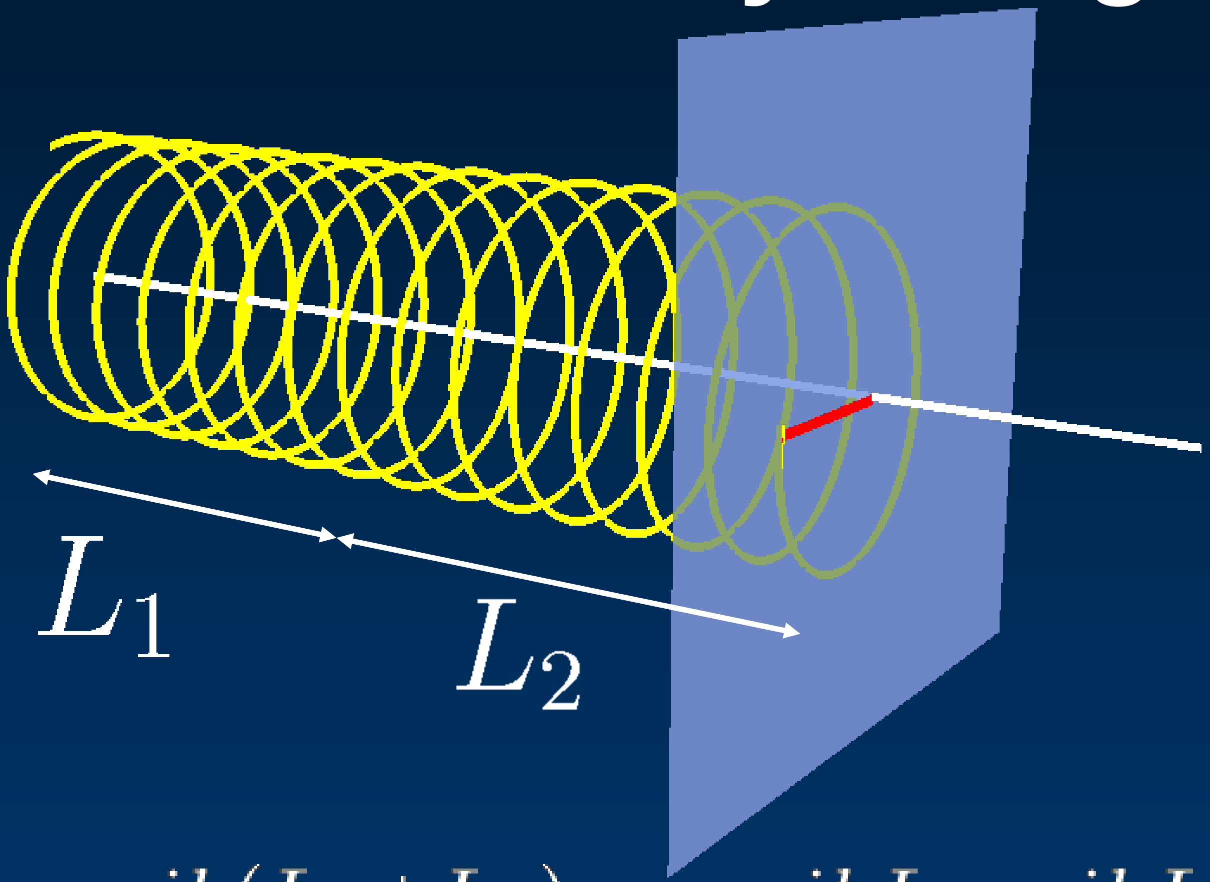
$$k = \frac{2\pi}{\lambda}$$

# Wave Theory of Light



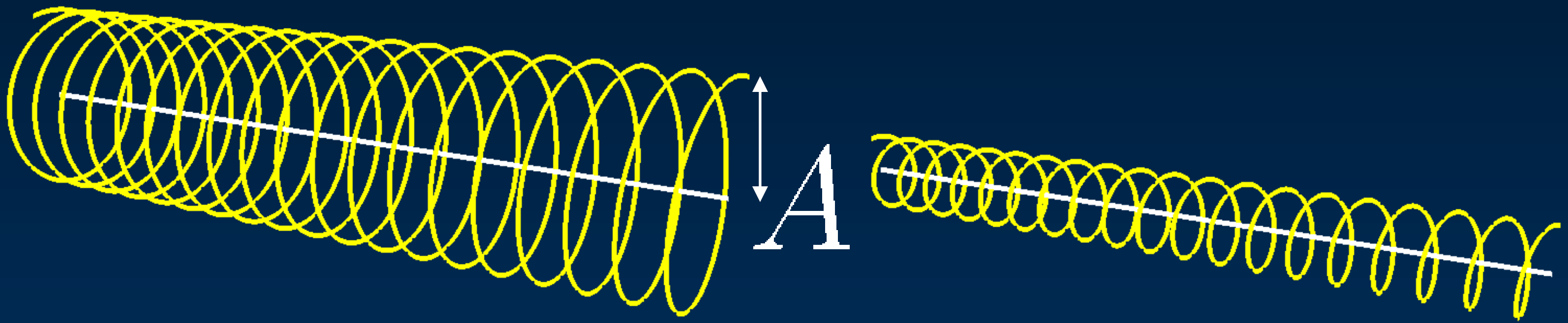

$$\boxed{e^{ikL_1}} = \cos(kL_1) + i\sin(kL_1) \quad k = \frac{2\pi}{\lambda}$$

# Wave Theory of Light




$$e^{ik(L_1+L_2)} = e^{ikL_1}\ e^{ikL_2}$$

# Intensity of a Wave



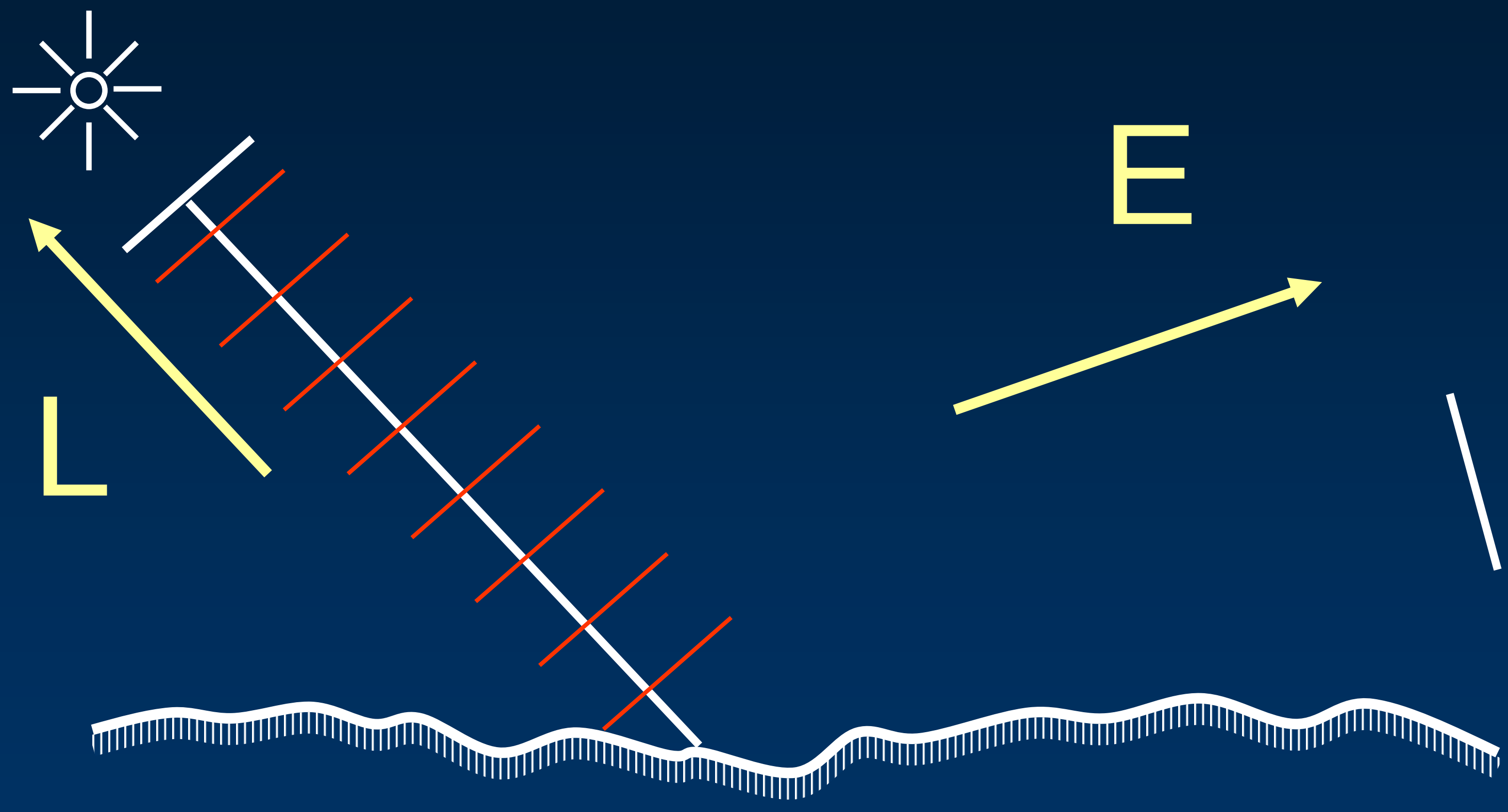

