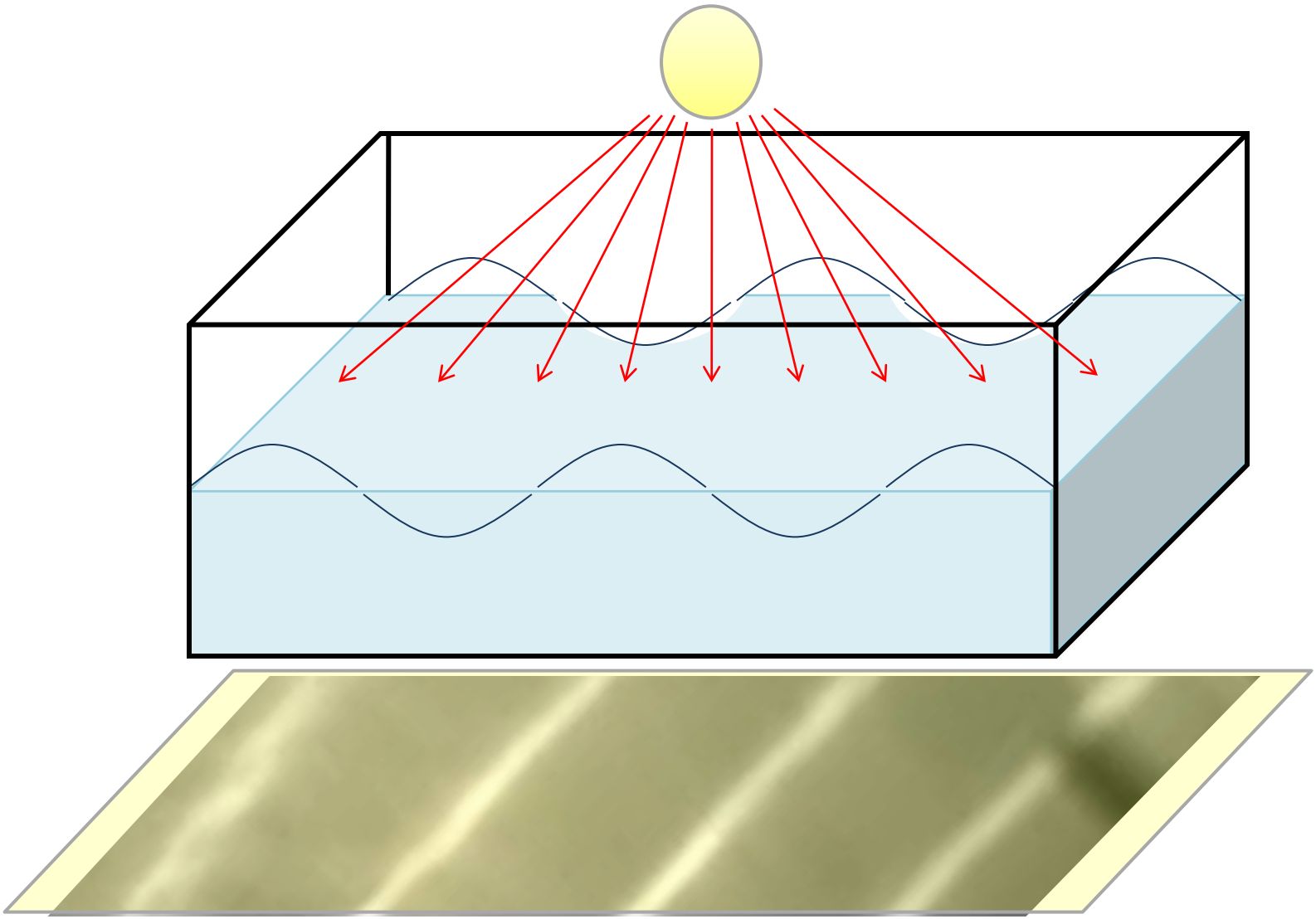
Problem #5

Bright Waves

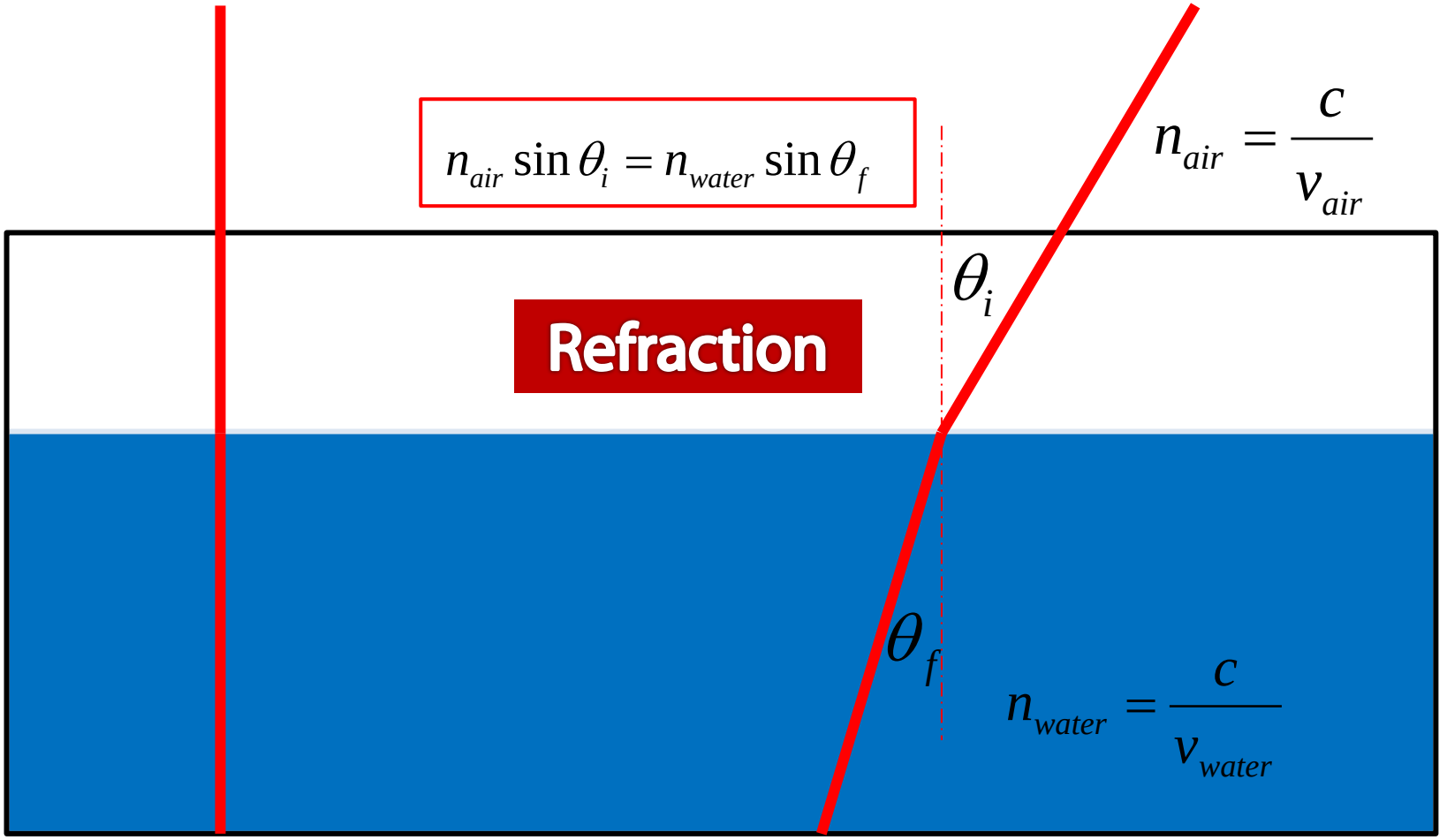
Team
Korea

Suh Hyungju

Problem Statement

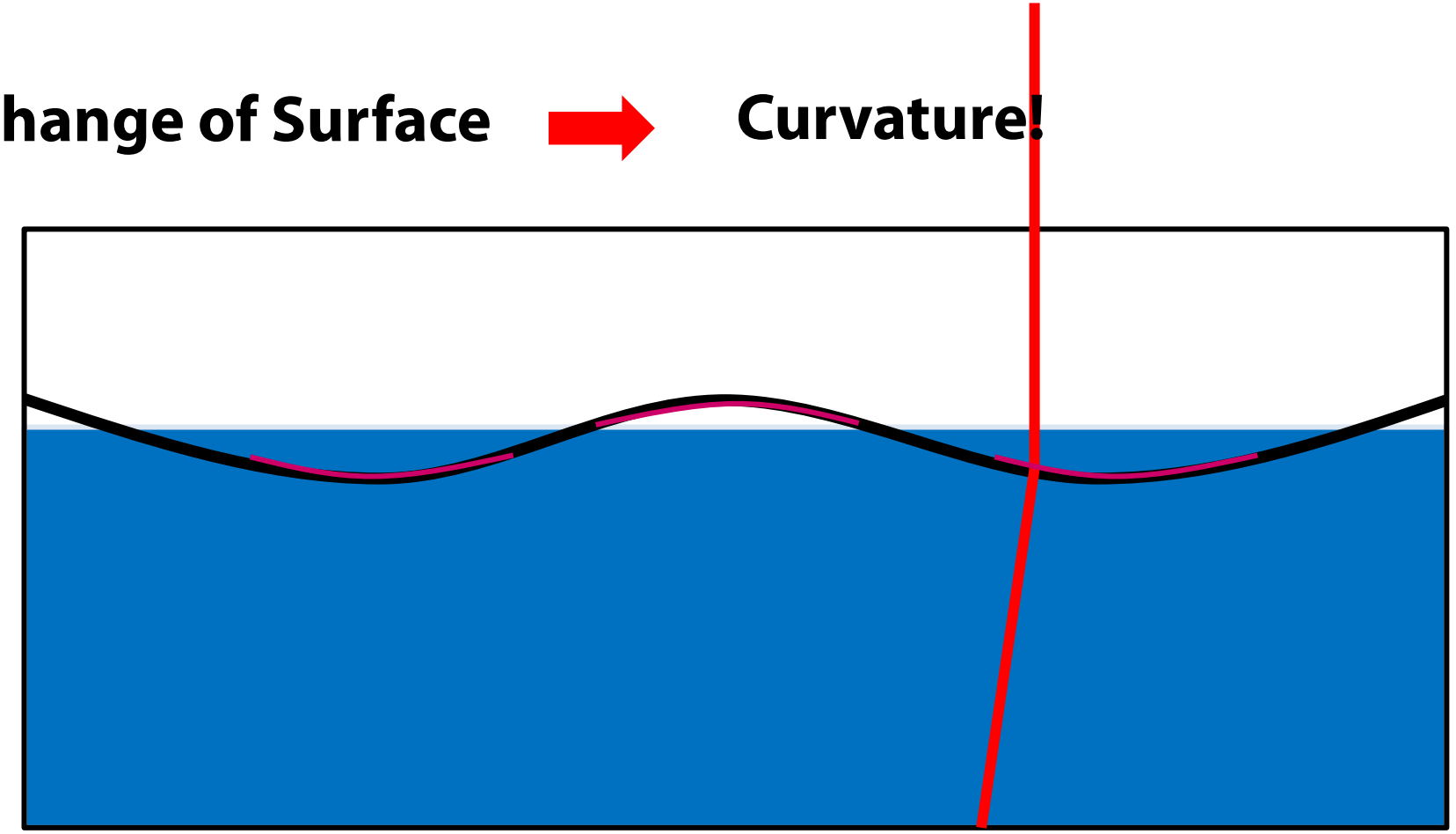


Illumination in Water



Waves on Water

Change of Surface → **Curvature!**



Unequal Distribution of Light Rays → **Pattern!**

Presentation Flowchart

Theory

- Water Surface Modeling
- Light Flux Density
- Refraction

Experiment

Conclusion

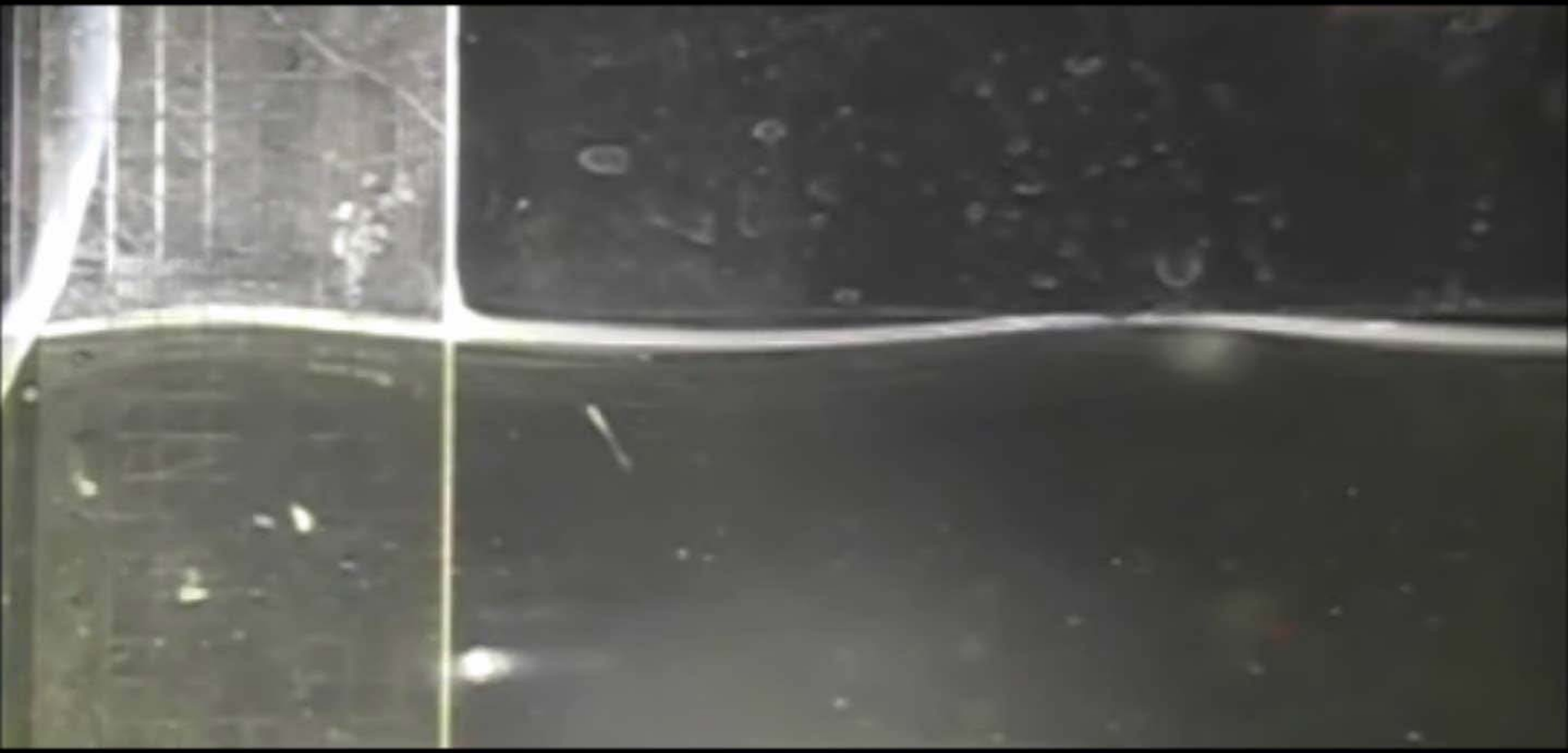
Actual Waves
Different Phenomenon

http://www.google.ca/imgres?imgurl=http://imaginezambia.org/wp-content/uploads/splash-water-waves-4565.jpg&imgrefurl=http://imaginezambia.org/2476/training-workshop-moringa-propogation-teams-quick-update/splash-water-waves-4565/&usg=__ouoxefwUL0whvrDUOOQBnp3NR40=&h=324&w=620&sz=42&hl=ko&start=17&zoom=1&tbnid=zsBhBUfaehuTBM:&tbnh=71&tbnw=136&ei=84LyT9G2NcWjiAfnn_C6Aw&prev=/search%3Fq%3Dwater%2Bwaves%26um%3D1%26hl%3Dko%26tbm%3Disch&um=1&itbs=1

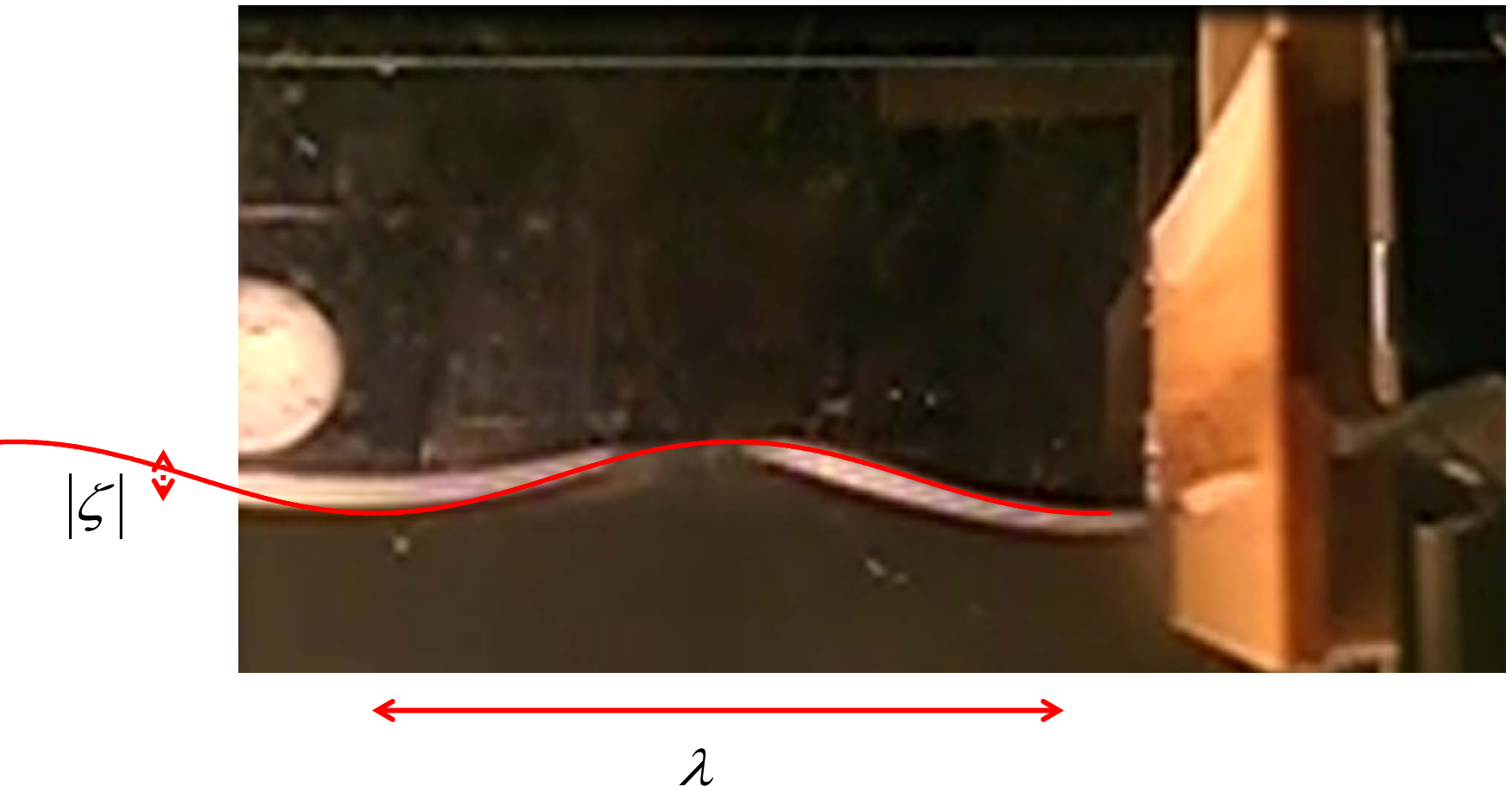
http://www.shutterstock.com/pic-3965908/stock-photo-water-waves.html

Surface of Waves

Sinusodial Shape - Observation

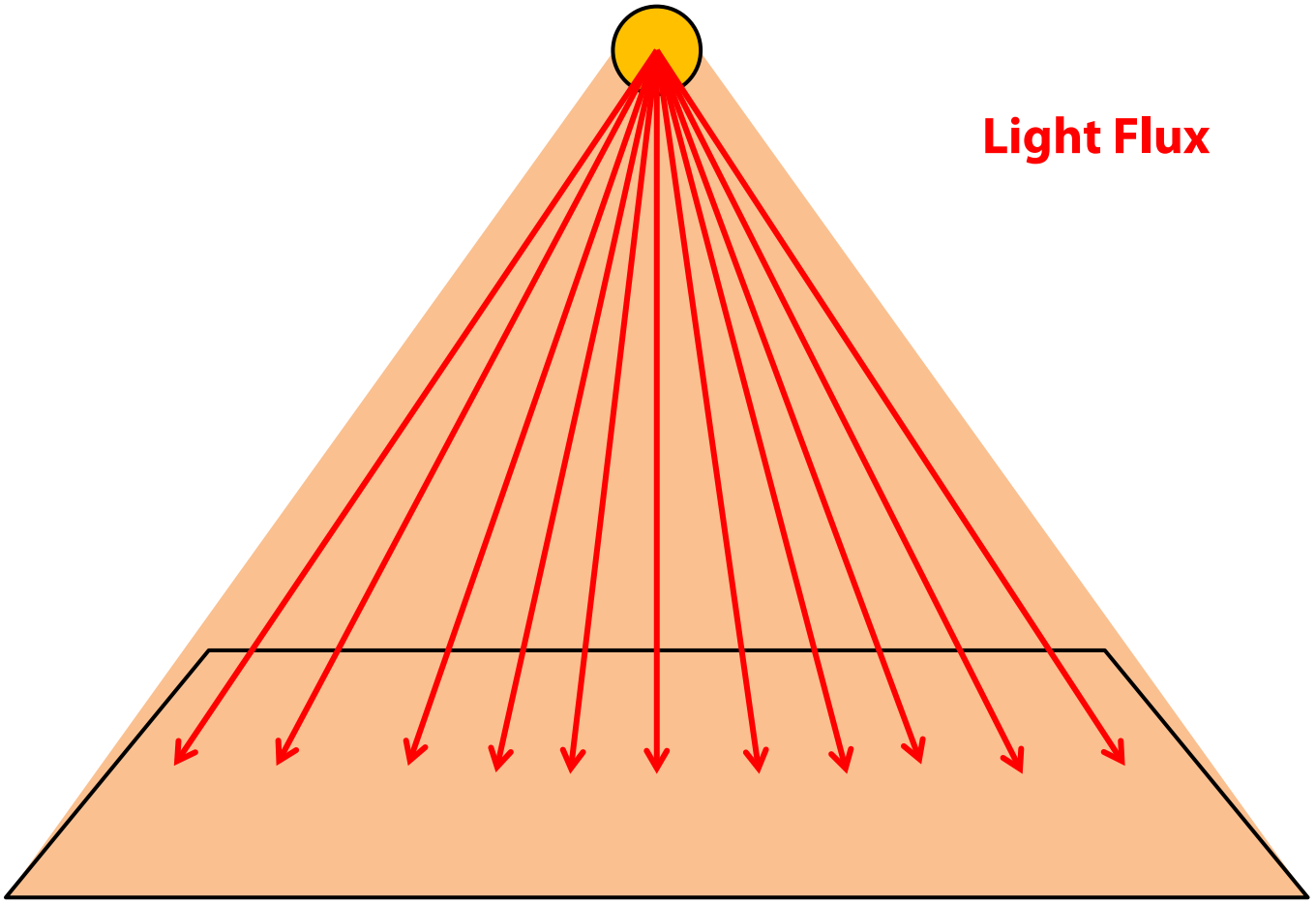


Sine Wave Approximation



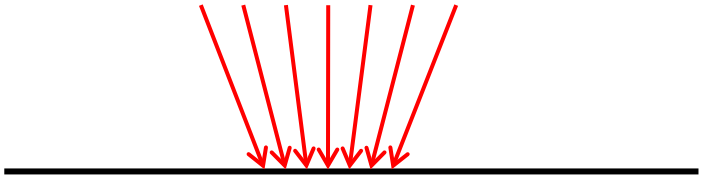
Patterns of Light

Theory – Light Flux Density



Theory – Light Flux Density

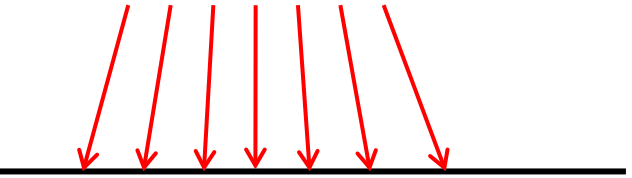
Different Concentrations of Light Flux!



High Light Flux Density → High Intensity

Image Source

http://www.google.ca/imgres?q=caustics&um=1&hl=ko&sa=X&tbs=isz:l&tbm=isch&tbnid=ZkfOhJ4Ec0ZEgM:&imgrefurl=http://dxbigd.deviantart.com/art/Glass-VRay-Caustics-Test-50302568&docid=Ag6X_5I5UllUkM&imgurl=http://www.deviantart.com/download/50302568/Glass___VRay_Caustics_Test_by_DXBigD.jpg&w=1024&h=768&ei=Jp_xT8DRAemYiAfck_2xDQ&zoom=1&iact=hc&vpx=600&vpy=211&dur=247&hovh=164&hovw=225&tx=123&ty=76&sig=106441543725892116471&page=1&tbnh=161&tbnw=221&start=0&ndsp=8&ved=1t:429,r:2,s:0,i:79&biw=1120&bih=576

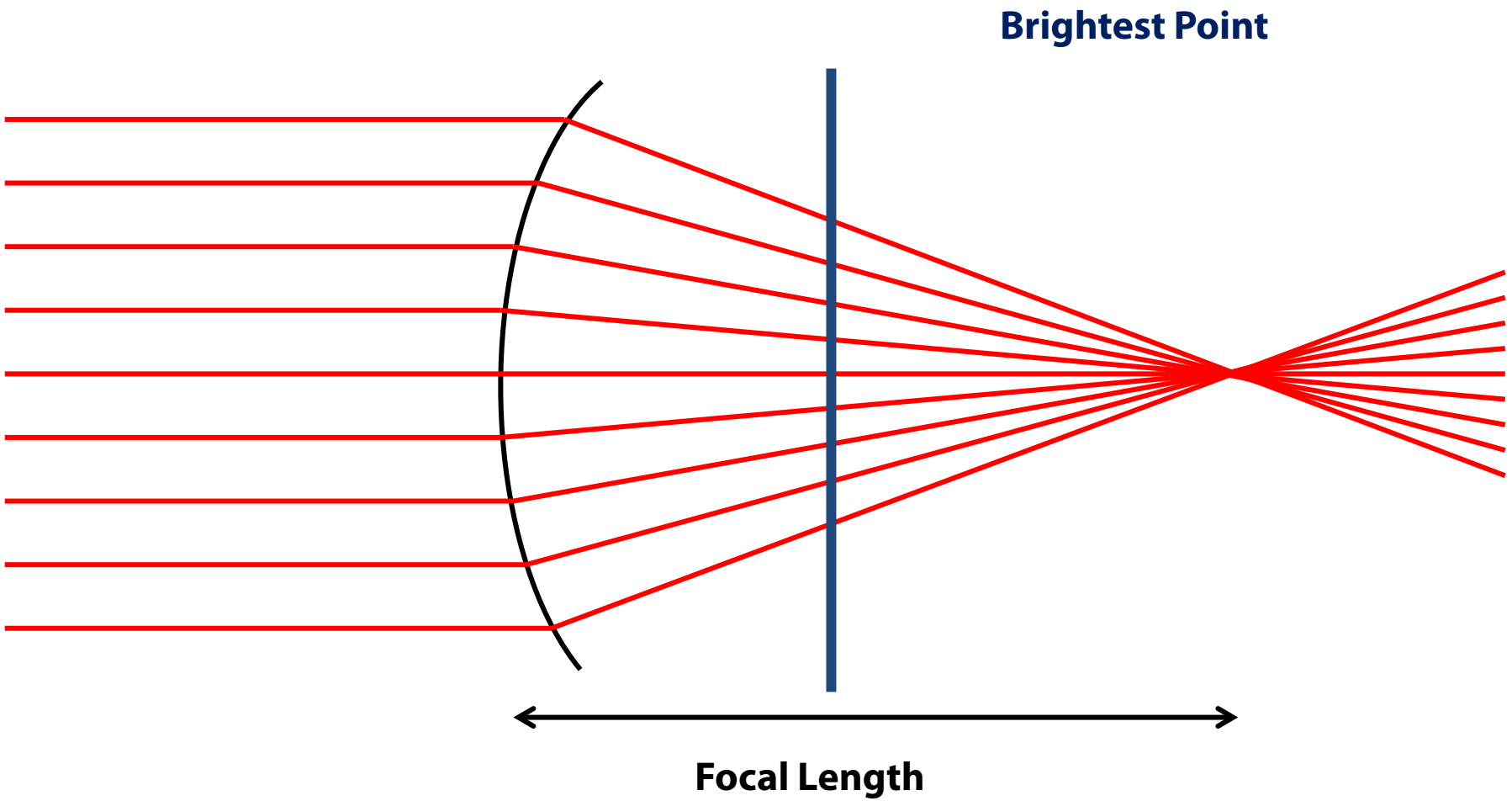


Low Light Flux Density → Low Intensity

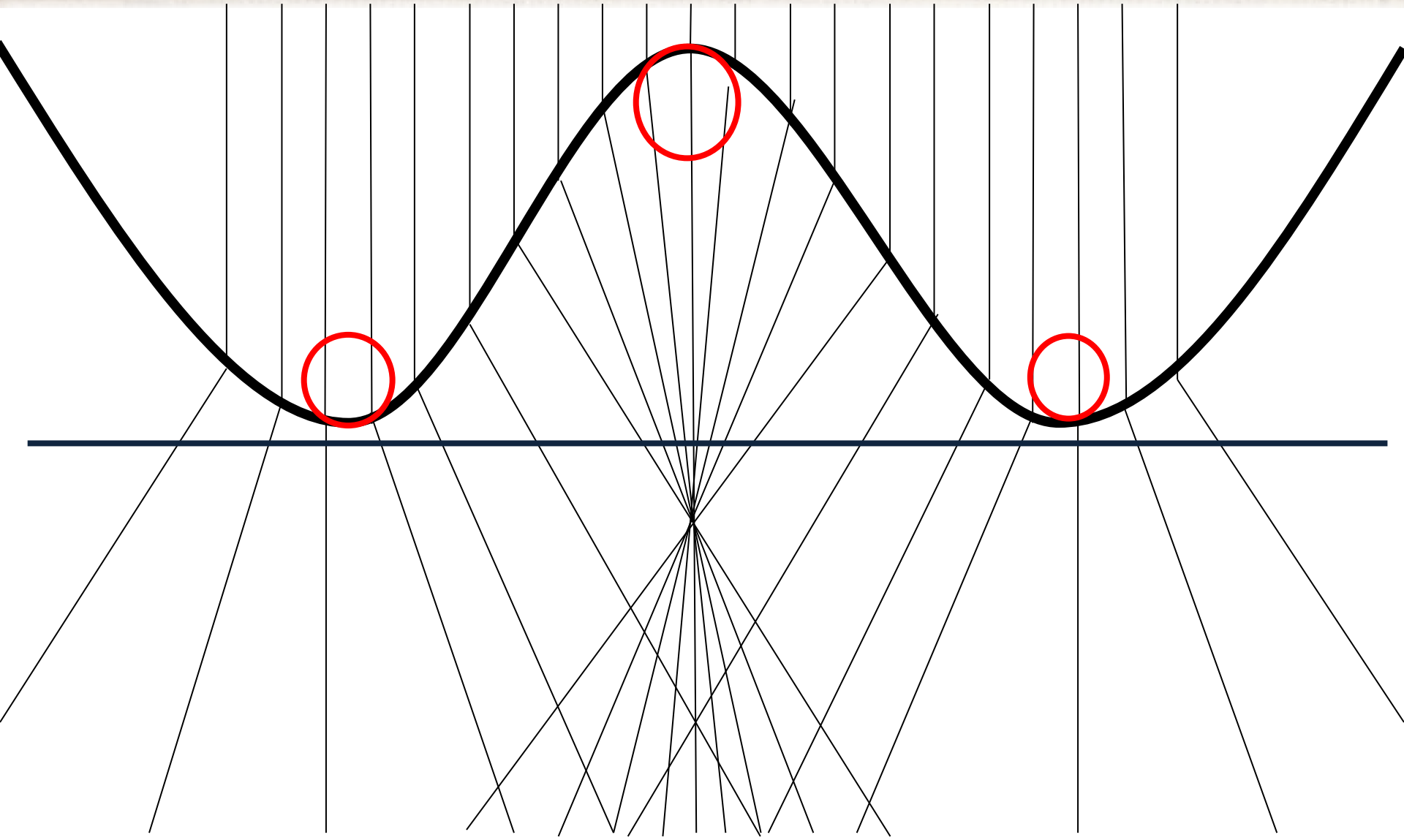
Image Source

http://www.google.ca/imgres?q=caustics&um=1&hl=ko&sa=X&tbs=isz:l&tbm=isch&tbnid=WaBPapCHOju9dM:&imgrefurl=http://etacar.put.poznan.pl/piotr.pieranski//Physics%2520Around%2520Us/Physics%2520around%2520us.html&docid=MXJT4dwA74pQGM&imgurl=http://etacar.put.poznan.pl/piotr.pieranski//Physics%252520Around%252520Us/Caustics%25252004.JPG&w=1280&h=960&ei=Jp_xT8DRAemYiAfck_2xDQ&zoom=1&iact=hc&vpx=93&vpy=105&dur=919&hovh=194&hovw=259&tx=140&ty=94&sig=106441543725892116471&page=2&tbnh=123&tbnw=165&start=8&ndsp=23&ved=1t:429,r:6,s:8,i:120&biw=1120&bih=576