$$I = |A\, e^{ikL}|^2 = A^2$$

# Diffraction

$$|A_1\, e^{ikL_1} + A_2\, e^{ikL_2}|^2 \neq A_1^2 + A_2^2$$

Intensities don’t add up in general

# Interaction: Light-Surface



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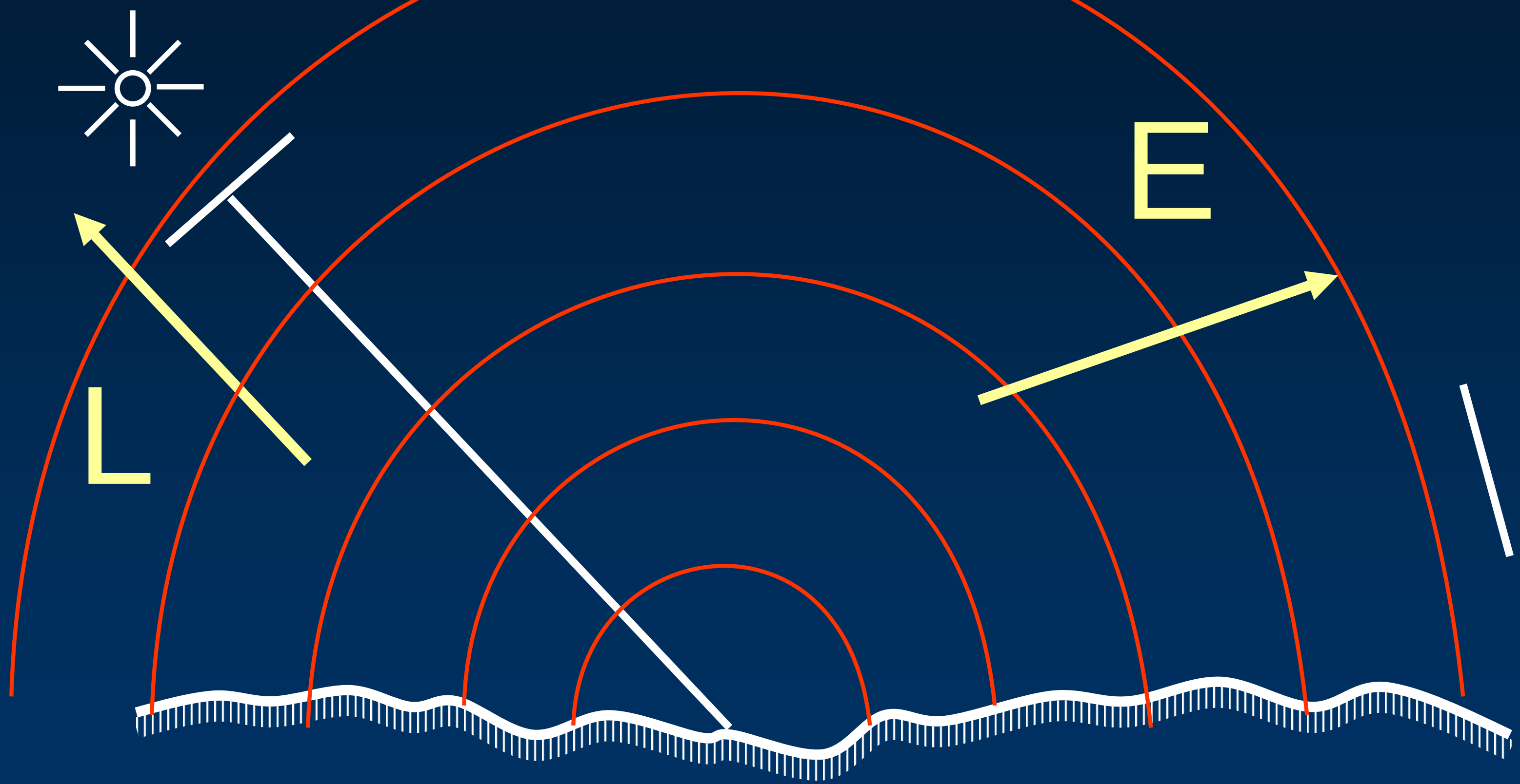

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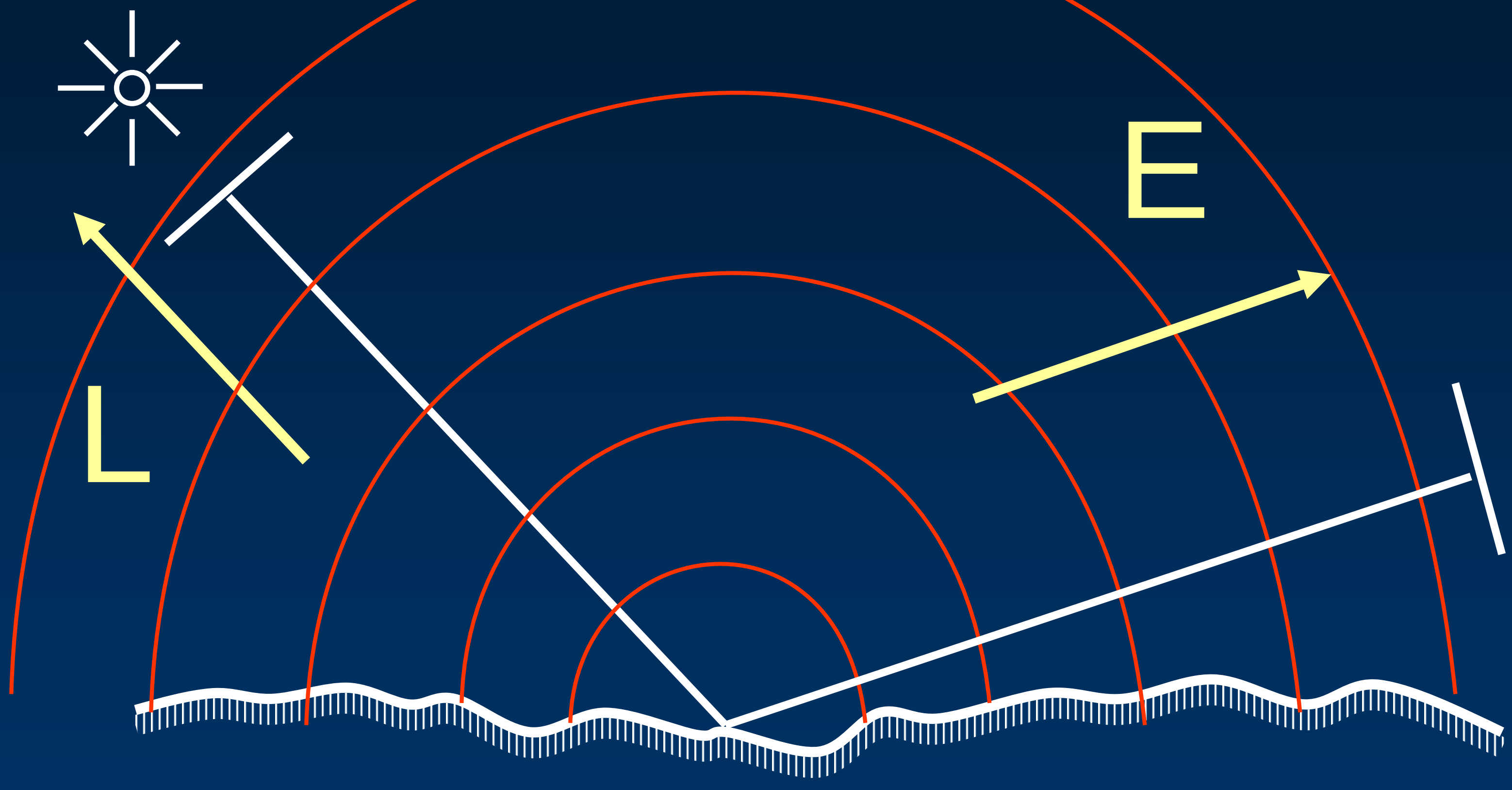