Theory – Flux Density in Lens



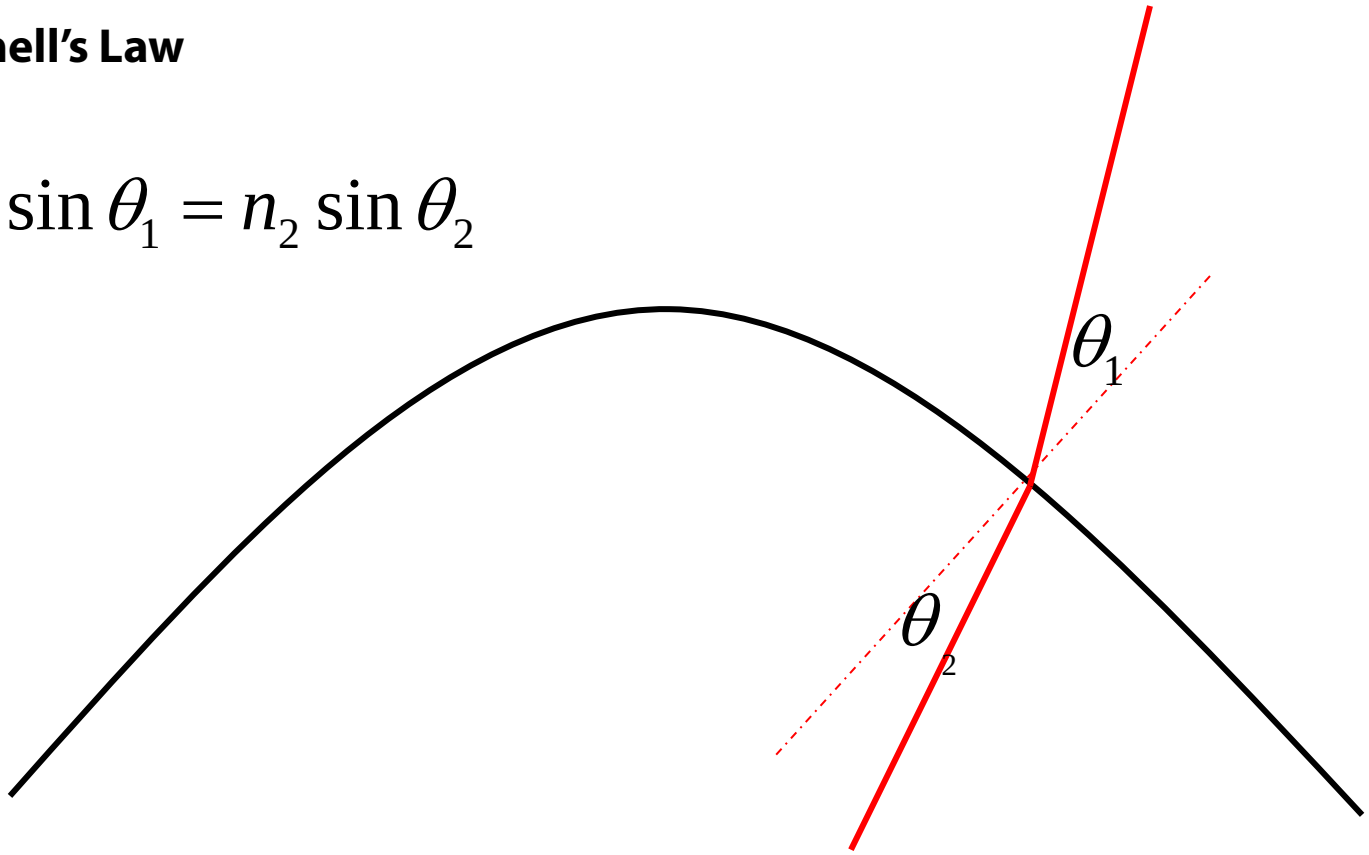
Theory – Flux Density on Water Surface



Refraction in Different Medium

Snell's Law

$$n_1 \sin\theta_1 = n_2 \sin\theta_2$$



Refraction ⇨ **Flux Density** ⇨ **Bright Waves Patterns**

Water Surface and Refraction

Snell's Law

$$n_1 \sin(a\cos(\frac{\vec{n}\cdot\vec{l}}{|\vec{n}||\vec{l}|})) = n_2 \sin(a\cos(\frac{(-\vec{n})\cdot\vec{l}`}{|\vec{n}||\vec{l}`|}))$$

Normalization

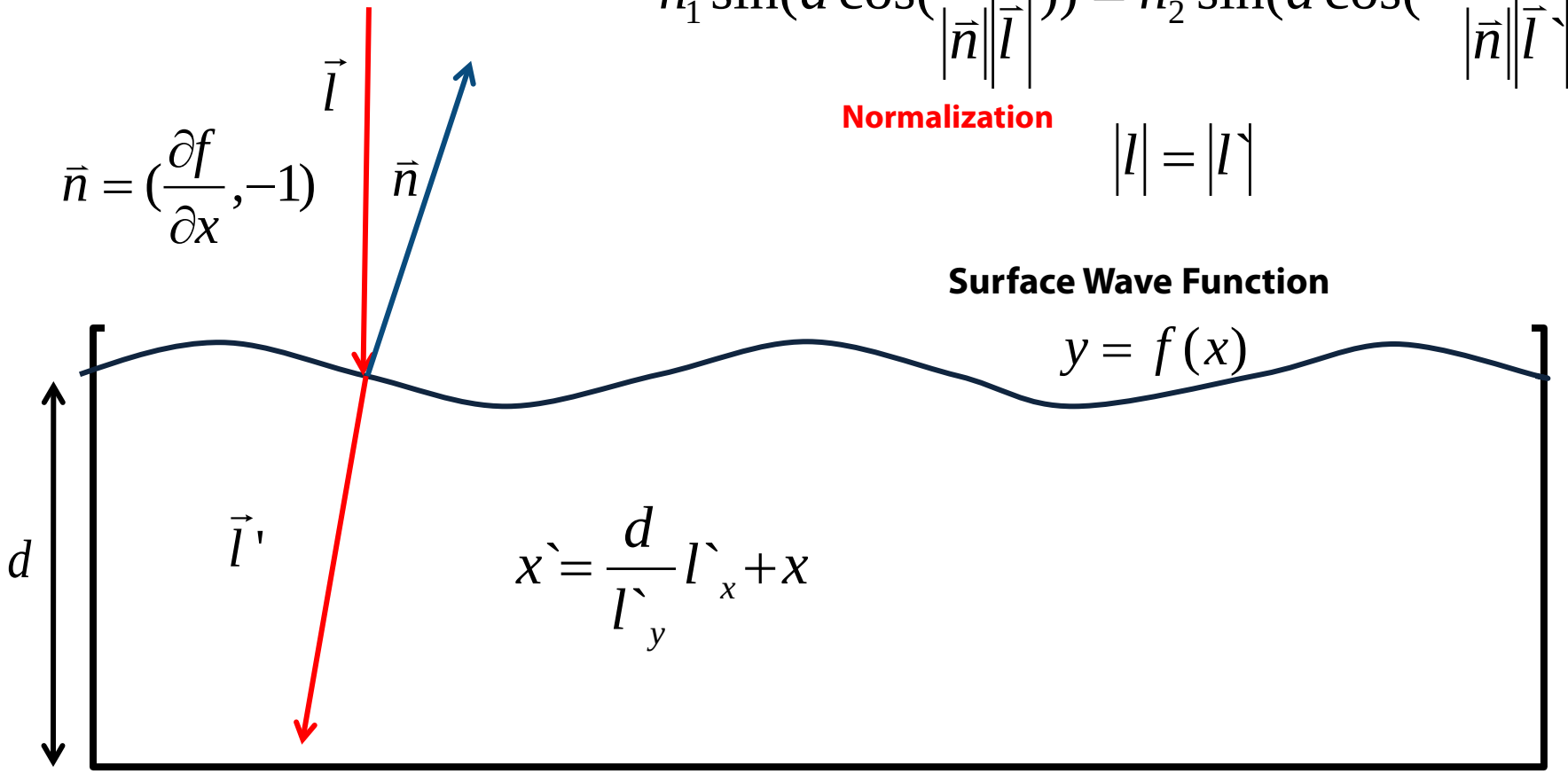
$$|l| = |l`|$$

$$\vec{n} = (\frac{\partial f}{\partial x}, -1)$$

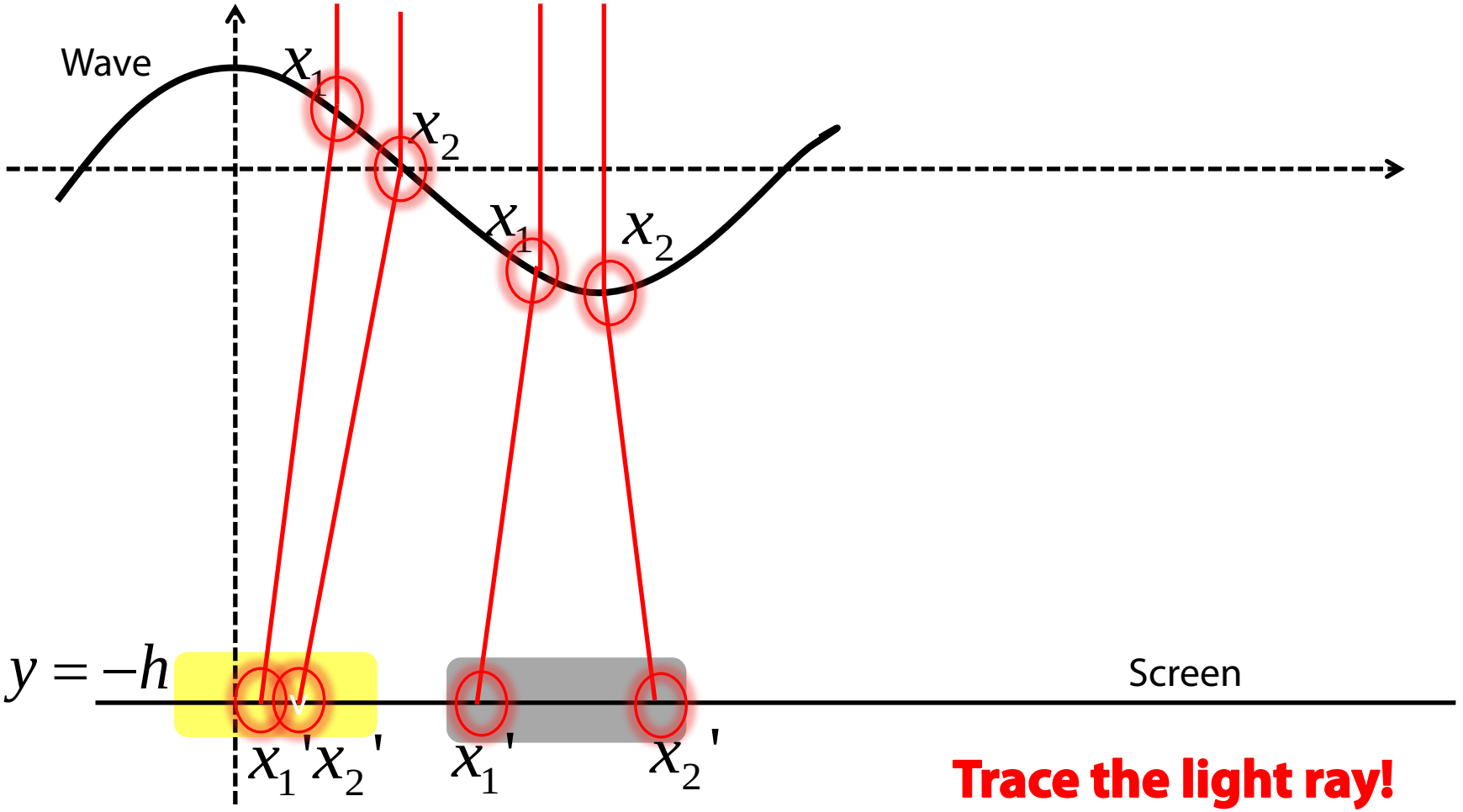
Surface Wave Function

$$y = f(x)$$

$$x` = \frac{d}{l`_y} l`_x + x$$

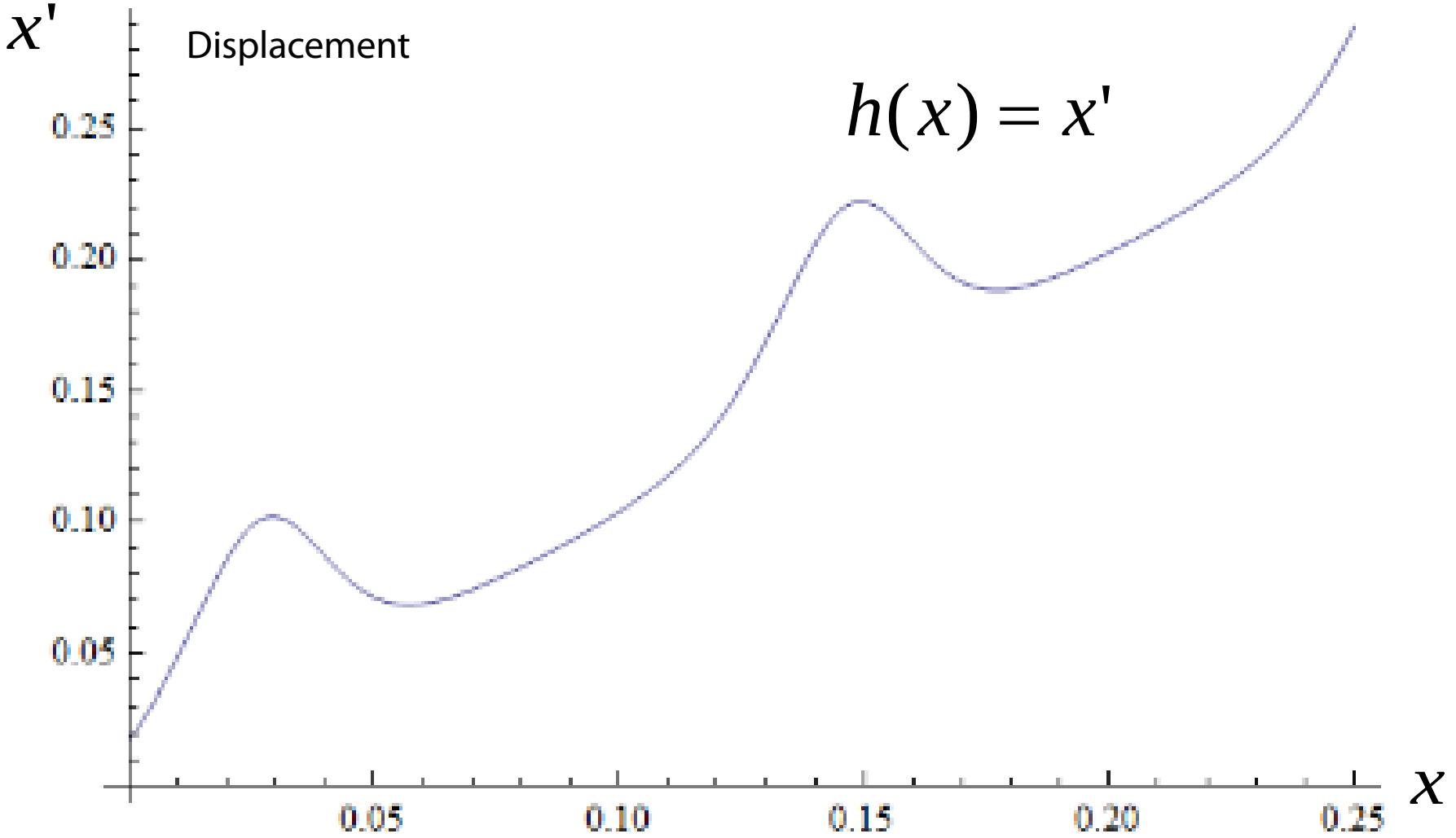


Light Flux Density



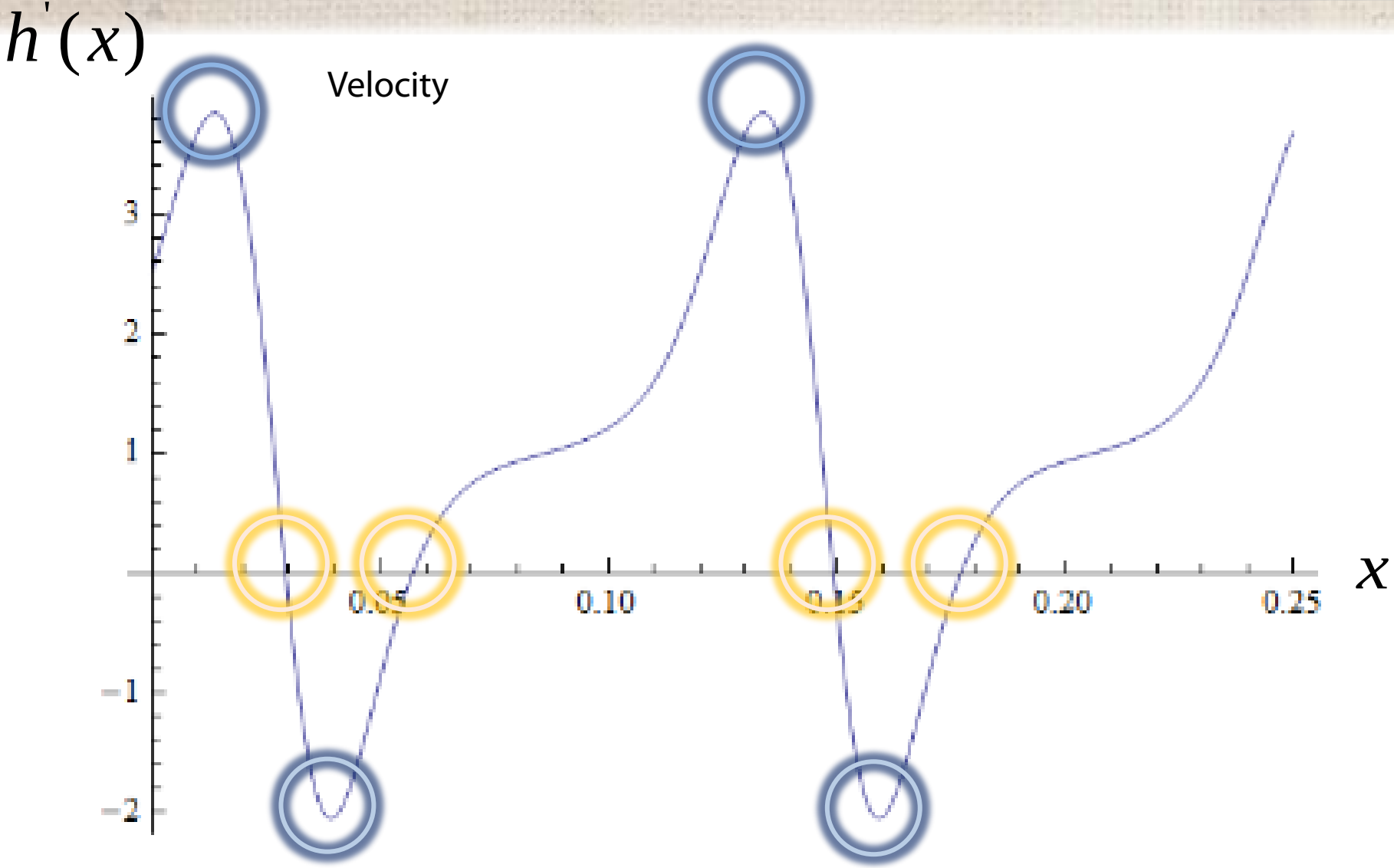
Trace the light ray!