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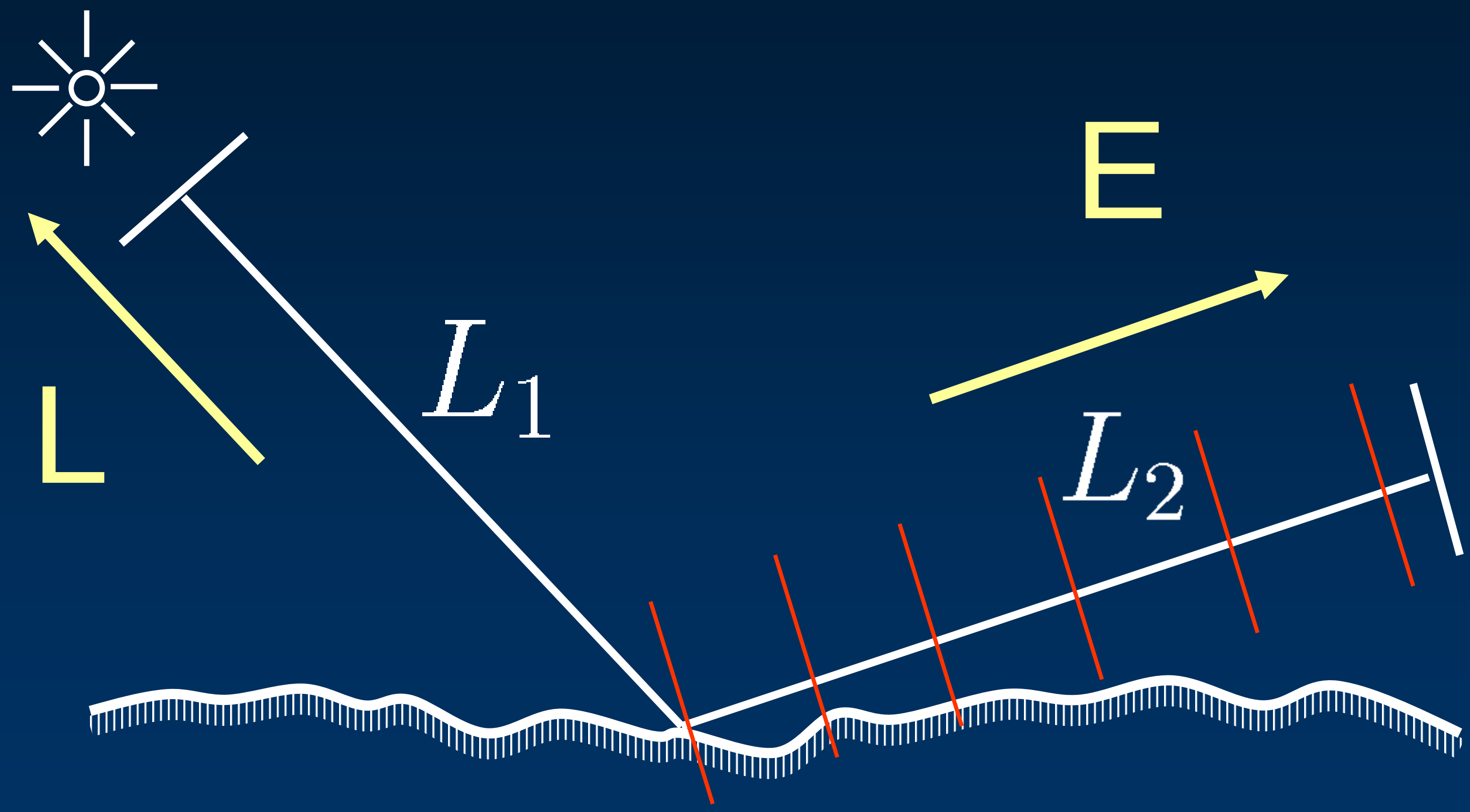
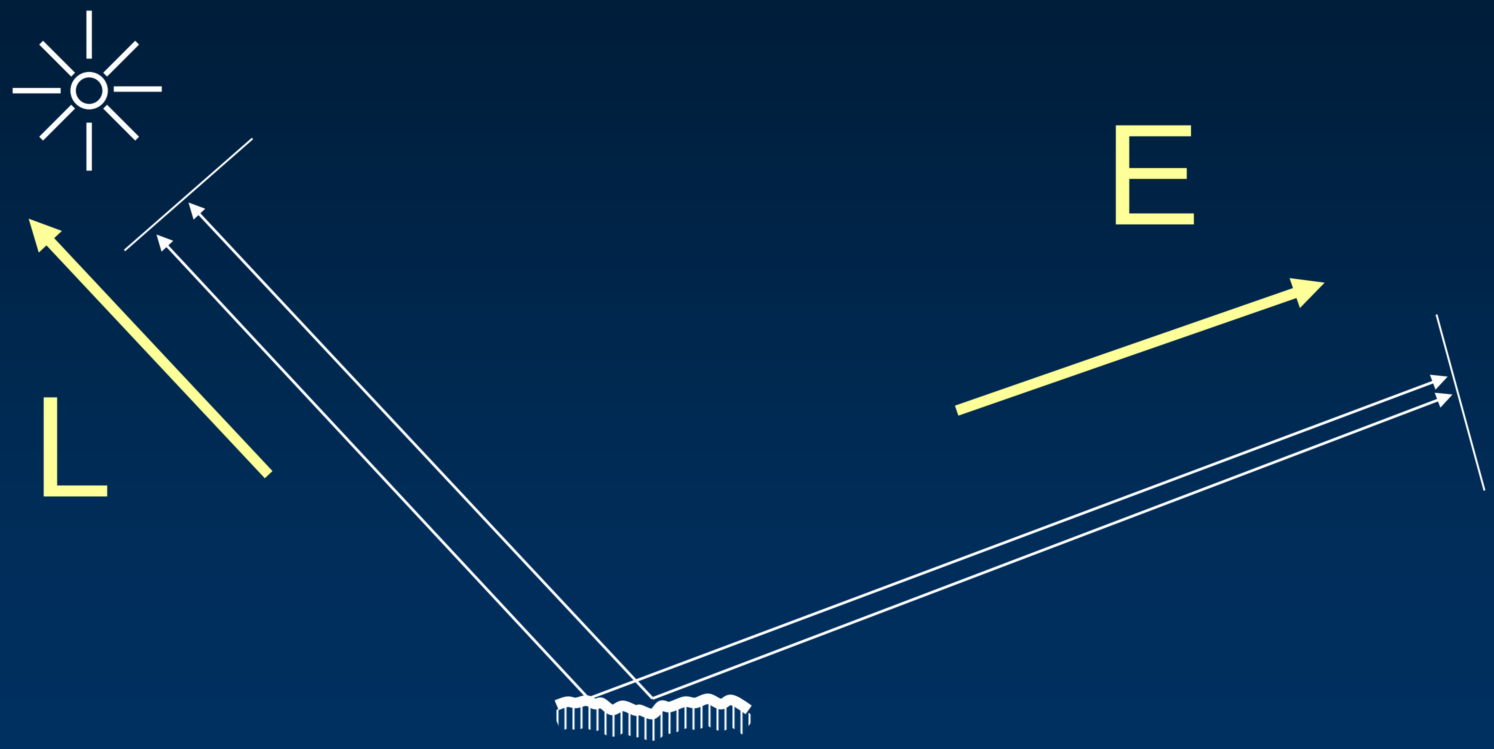



$$e^{ik(L_1+L_2)} = e^{ikL_1}\ e^{ikL_2}$$

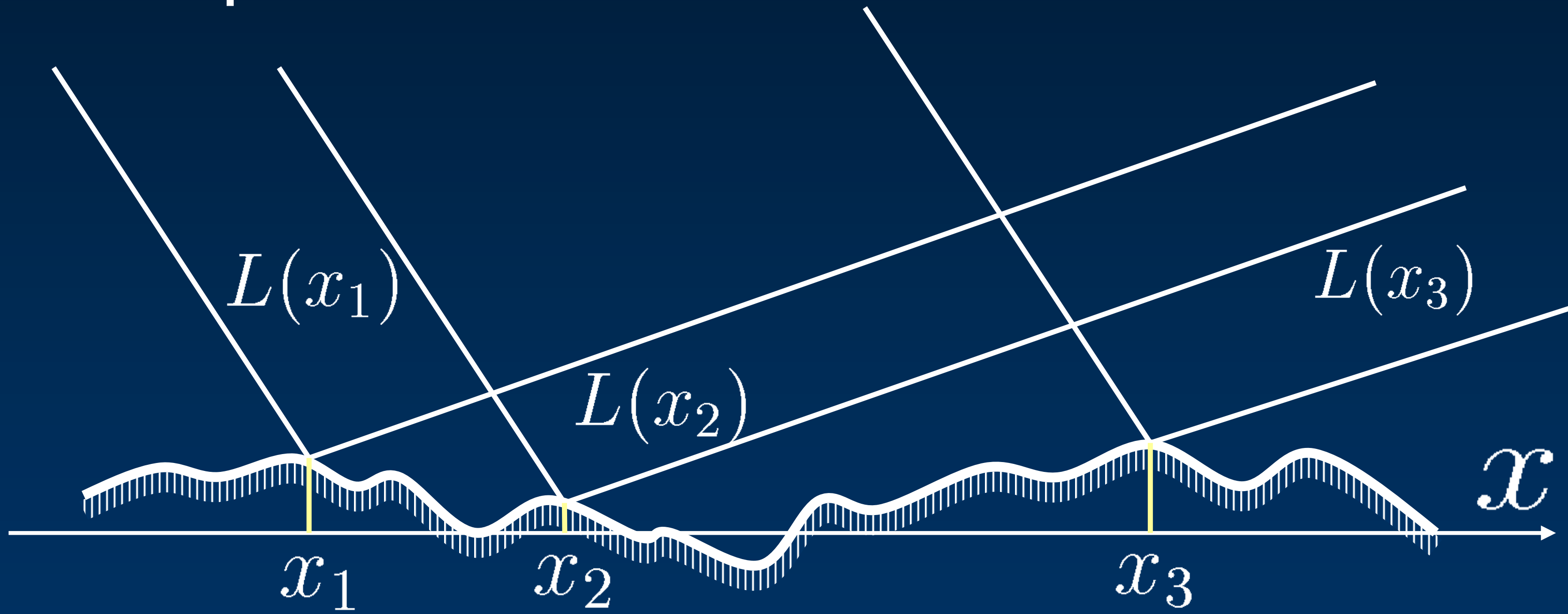
# Interaction: Light-Surface




Source and observer “far away”