Prediction of Pattern – Changed Coordinates

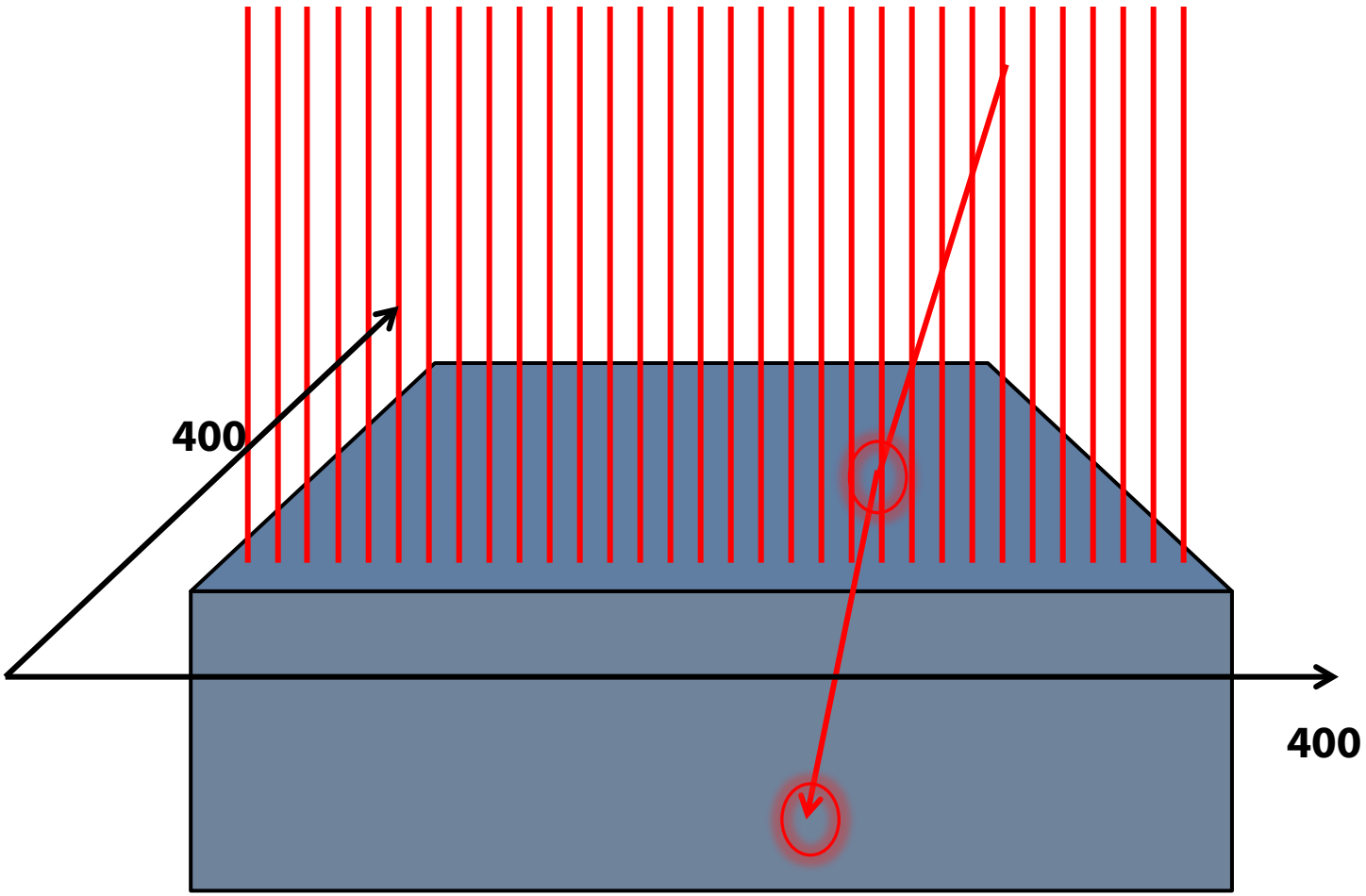


$$f[x\_] := x + \left(h + \frac{a}{2} + \frac{a}{2} * \text{Cos}\left[\text{Pi} * \frac{x}{l}\right]\right) \left(\text{Tan}\left[\text{Pi}/4 - \text{ArcTan}\left[-a * \frac{\text{Pi}}{2 * l} * \text{Sin}\left[\text{Pi} * \frac{x}{l}\right]\right]\right] - \text{ArcSin}\left[\frac{n1}{n2} * \text{Sin}\left[\text{Pi}/4 - \text{ArcTan}\left[-a * \frac{\text{Pi}}{2 * l} * \text{Sin}\left[\text{Pi} * \frac{x}{l}\right]\right]\right]\right]\right)$$

Velocity of Ejected Light

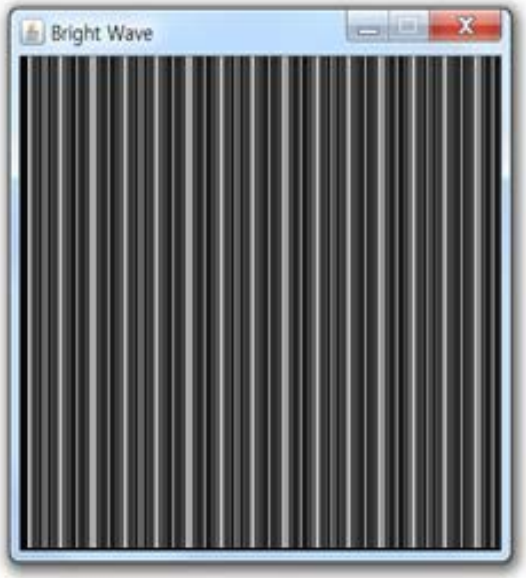


Visualization – Numerical Solution

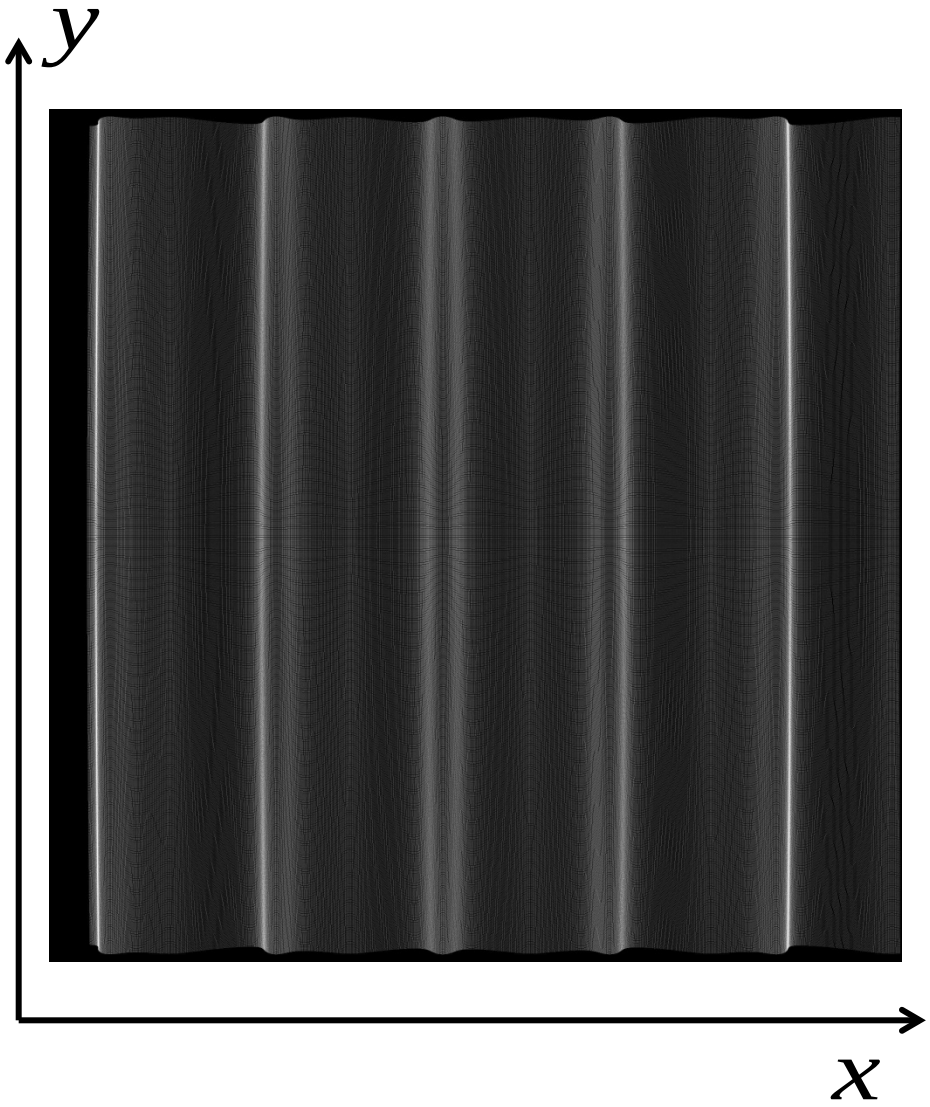


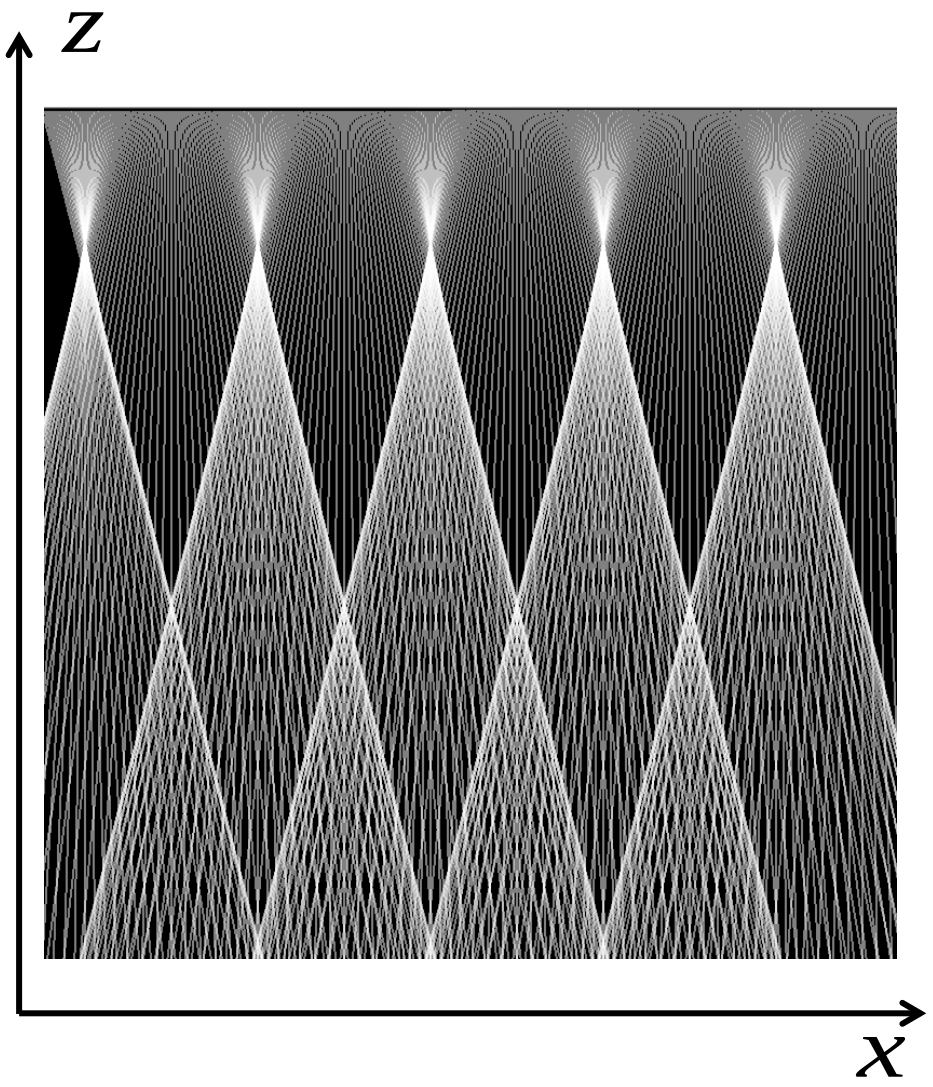
Simulation – Pattern Drawing

```
import java.awt.Canvas;
import java.awt.Color;
import java.awt.Container;
import java.awt.Graphics;
import java.awt.Graphics2D;
import java.awt.image.BufferedImage;
import java.io.File;
import java.io.IOException;

import javax.imageio.ImageIO;
import javax.swing.JFrame;
import javax.vecmath.Vector3d;

public class BrightWave extends Canvas{

    private final double nn = 1.33;
    private final double nnn= 1.59;

    private static int sizeX = 1000;
    private static int sizeY = 1000;


    private int NX = 300;
    private int NY = 300;
    private double kX =30;
    private double kY = 2;
    private double ampX = 1.2;
    private double ampY = 0;
    private double piX = 0;
    private double piY = 0;


    private Vector3d l = new Vector3d(0.01,0.01,-1);

    private boolean isPointSource = true;
    private Vector3d pointLight = new Vector3d(150,150,935);

    private static int depth =130;//800*4/7;
    // depth >=  0 : Caustics at the specific depth
    // depth == -1 : animation from initial depth to final depth
    // depth == -2 : Graph using depth as a y axis

    private boolean isGlass = true;
    private double thickness = 8;

    public static int real_sizeX = 1000;//sizeX;
    public static int real_sizeY = 1000;//sizeY;
    public static double inital_x=(real_sizeX-sizeX)/2;
```

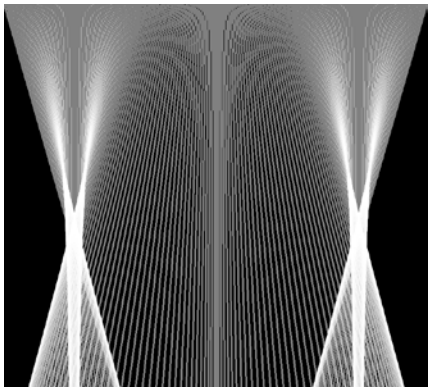


Simulation Results

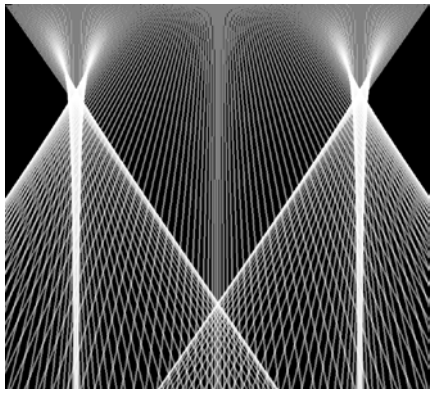




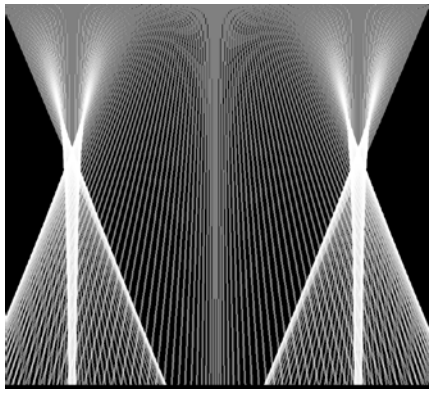
Lens Approximation for Surface Waves



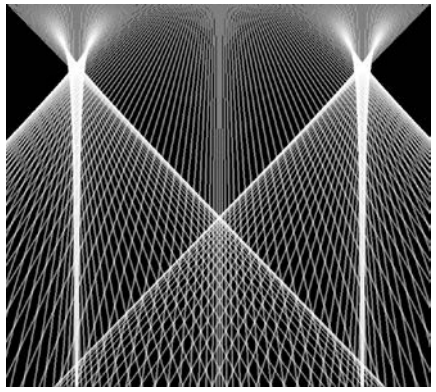
Amplitude: 7



Amplitude: 11

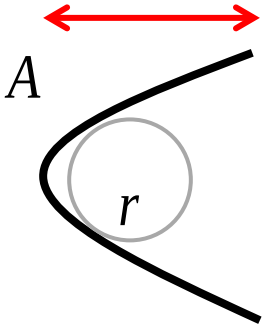


Amplitude: 9



Amplitude: 13

Amplitude and Curvature



Focal Length Decrease

Presentation Flowchart

Theory

- Water Surface Modeling
- Light Flux Density
- Refraction

↓

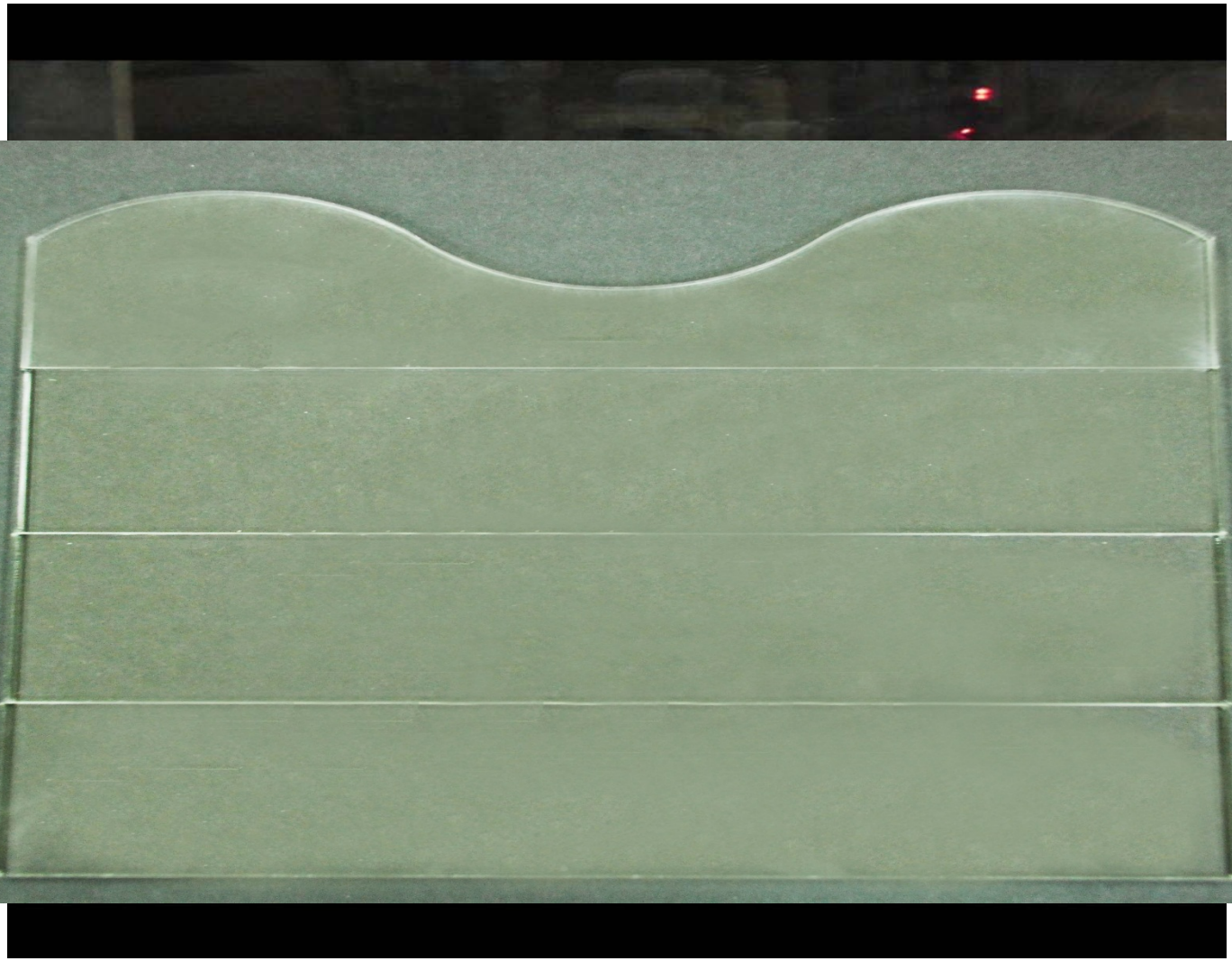
- Analytical Prediction
- Numerical Simulation
- Lens Approximation

Experiment

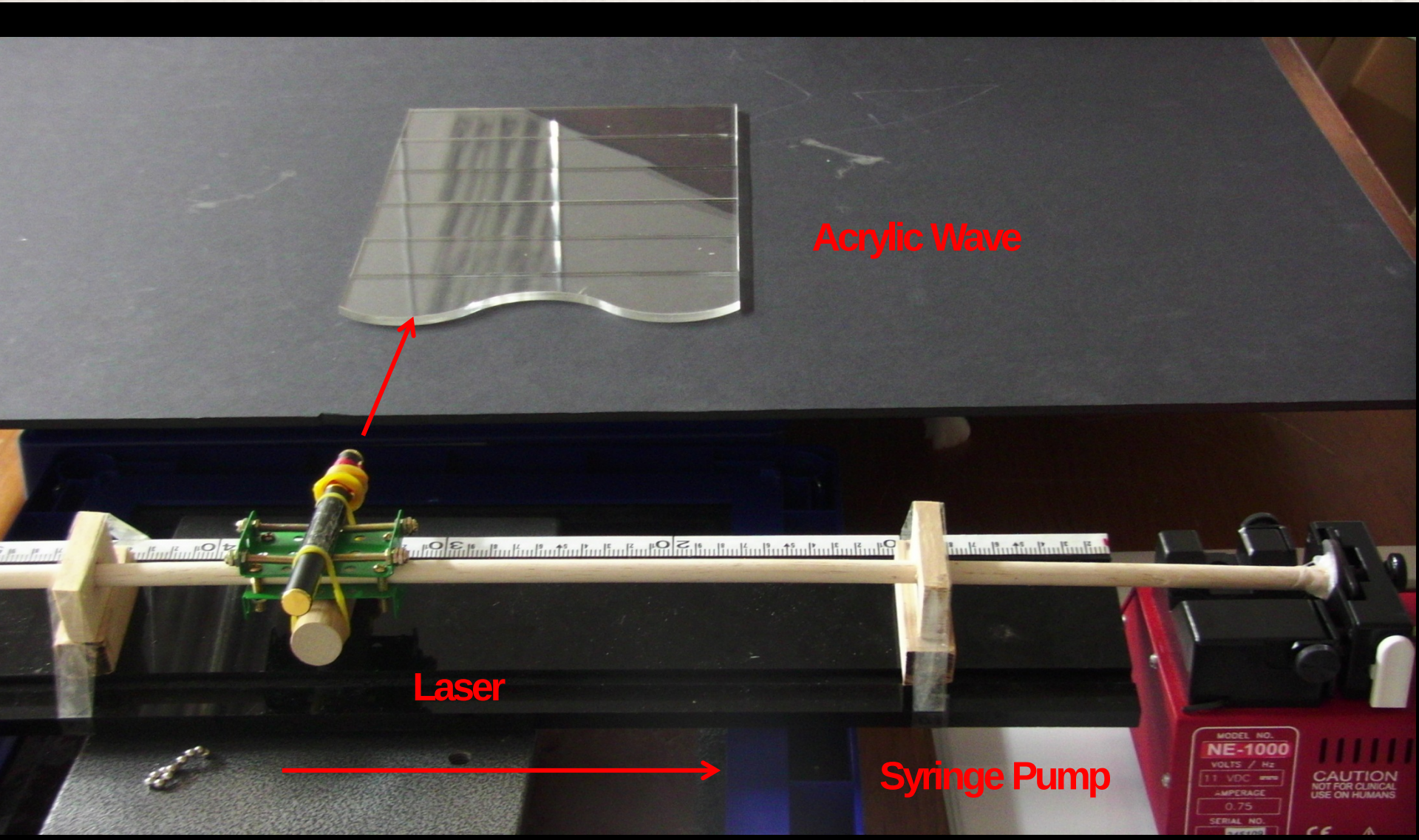
Conclusion

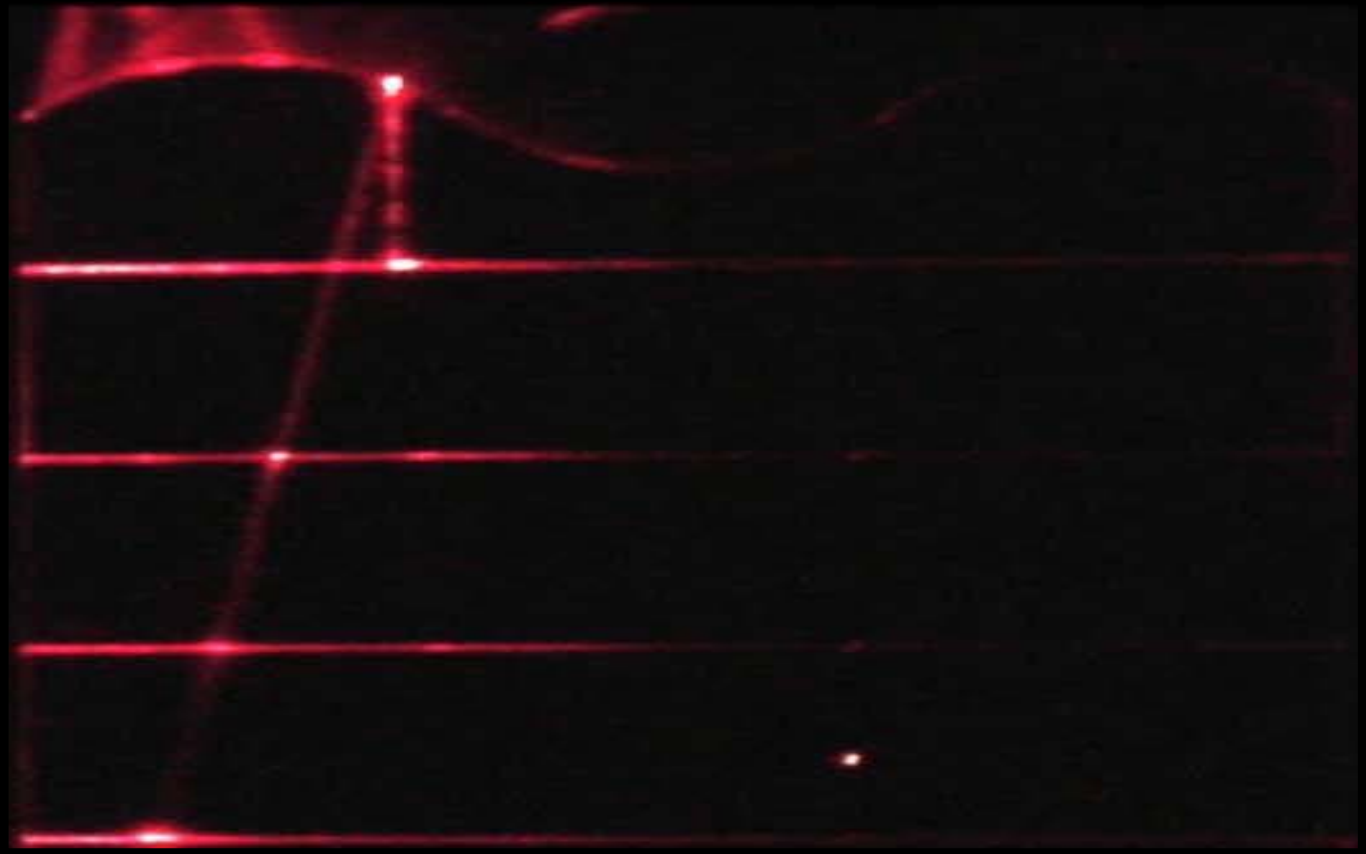
Experiment

Initial Experiment - Observation

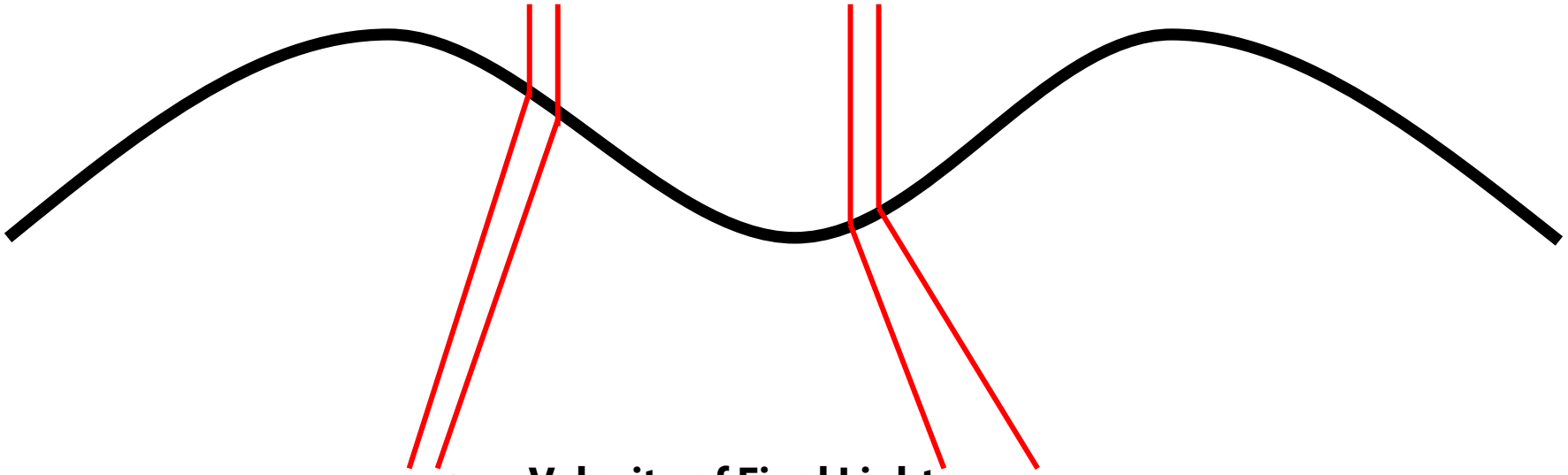


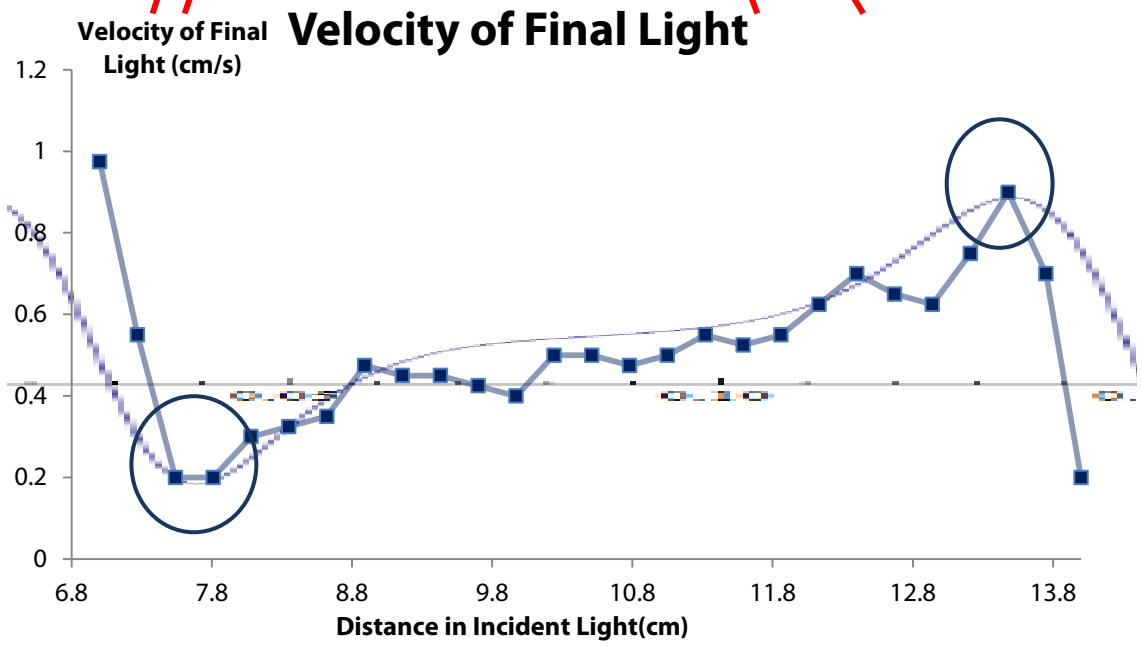
Experiment – Refraction of Waves





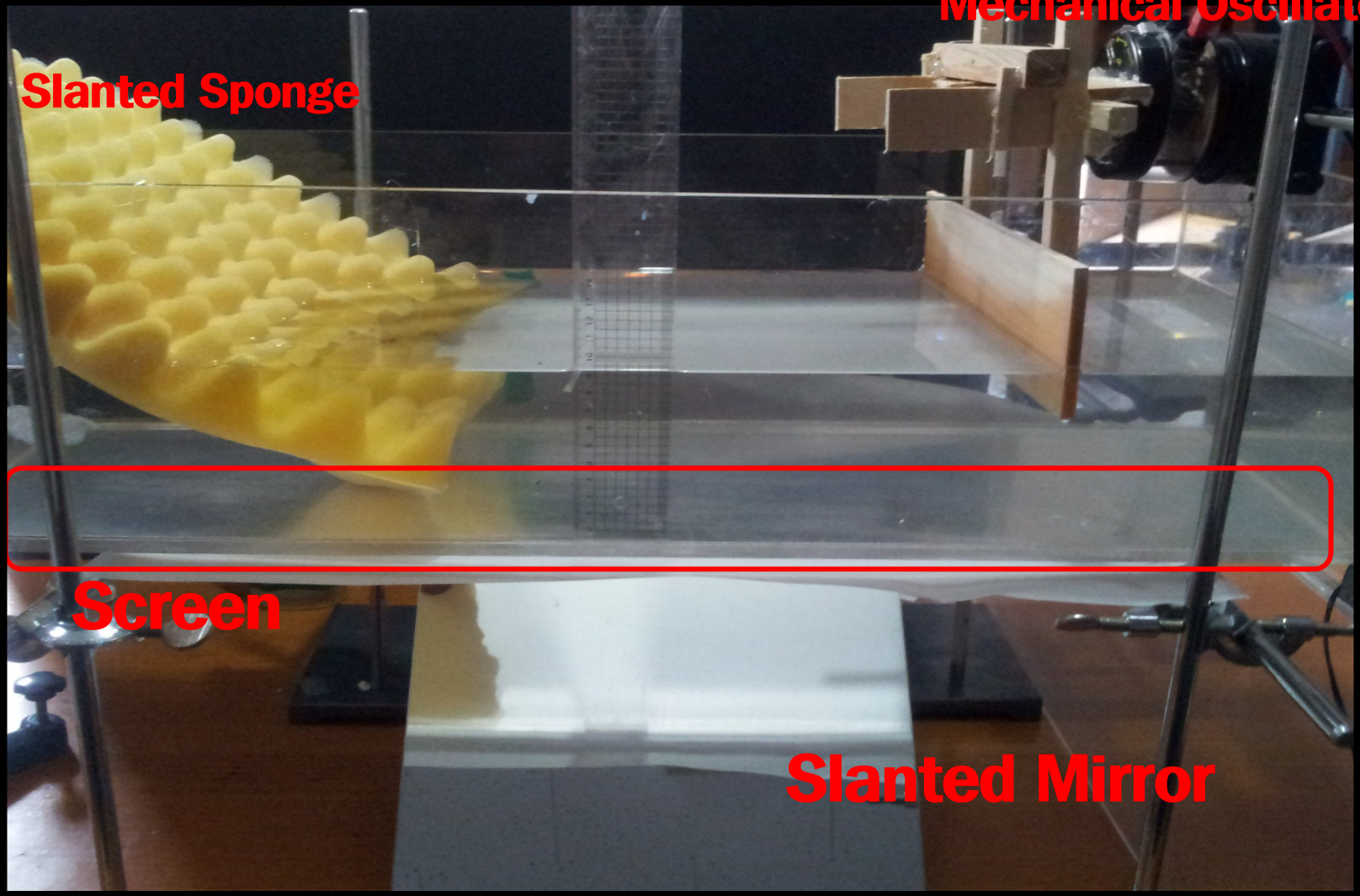
Experiment – Refraction of Waves



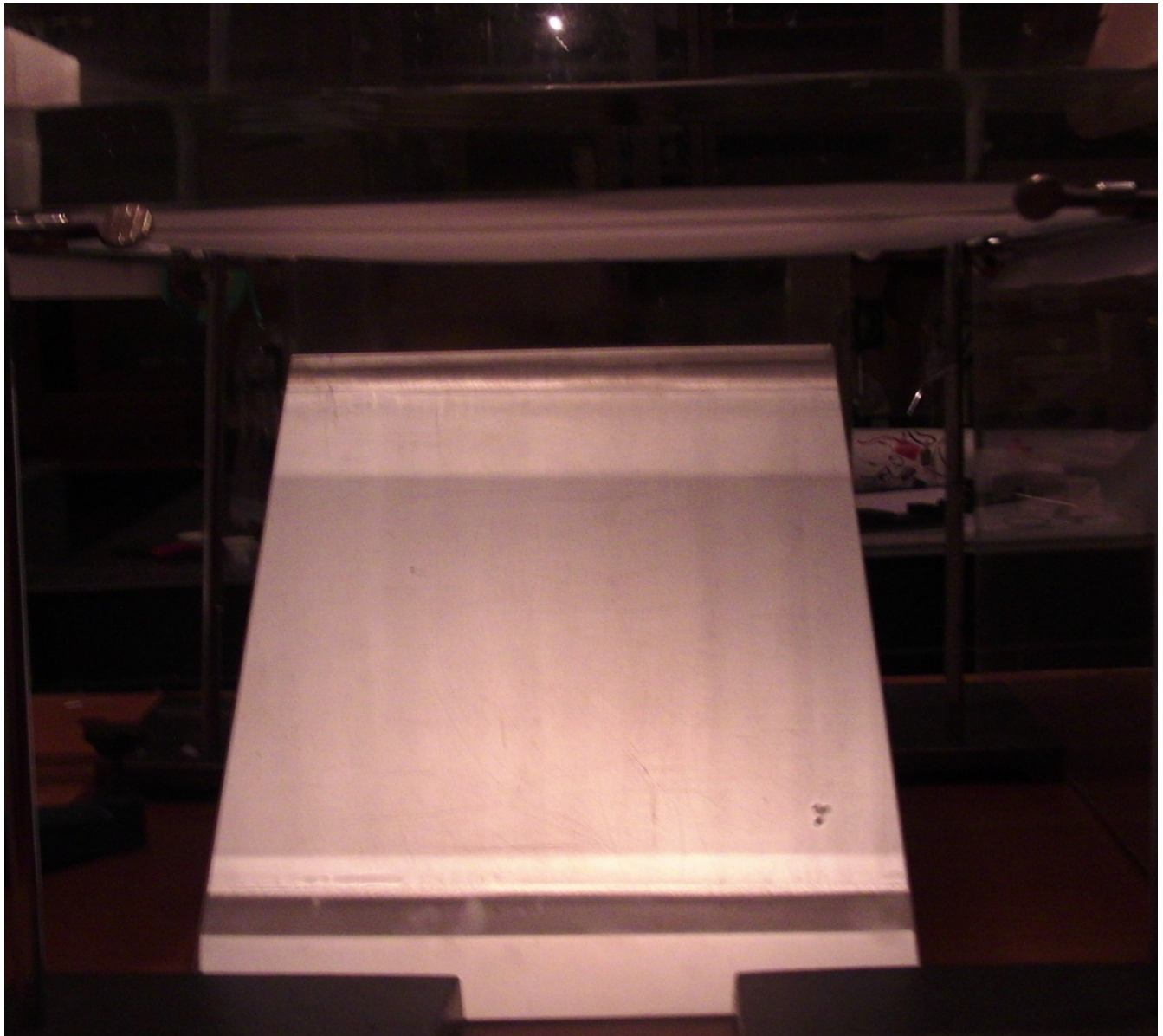


Experiment in Water

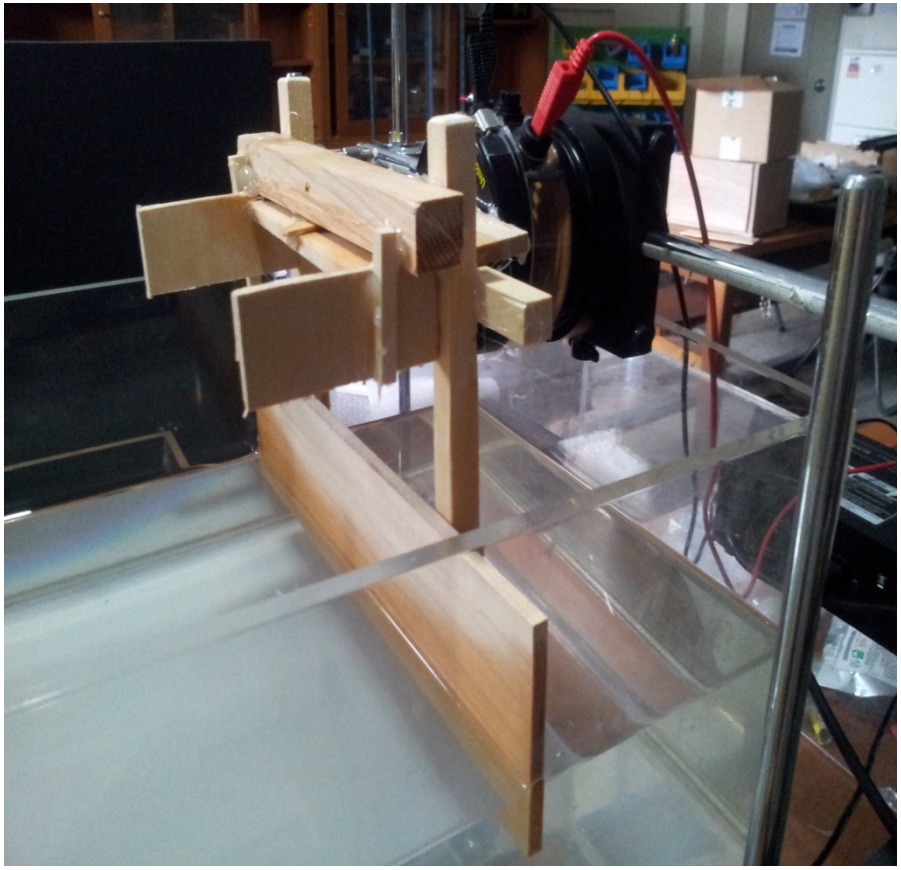
Experiment Setting – Water



Experiment Setting – Slanted Mirror