# Interaction: Light-Surface

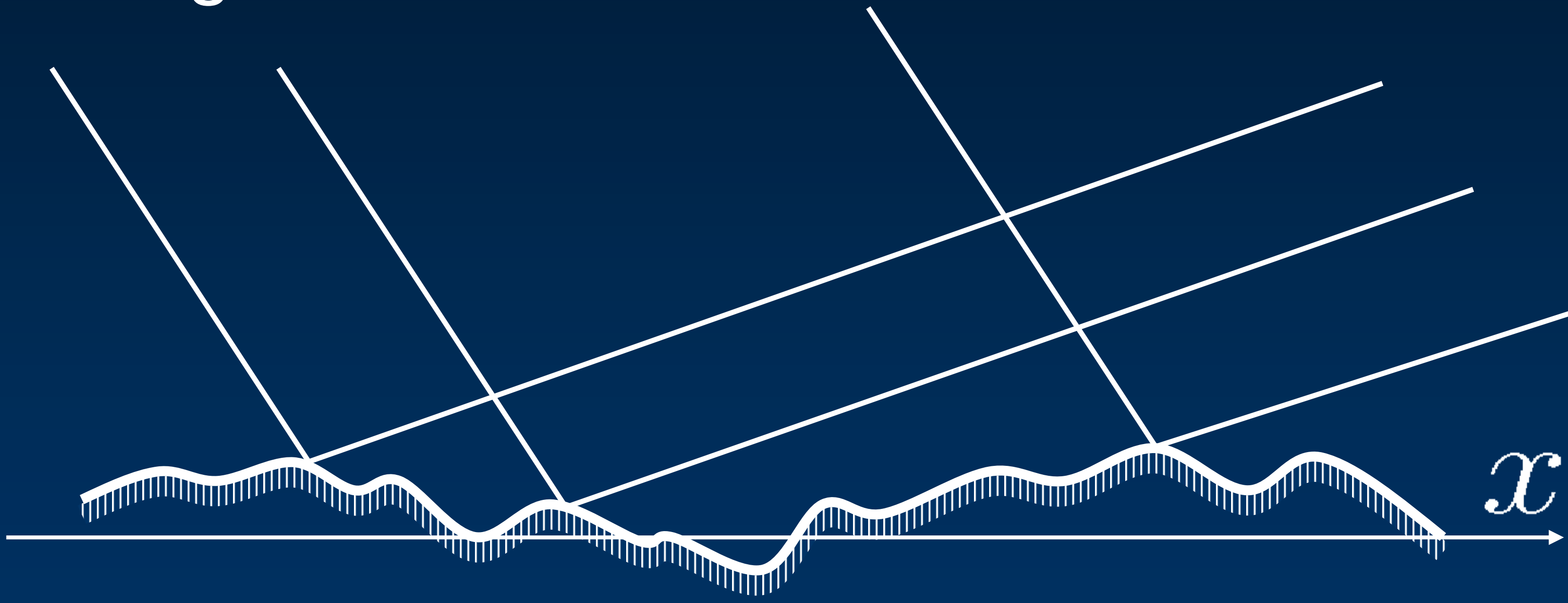
Add up contributions




$$\psi = e^{ikL(x_1)} + e^{ikL(x_2)} + e^{ikL(x_3)} + \cdots$$

# Interaction: Light-Surface

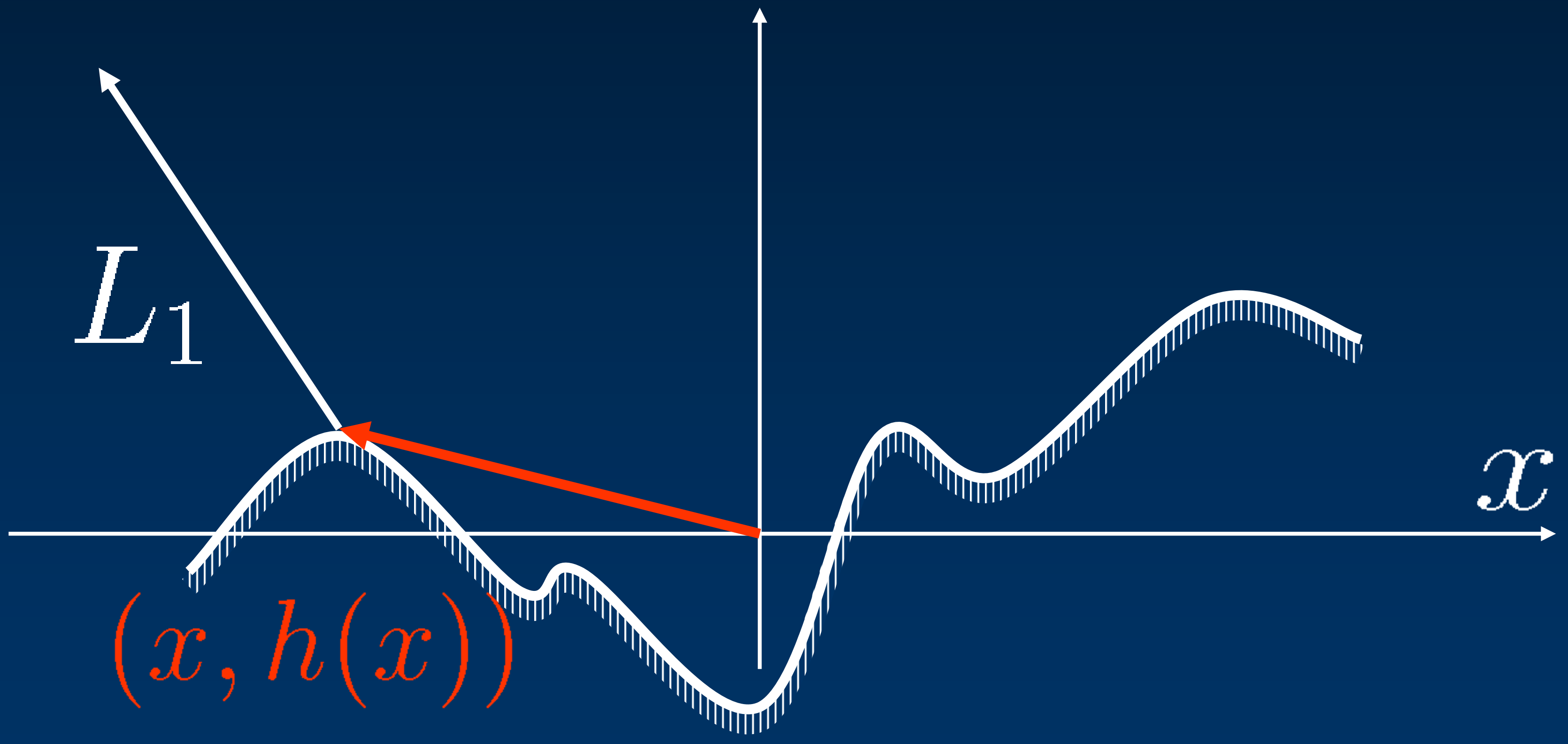
Integral in the limit



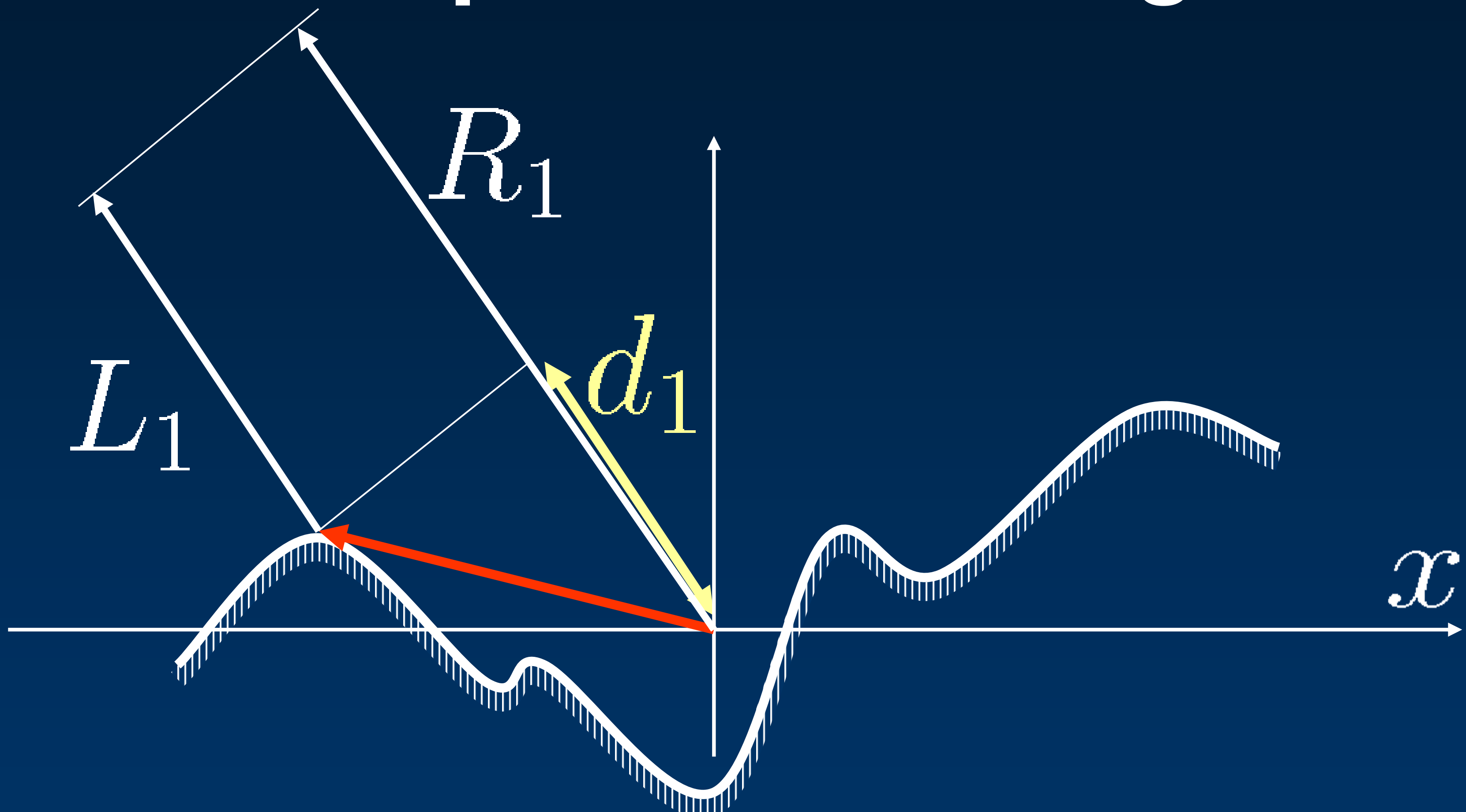

$$\psi = \int e^{ikL(x)}\, dx$$

# Compute Path Length

Distance from source

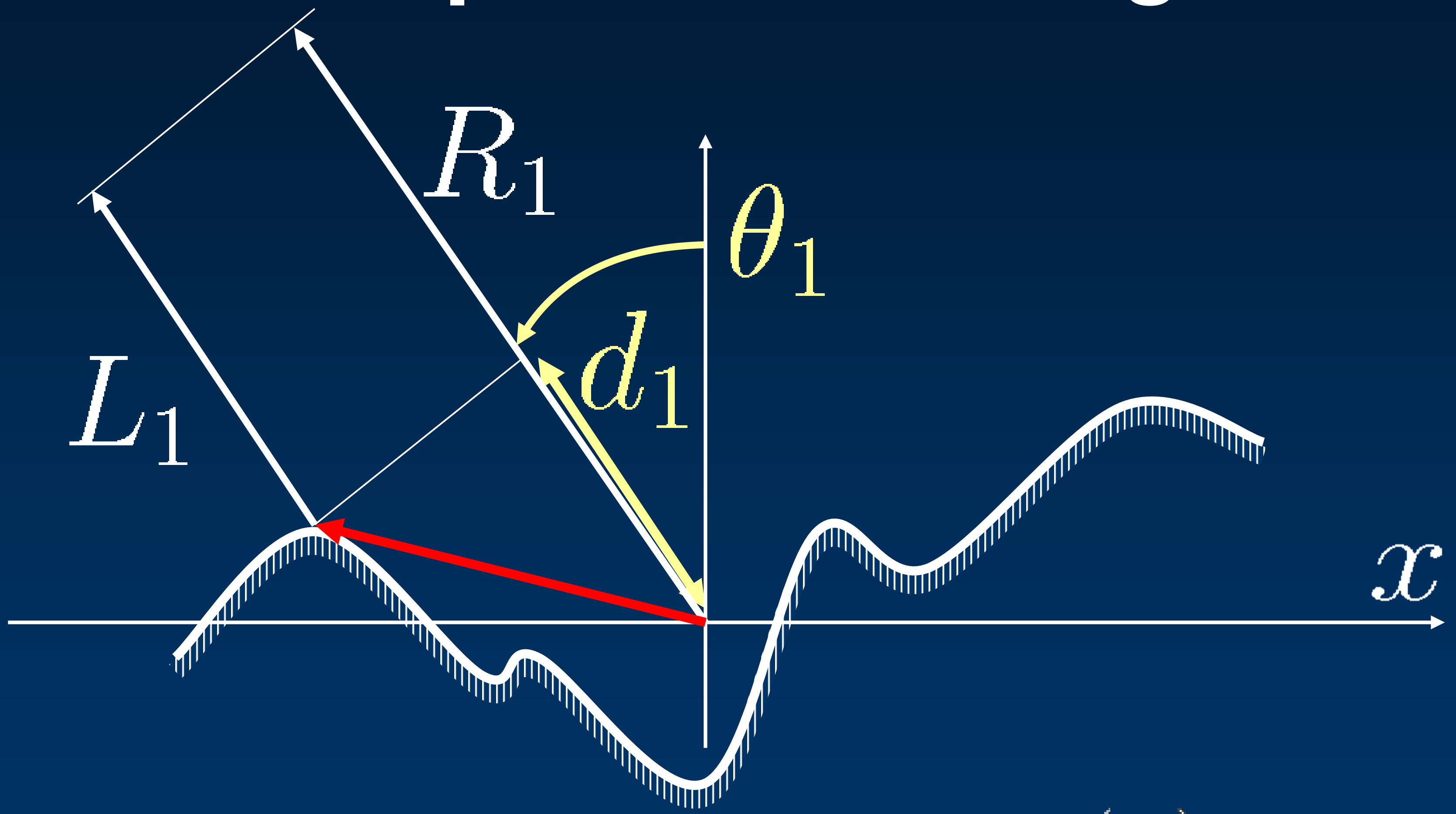


# Compute Path Length




$$L_1 = R_1 - d_1$$

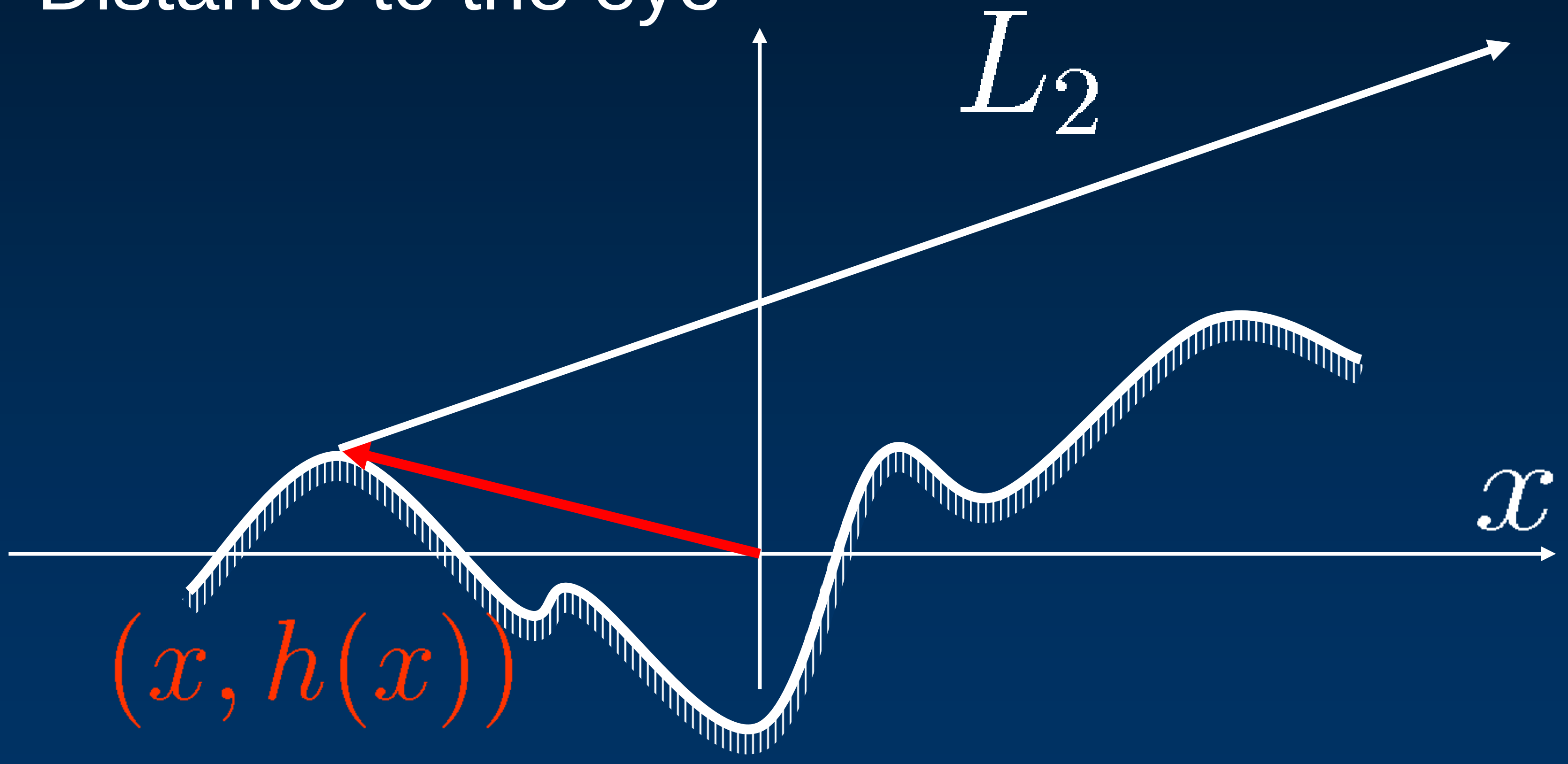
# Compute Path Length



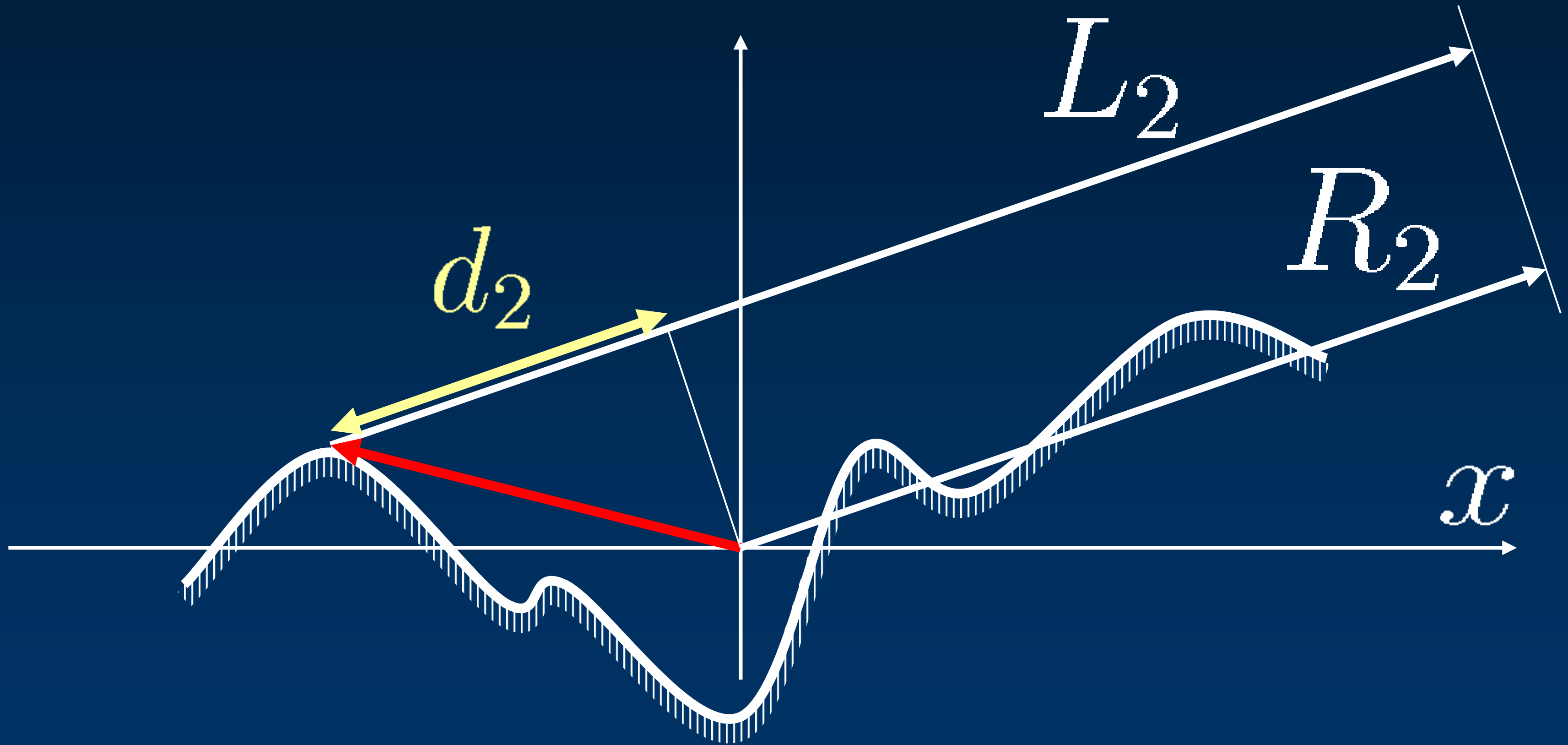

$$L_1 = R_1 + x \sin\theta_1 - h(x)\cos\theta_1$$

# Compute Path Length

Distance to the eye

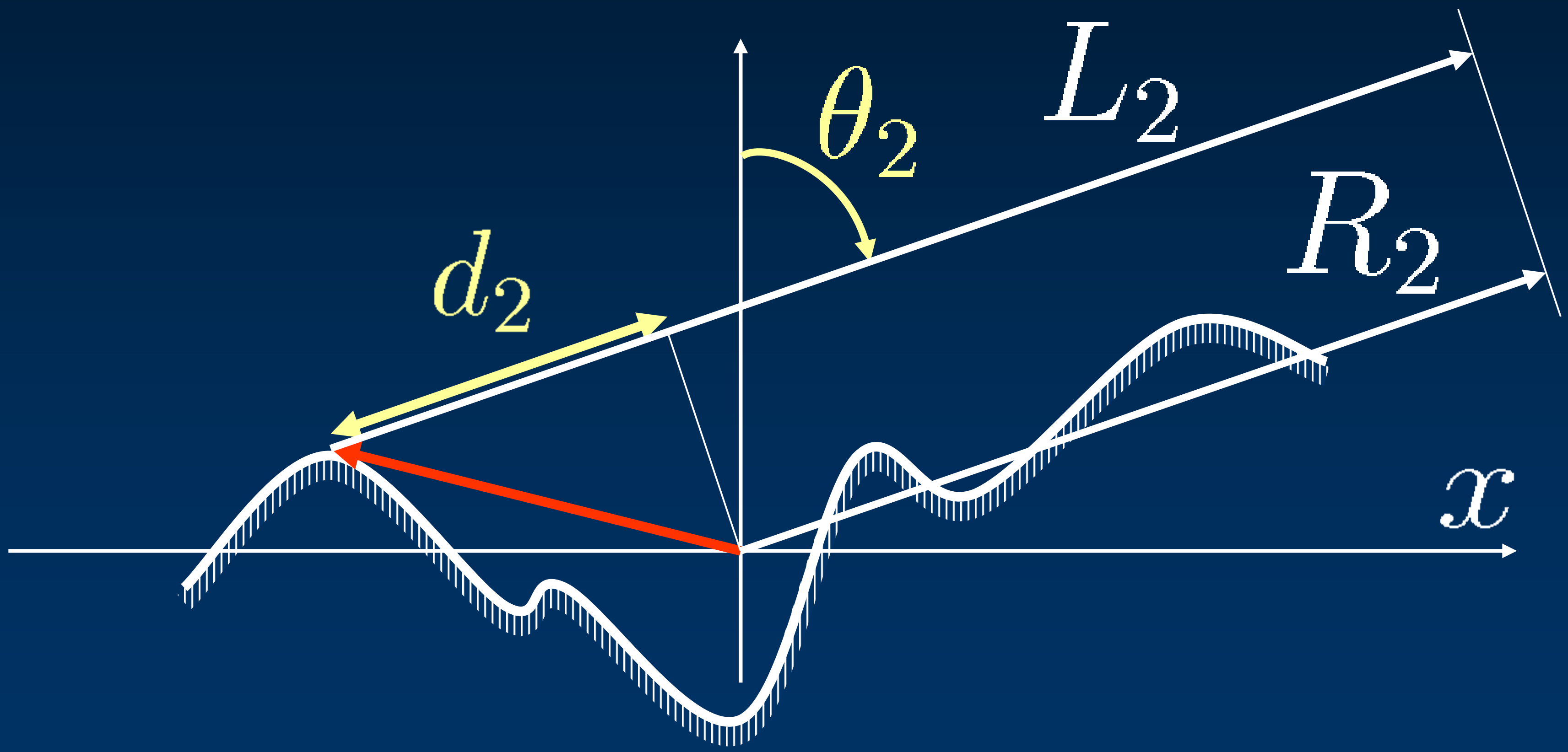


# Compute Path Length




$$L_2 = R_2 + d_2$$

# Compute Path Length




$$L_2 = R_2 - x\sin\theta_2 - h(x)\cos\theta_2$$

# Compute Path Length

Putting the two together:

$$
\begin{aligned}
L_1 &= R_1 + x\sin\theta_1 - h(x)\cos\theta_1 \\
L_2 &= R_2 - x\sin\theta_2 - h(x)\cos\theta_2
\end{aligned}
$$

# Compute Path Length

Putting the two together:

$$
\begin{aligned}
L_1 &= R_1 + x\sin\theta_1 - h(x)\cos\theta_1 \\
+\ L_2 &= R_2 - x\sin\theta_2 - h(x)\cos\theta_2
\end{aligned}
$$

$$L(x) = R_1 + R_2 + ux + wh(x)$$

$$
\begin{aligned}
u &= \sin\theta_1 - \sin\theta_2 \\
w &= -\cos\theta_1 - \cos\theta_2
\end{aligned}
$$

# Reflected Wave

Now integrate over the surface:

$$L(x) = \underbrace{R_1 + R_2 + ux + wh(x)}$$

$$\psi = \int e^{ikL(x)} \, dx$$

# Reflected Wave

$$L(x) = \underbrace{R_1 + R_2}_{} + ux + wh(x)$$

$$\psi = C \int e^{ikwh(x)} \, e^{ikux} \, dx$$

# Fourier Transform

$$\psi = C \int p(x)\, e^{ikux}\, dx$$