Experiment Setting



Wave Generator

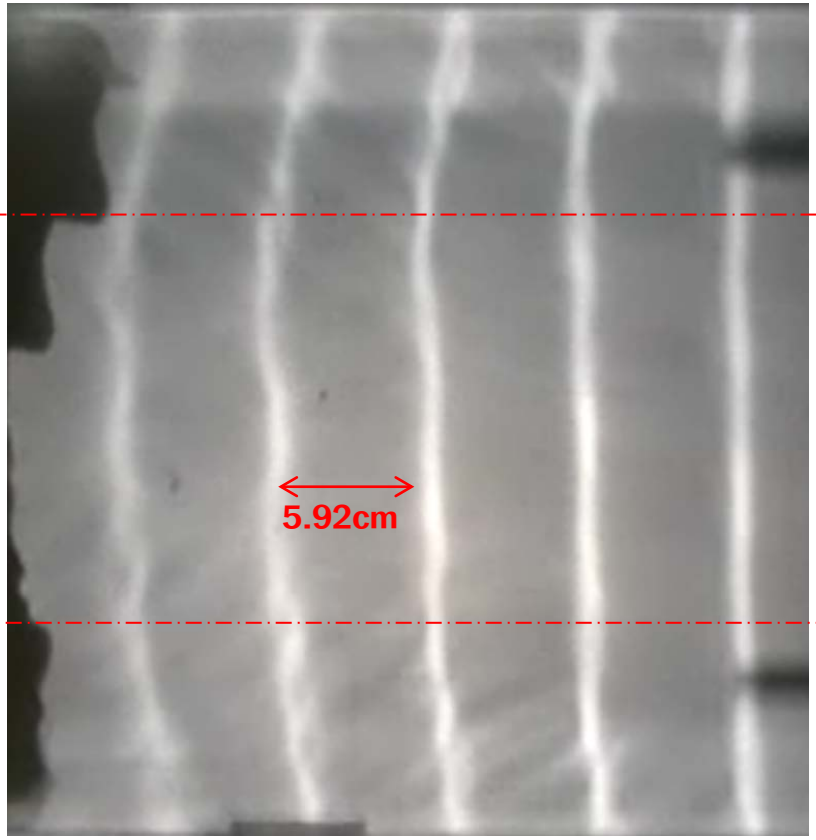
(Horizontal Push)

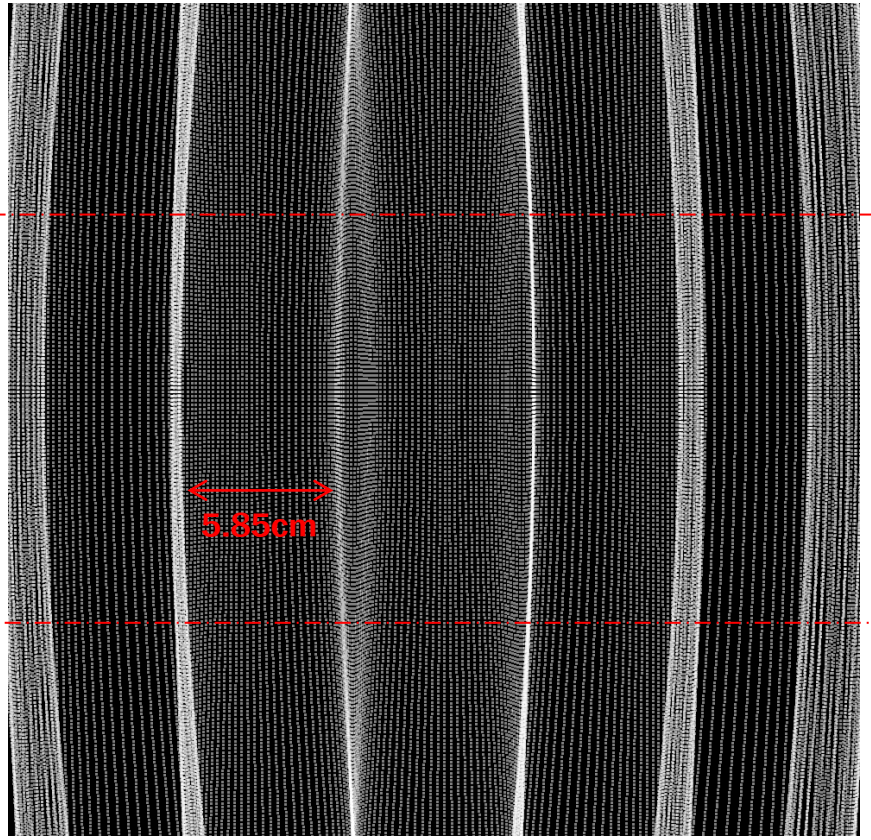
Spherical light source

(point source)

Simulation vs. Observed Waves

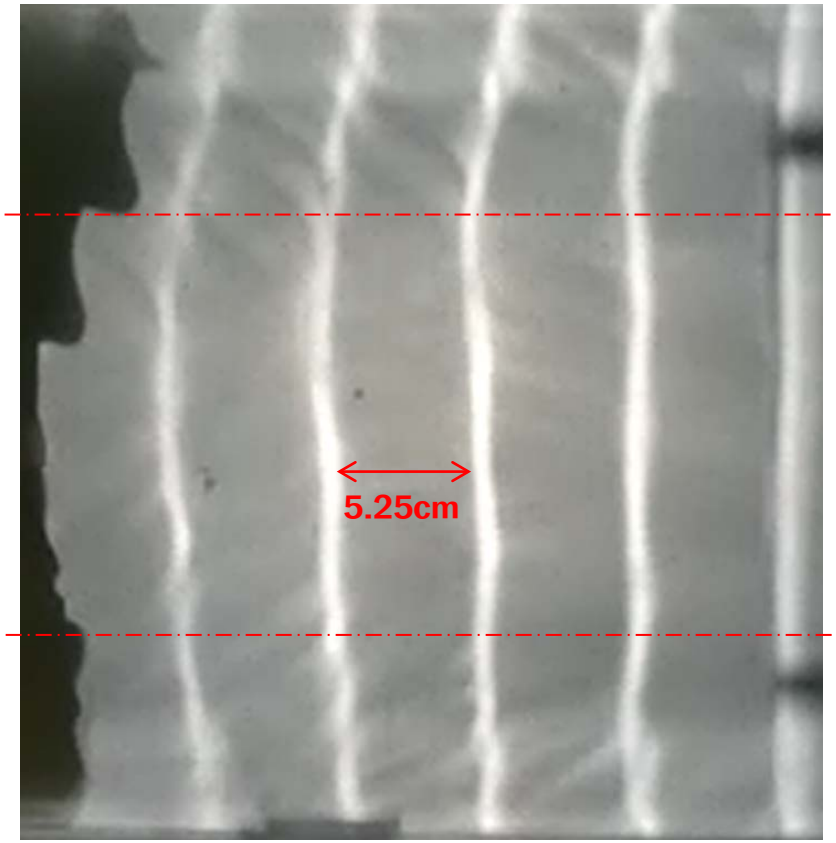
Surface Wave: Amplitude 3.2mm, Wavelength 42.9mm (Incoherent)

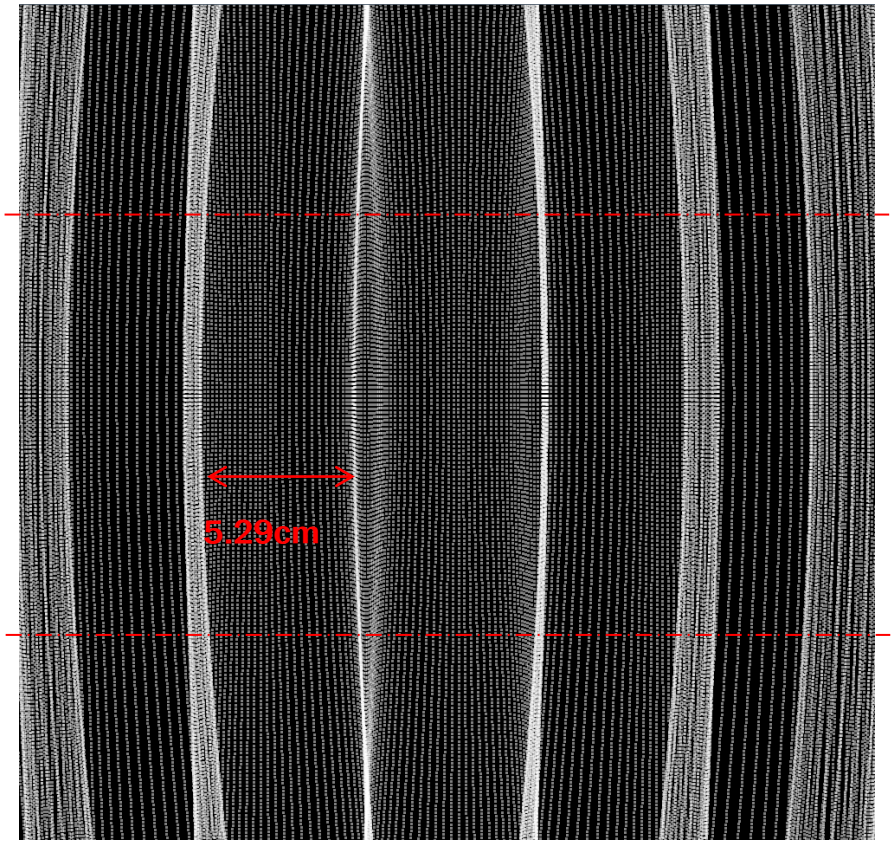




Simulation vs. Observed Waves

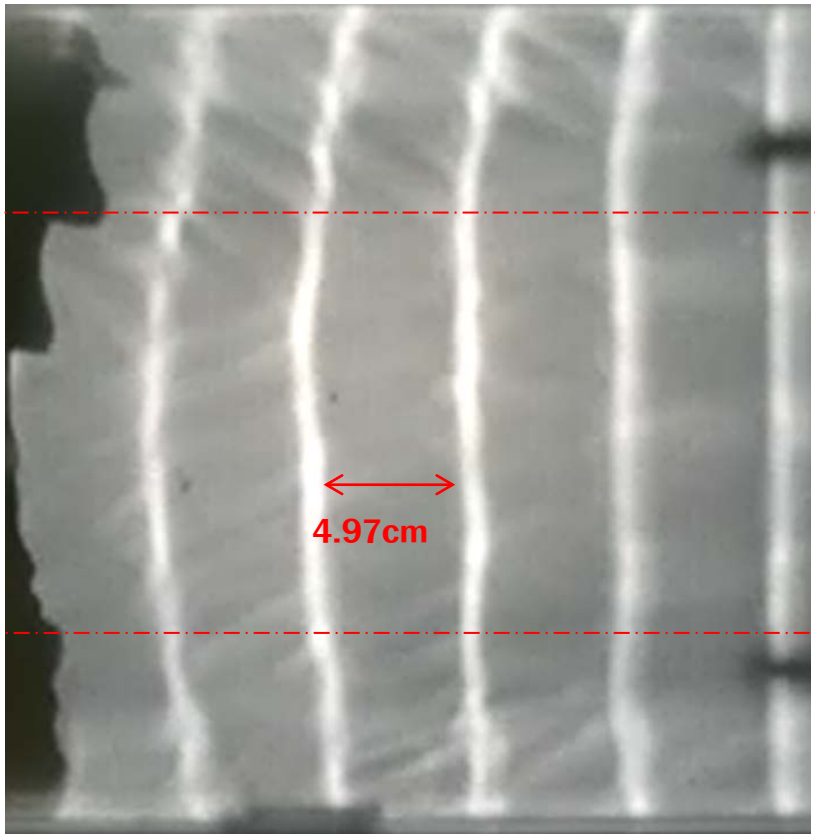
Surface Wave: Amplitude 3.6mm, Wavelength 42.9mm (Incoherent)

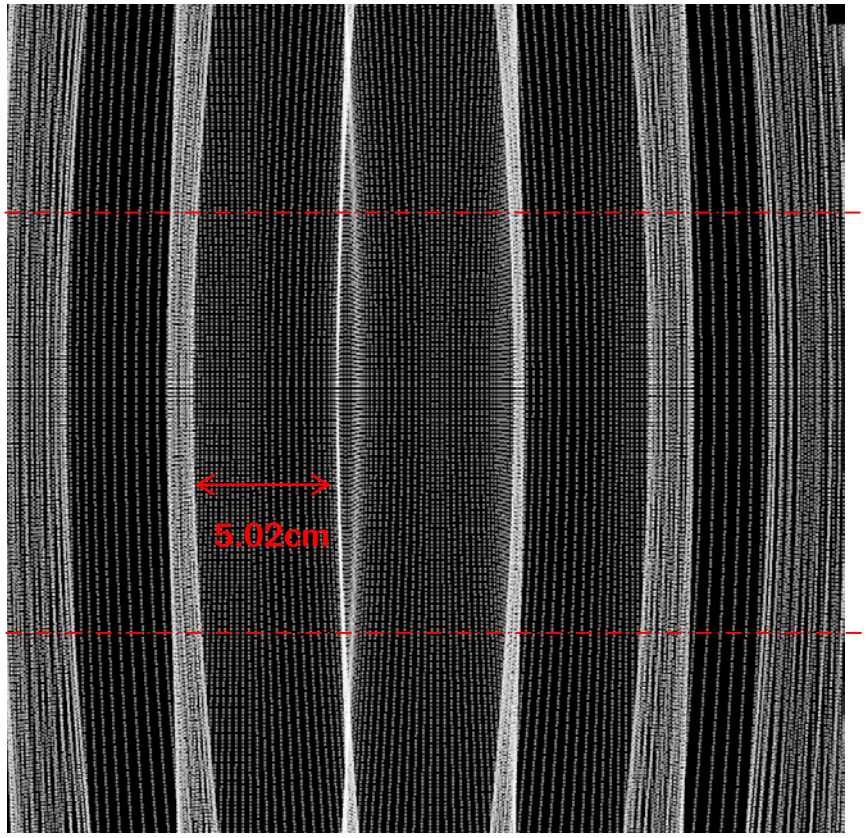




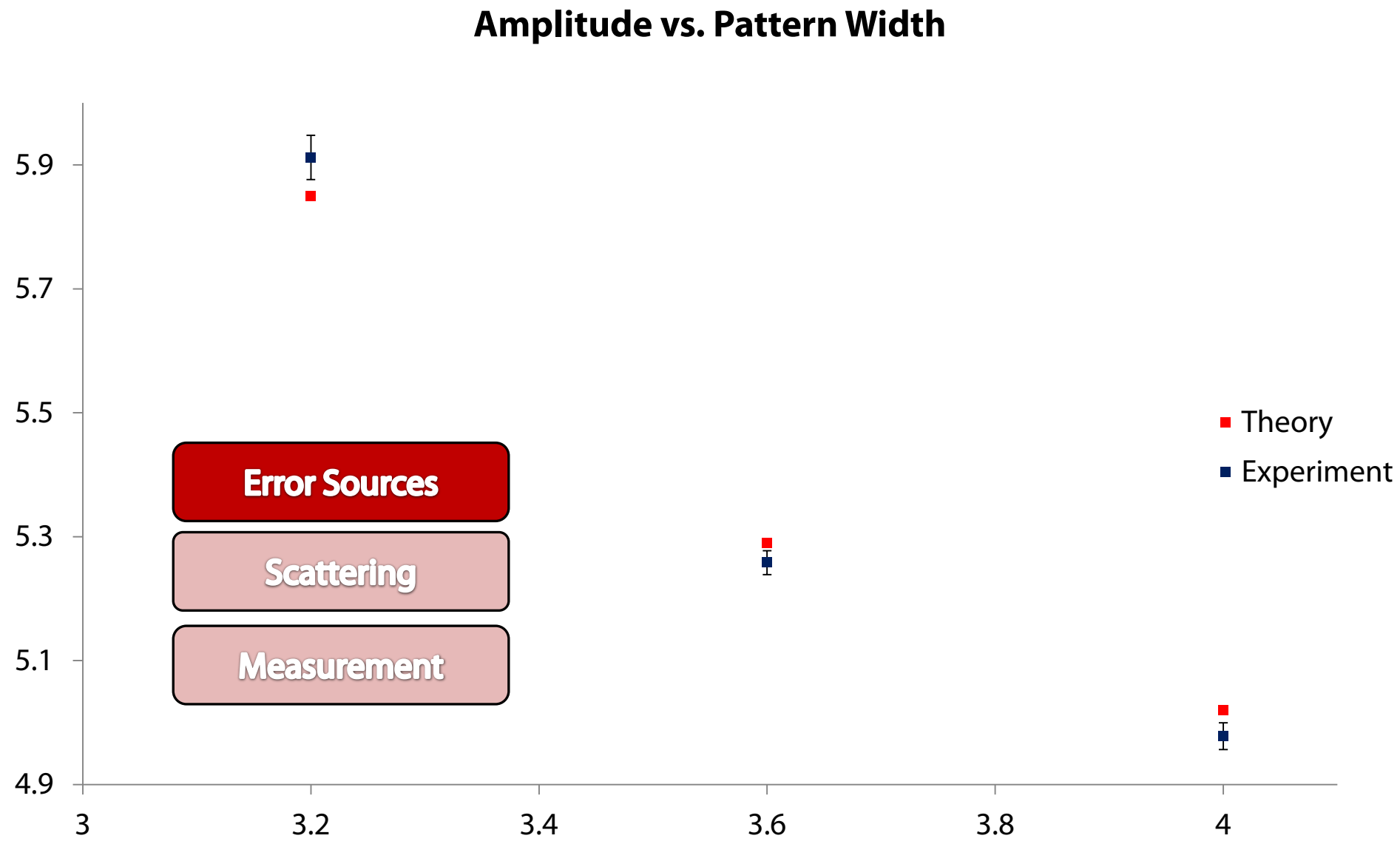
Simulation vs. Observed Waves

Surface Wave: Amplitude 4.0mm, Wavelength 42.9mm (Incoherent)

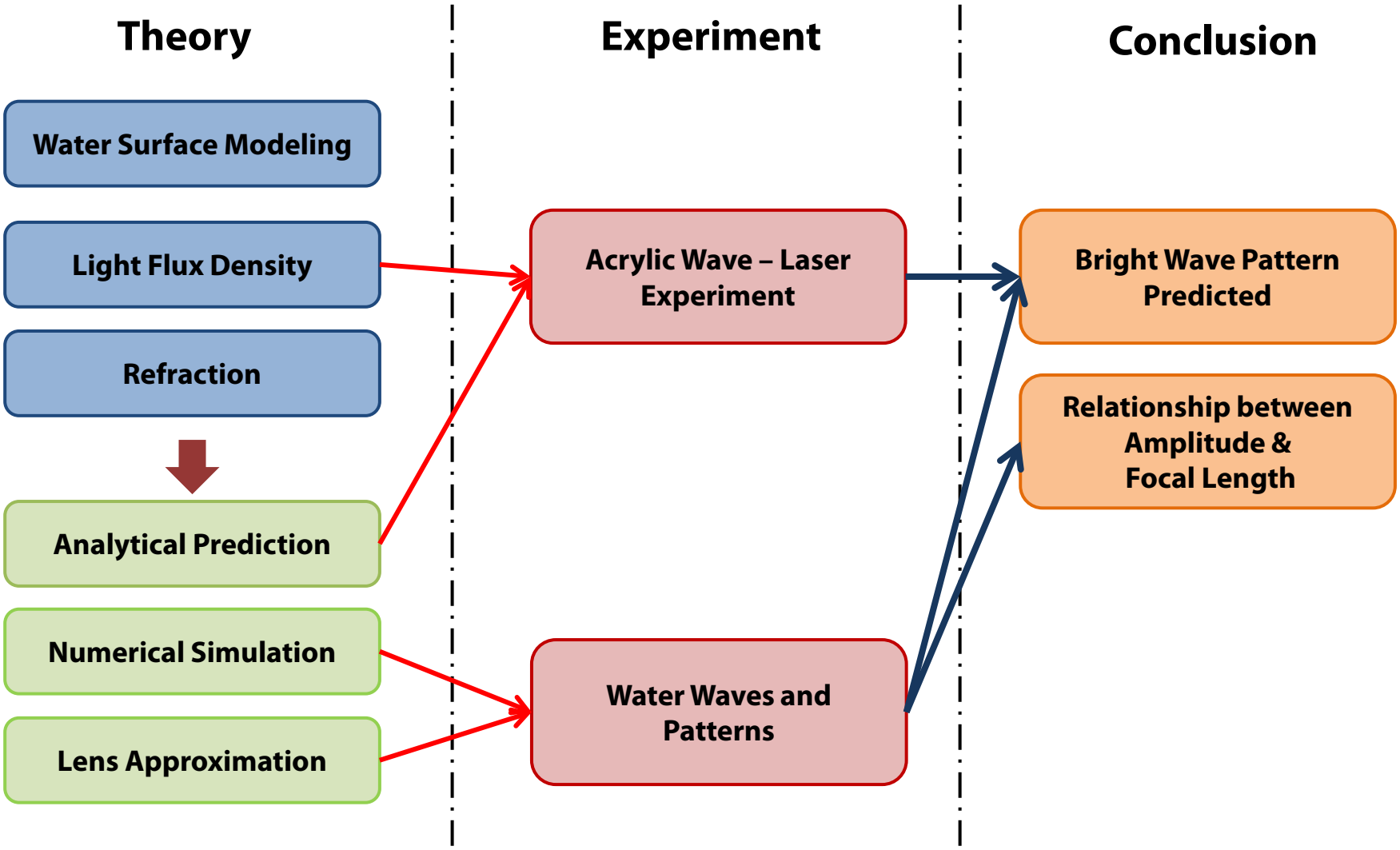




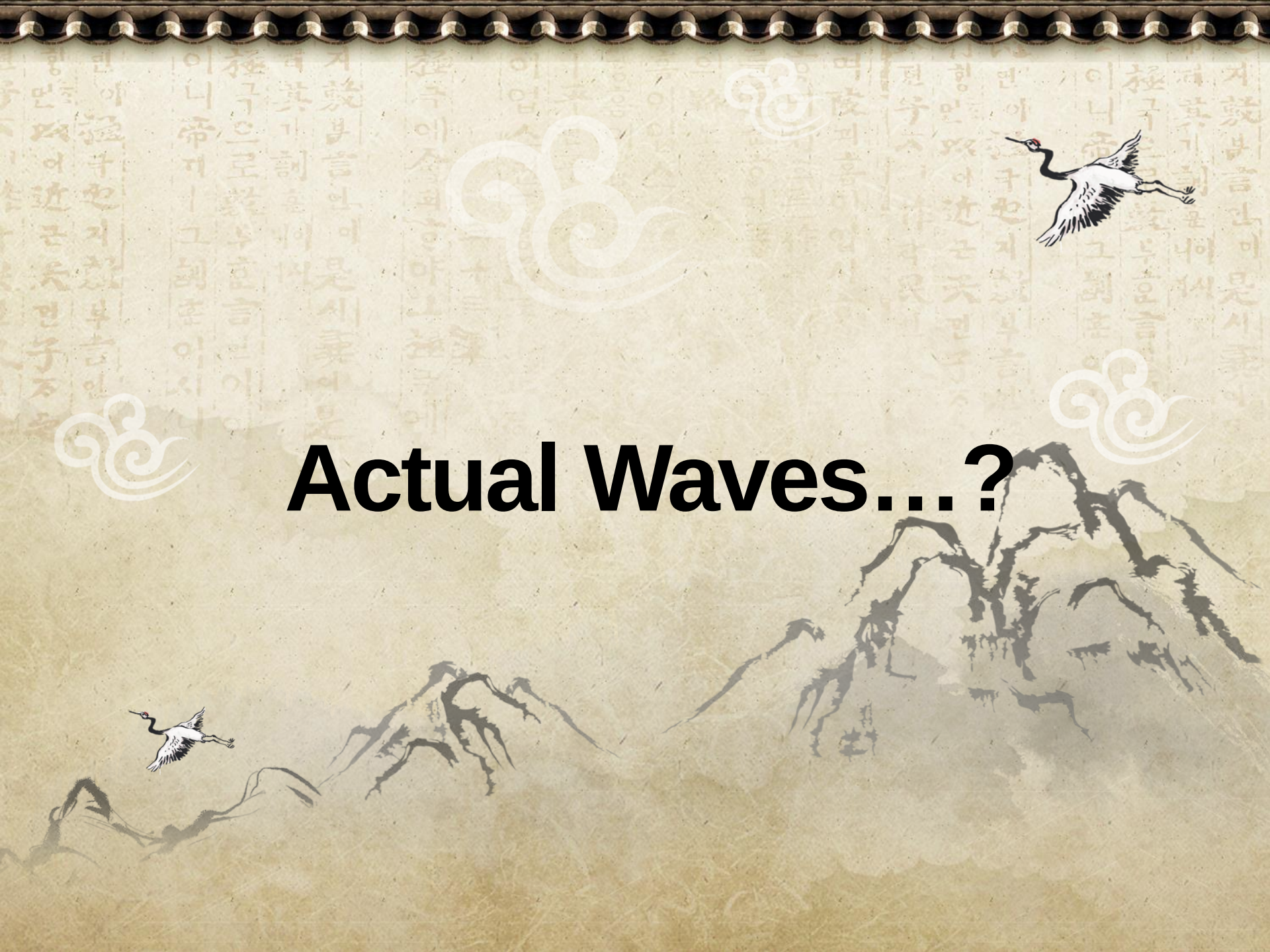
Simulation vs. Observed Waves



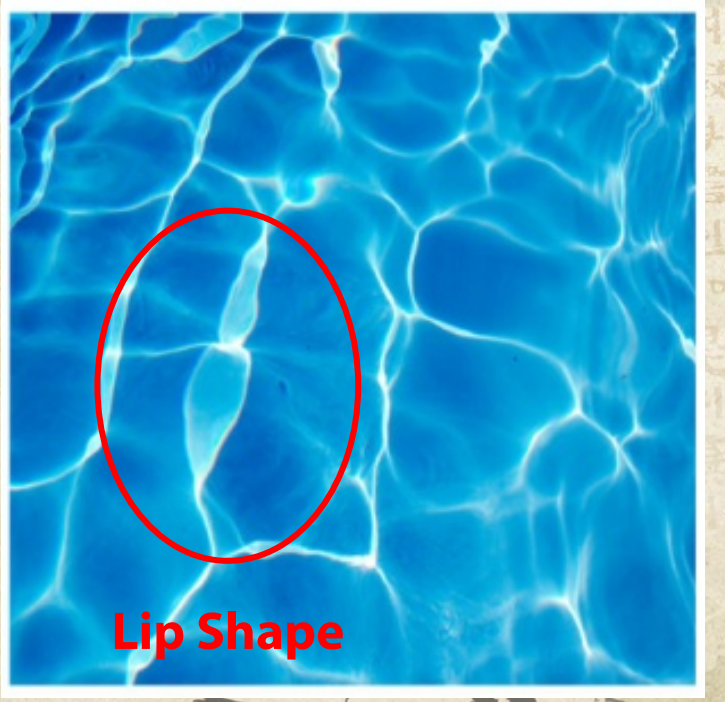
Presentation Flowchart



Actual Waves…?