$$p(x) = e^{ikwh(x)}$$

Key insight of the paper

# Fourier Transform

$$\psi = C \; P(ku)$$

$$p(x) = e^{ikwh(x)}$$

Key insight of the paper

# Fourier Transform

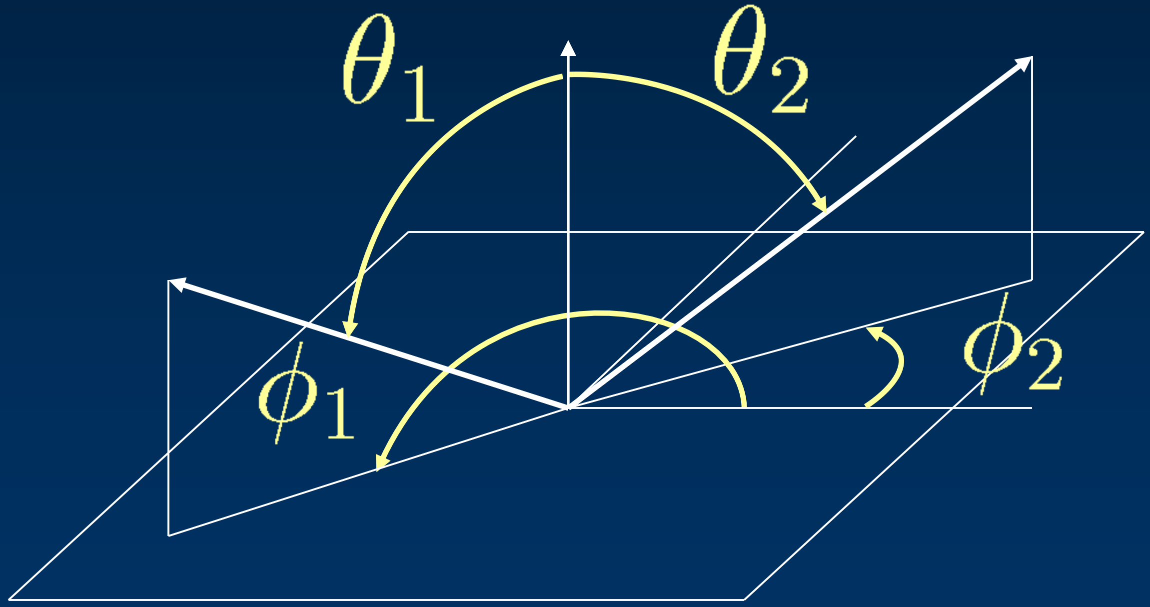
Simple relationship:

$$I = |P(ku)|^2$$

$$|C| = 1$$

# Two dimensions

Previous derivation extends to 2D



# Two dimensions

$$I = \left| P(ku, kv) \right|^2$$

$$p(x, y) = e^{ikwh(x,y)}$$

$$k = \frac{2\pi}{\lambda}$$

$$\begin{aligned} u &= -\cos\phi_1 \sin\theta_1 - \cos\phi_2 \sin\theta_2 \\ v &= \sin\phi_1 \sin\theta_1 - \sin\phi_2 \sin\theta_2 \\ w &= -\cos\theta_1 - \cos\theta_2 \end{aligned}$$

# Computing Shaders

Shader = computing Fourier transforms

I have done this for:

- Gaussian random surfaces
- Fractal random surfaces
- Periodic surfaces

Details in the paper...

# Implementation

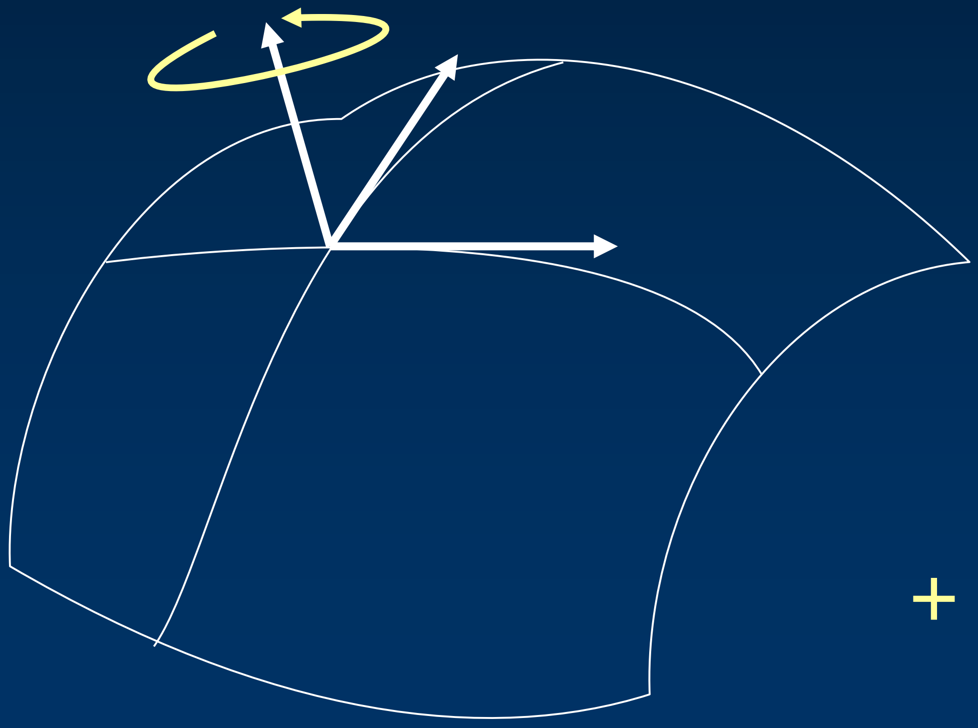
Implemented as MAYA plugin

$$I = |P(ku, kv)|^2$$

Straightforward

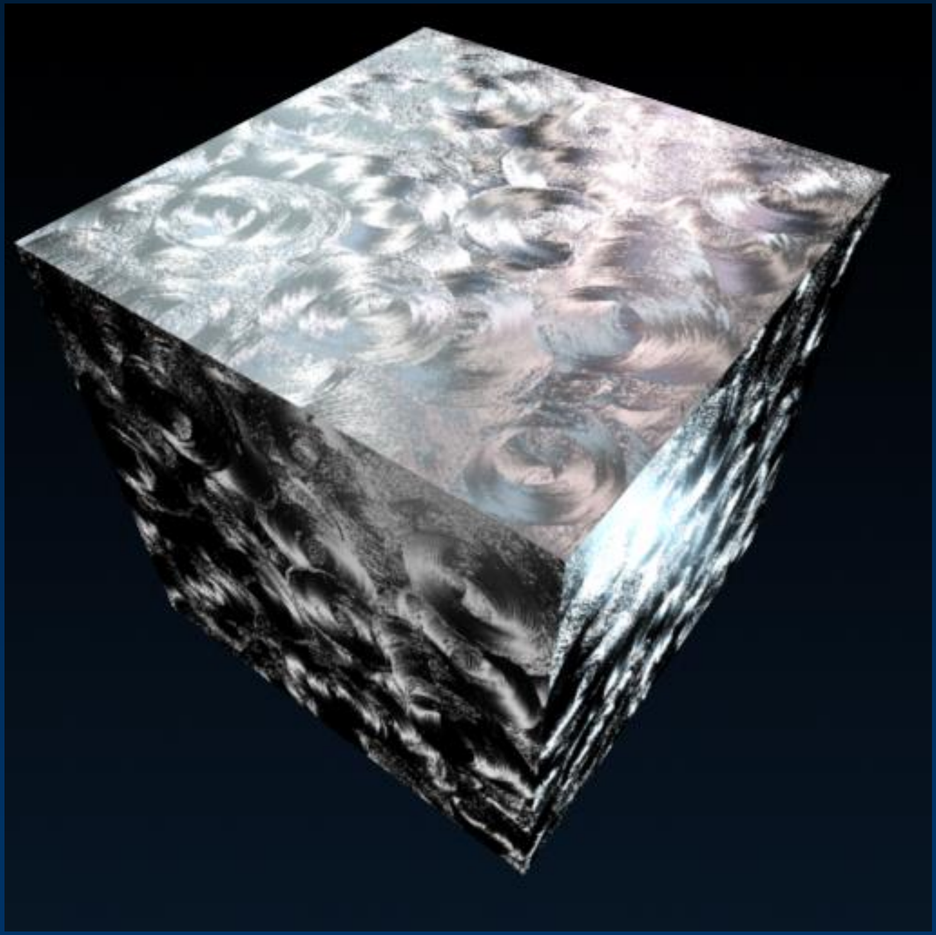
# Implementation

Assign frame to the surface

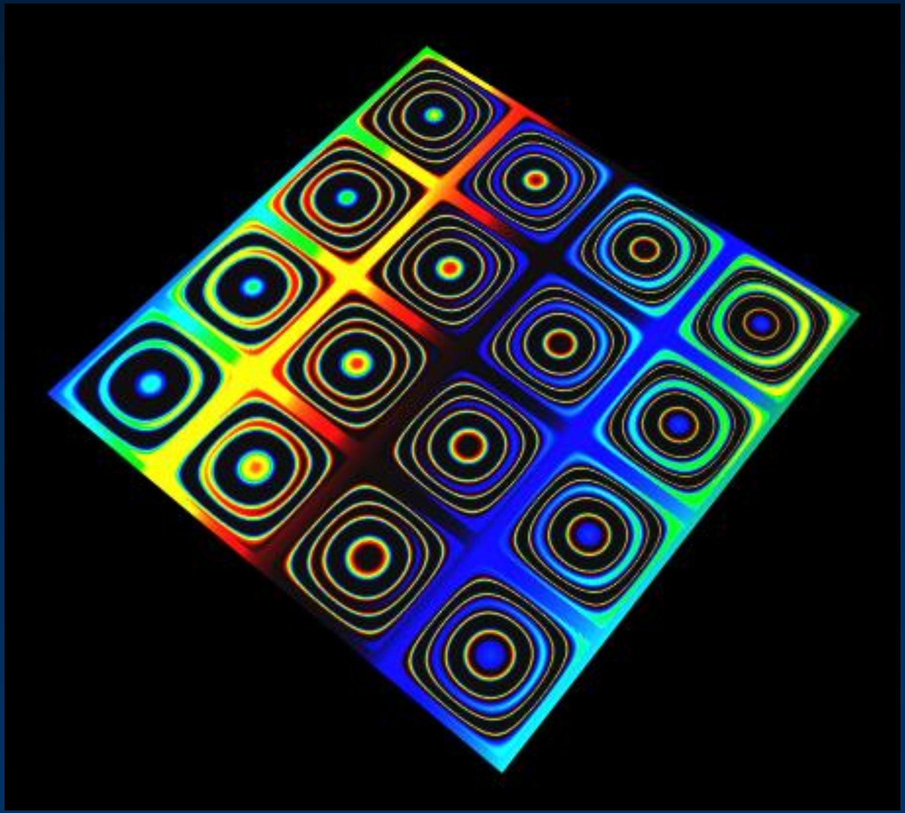


+ twist angle

# Brushed Metal



# Diffraction



# Compact Disk

Used Physical Dimensions:

- bump height : 150 *nm*
- bump width : 500 *nm*
- separation between tracks : 2500 *nm*


COMPUTER
GRAPHICS
PROCEEDINGS CD-ROM
8-13 August 1999
Los Angeles, California
A Publication of ACM SIGGRAPH

# Results

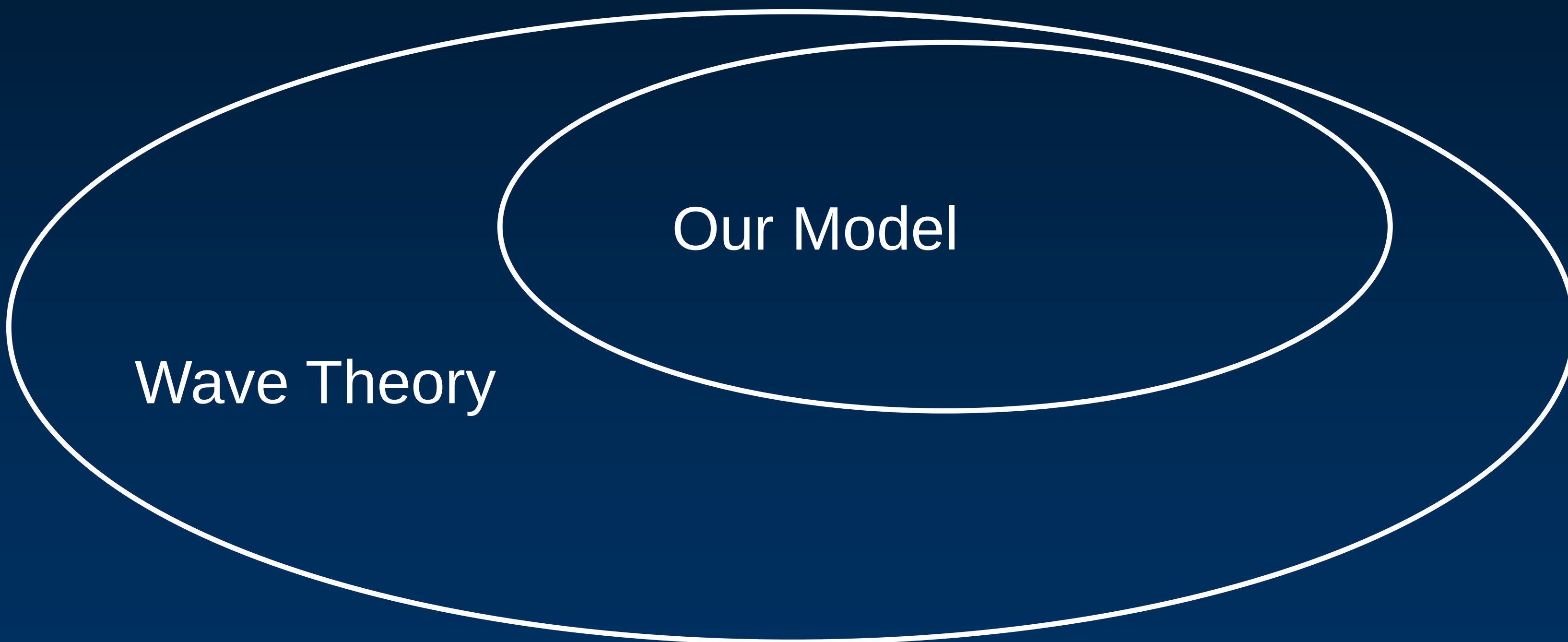
Animations Rendered in MAYA 2.0

# Conclusion

Fourier transform very powerful tool
Most general Illumination model:
He-Torrance special case

Experimental validation (?)

# Future Work




Multiple scattering, varying Fresnel coefficient, any distances, polarization, non-height field surfaces, subsurface scattering, etc.