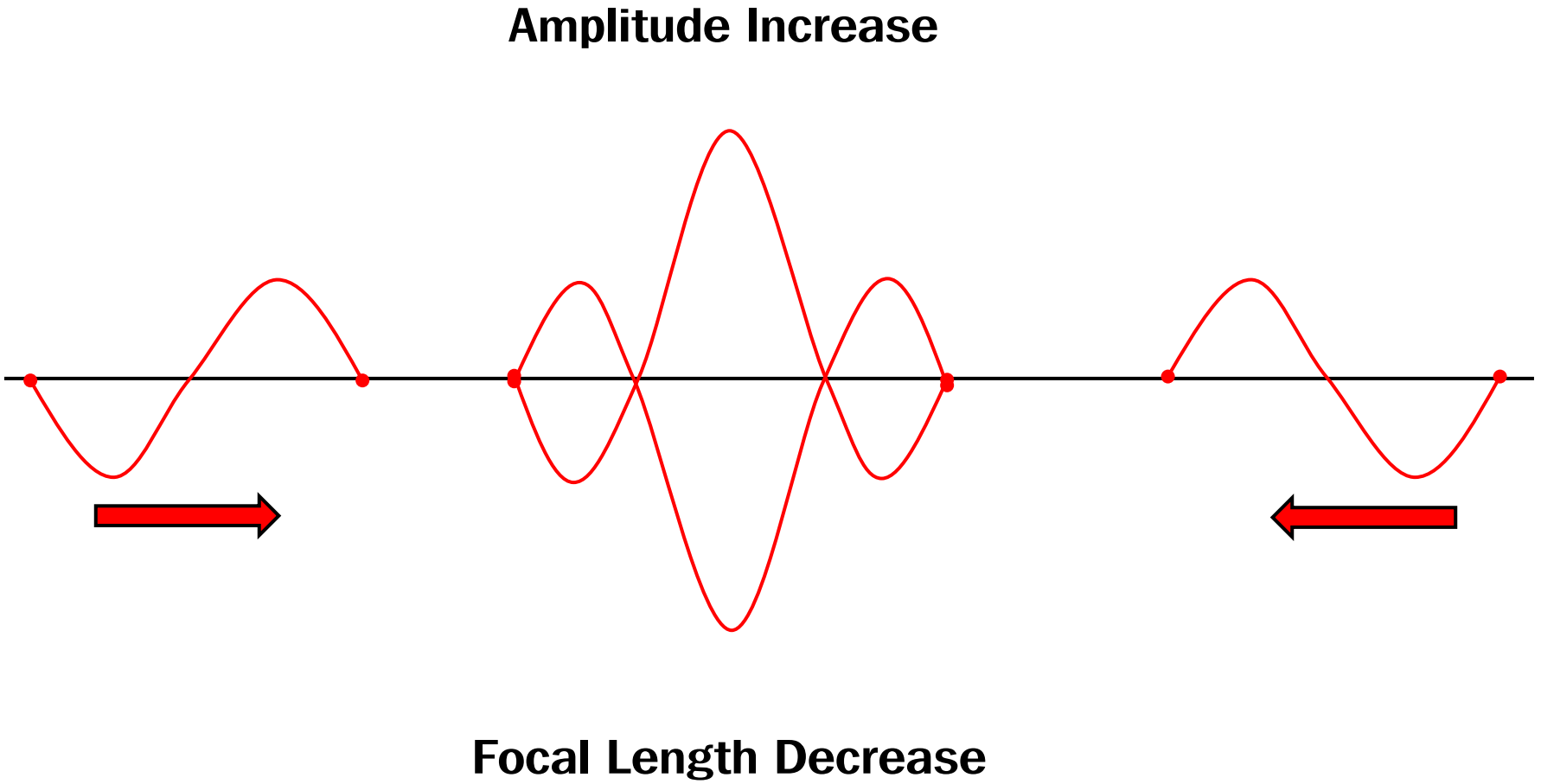
Actual Waves
Different Phenomenon



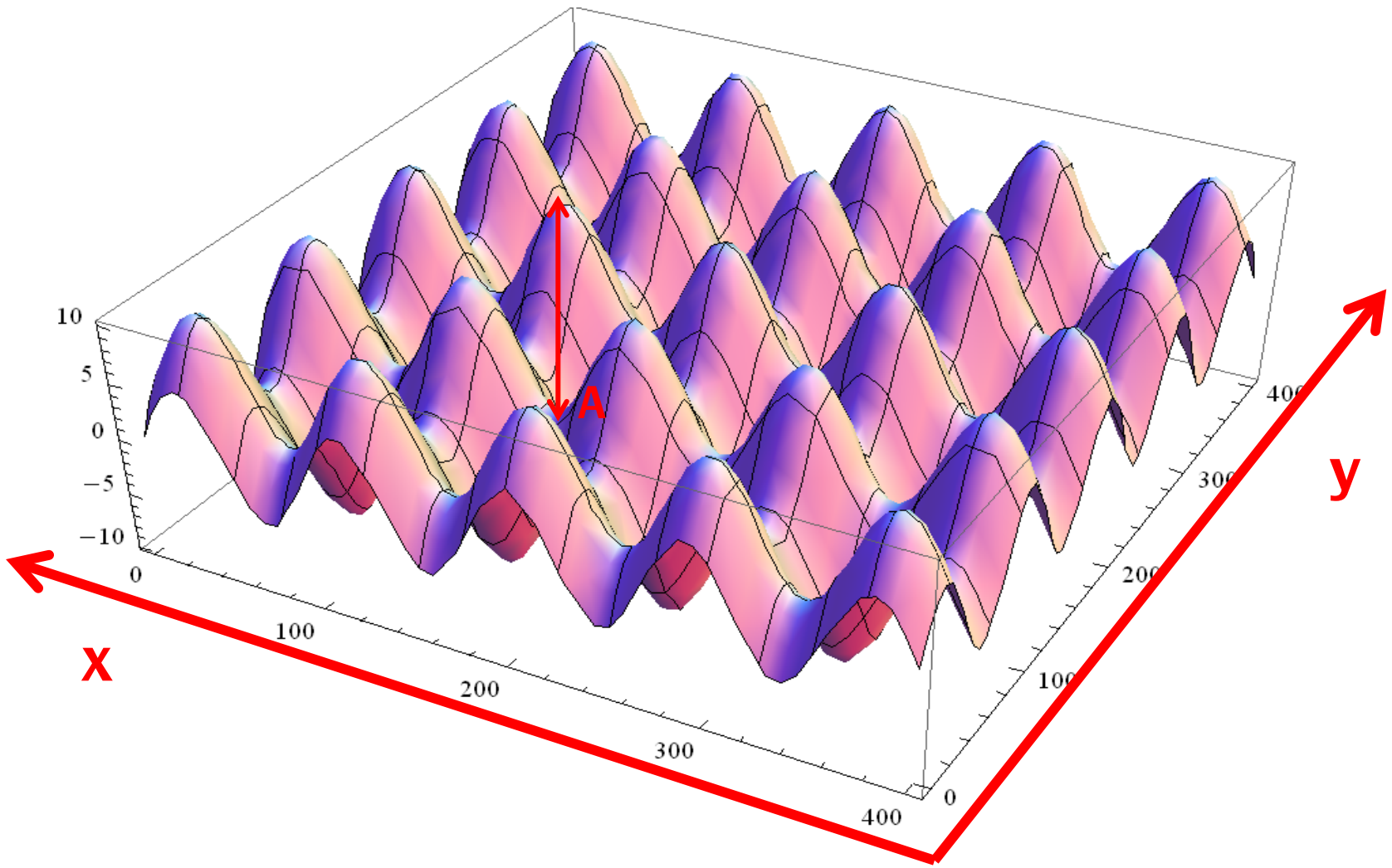
http://www.shutterstock.com/pic-3965908/stock-photo-water-waves.html

http://www.google.ca/imgres?imgurl=http://imaginezambia.org/wp-content/uploads/splash-water-waves-4565.jpg&imgrefurl=http://imaginezambia.org/2476/training-workshop-moringa-propogation-teams-quick-update/splash-water-waves-4565/&usg=__ouoxefwUL0whvrDUOOQBnp3NR40=&h=324&w=620&sz=42&hl=ko&start=17&zoom=1&tbnid=zsBhBUfaehuTBM:&tbnh=71&tbnw=136&ei=84LyT9G2NcWjiAfnn_C6Aw&prev=/search%3Fq%3Dwater%2Bwaves%26um%3D1%26hl%3Dko%26tbm%3Disch&um=1&itbs=1

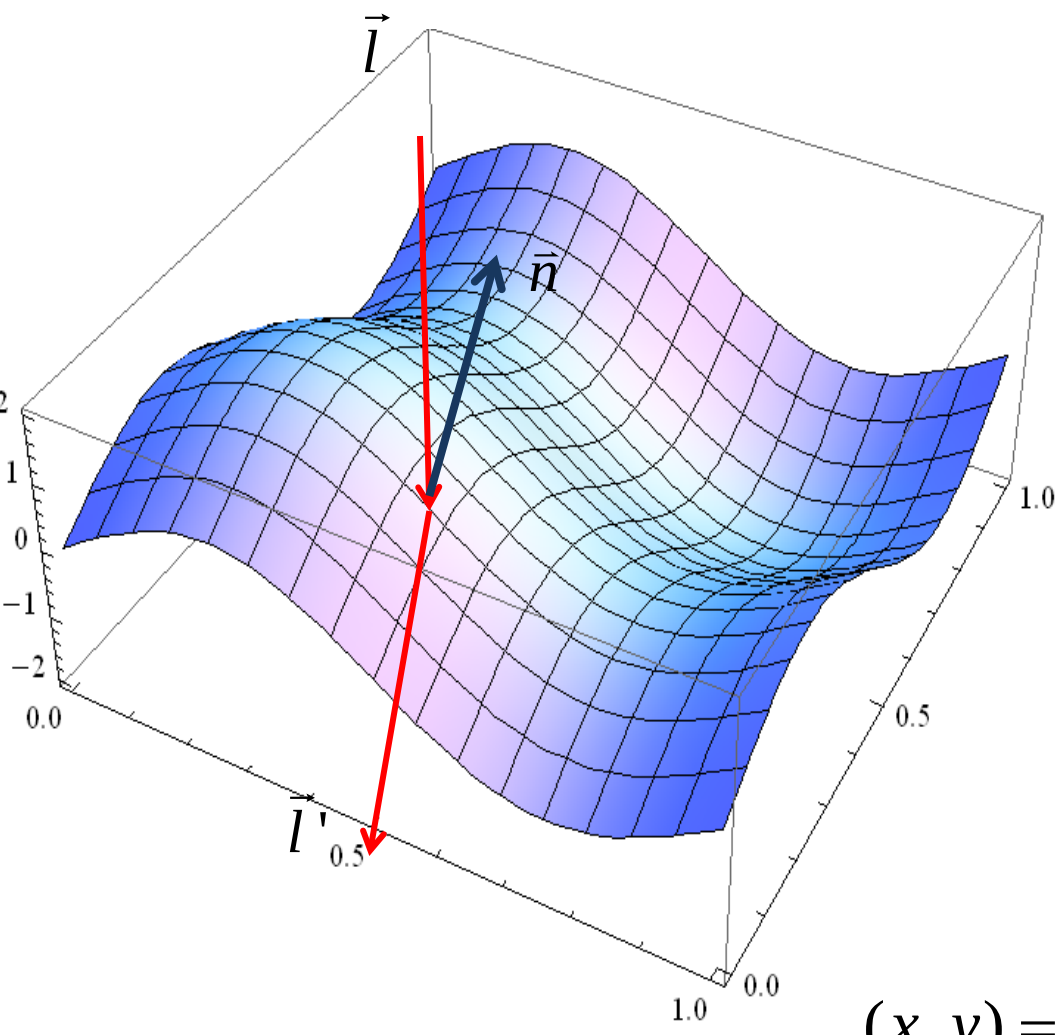
Interference Waves – Amplitude Increase



Interference Waves – 3D



Water Surface and Refraction 3D



$$z = h + f(x, y)$$

$$\vec{n} = (\frac{\partial f}{\partial x}, \frac{\partial f}{\partial y}, -1)$$

Snell's Law

$$n_1 \sin(\frac{\vec{n} \cdot \vec{l}}{|\vec{n}||\vec{l}|}) = n_2 \sin(\frac{(-\vec{n}) \cdot \vec{l}`}{|\vec{n}||\vec{l}`|})$$

Normalization

$$|l| = |l`|$$

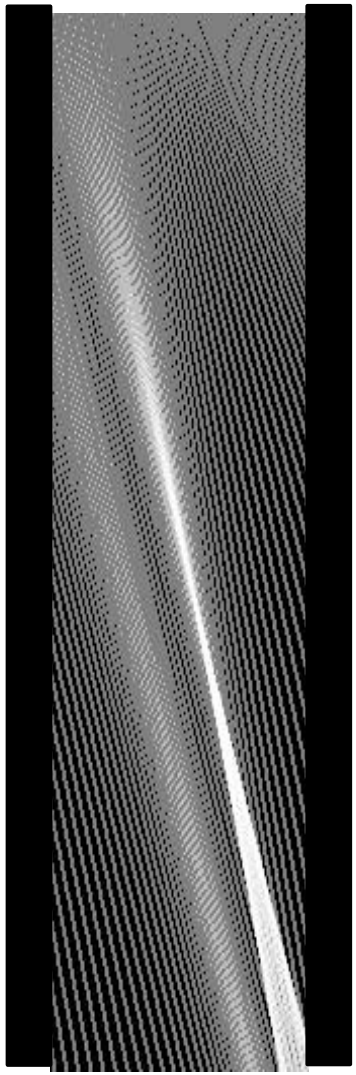
Same Plane Condition

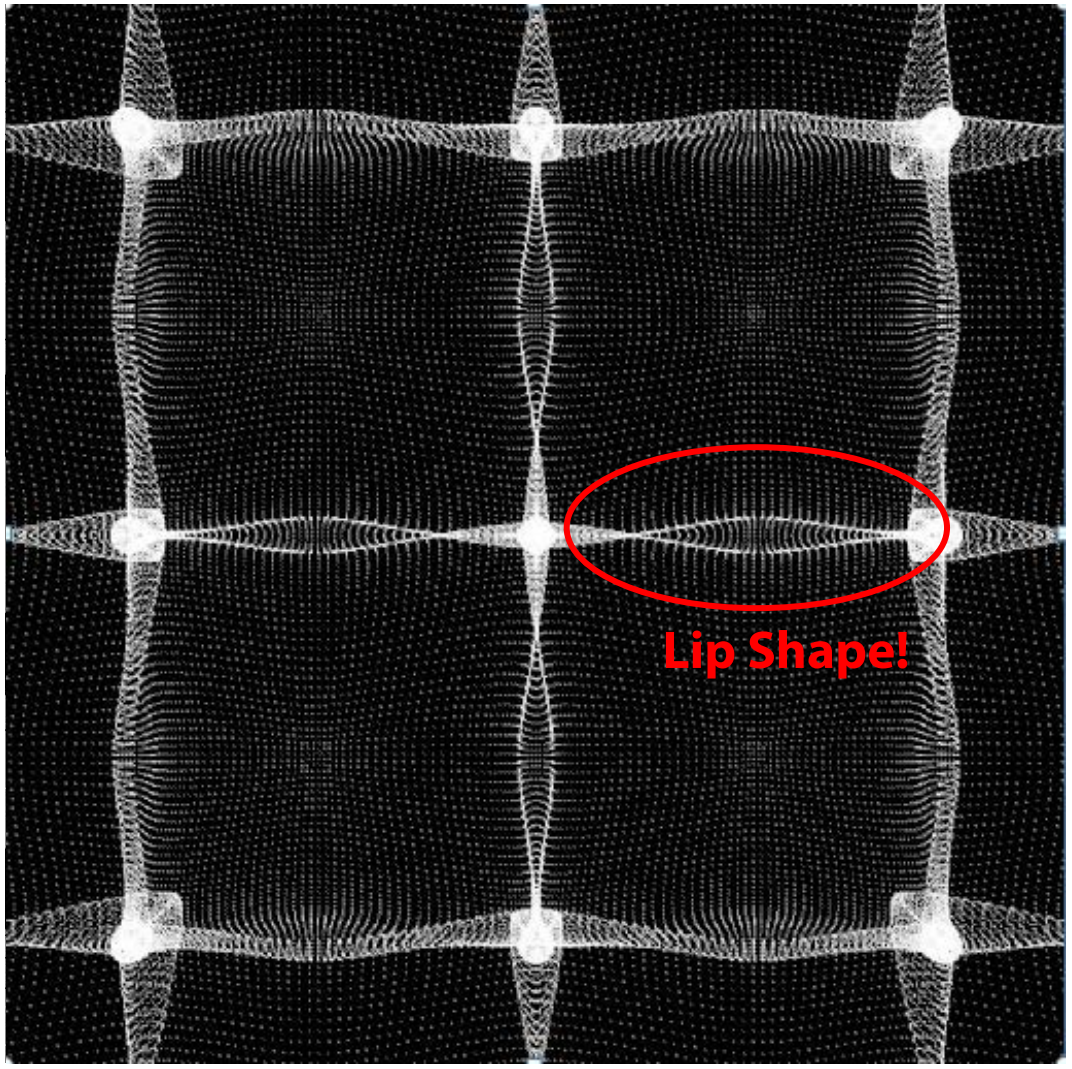
$$\vec{l} \times \vec{n} = \vec{n} \times \vec{l}`$$

$$(x, y) = (\frac{z + f(x, y)}{l`_z} l`_x, \frac{z + f(x, y)}{l`_z} l`_y)$$

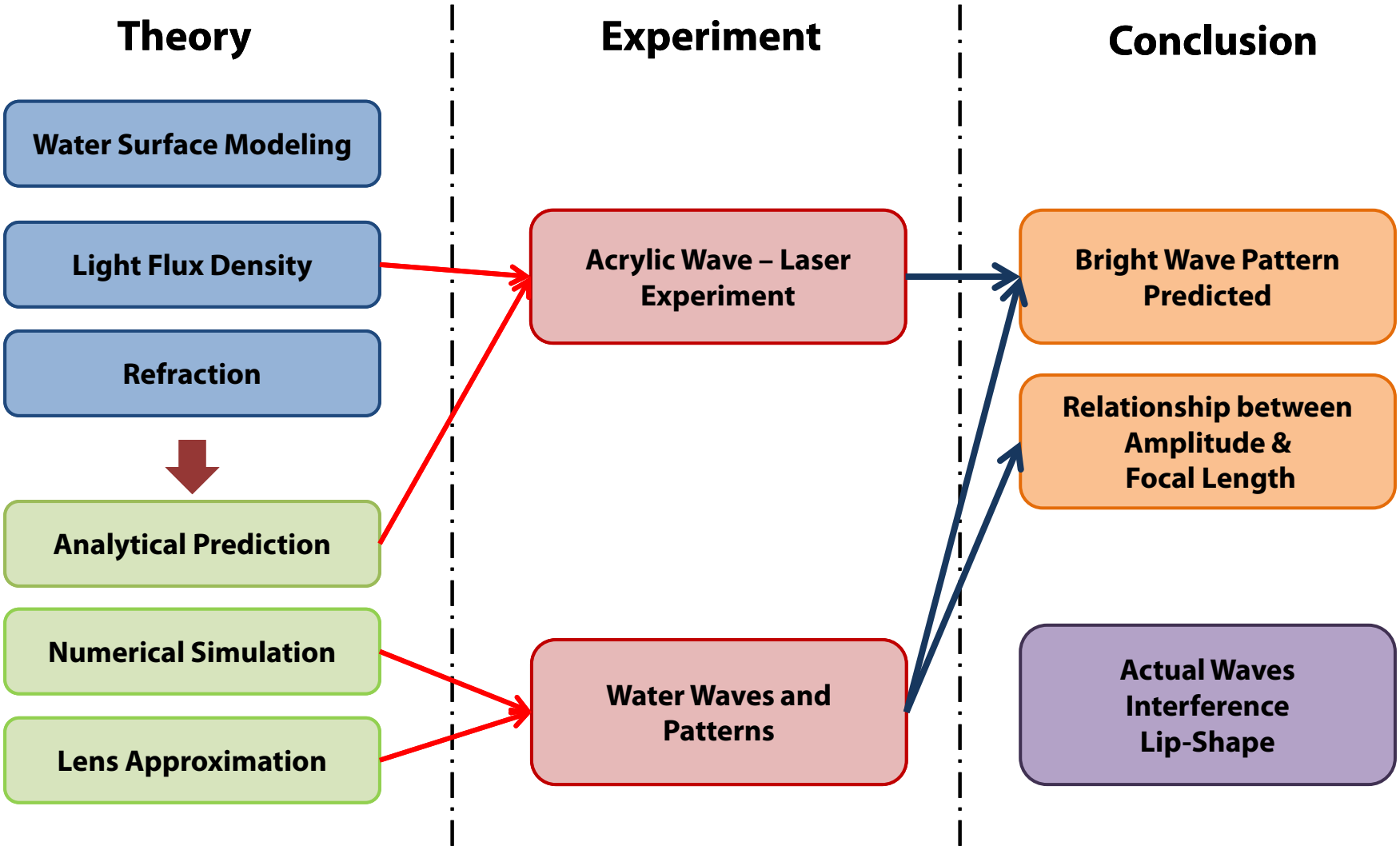
Focal Length Control – Lip Shape!

Depth Increase



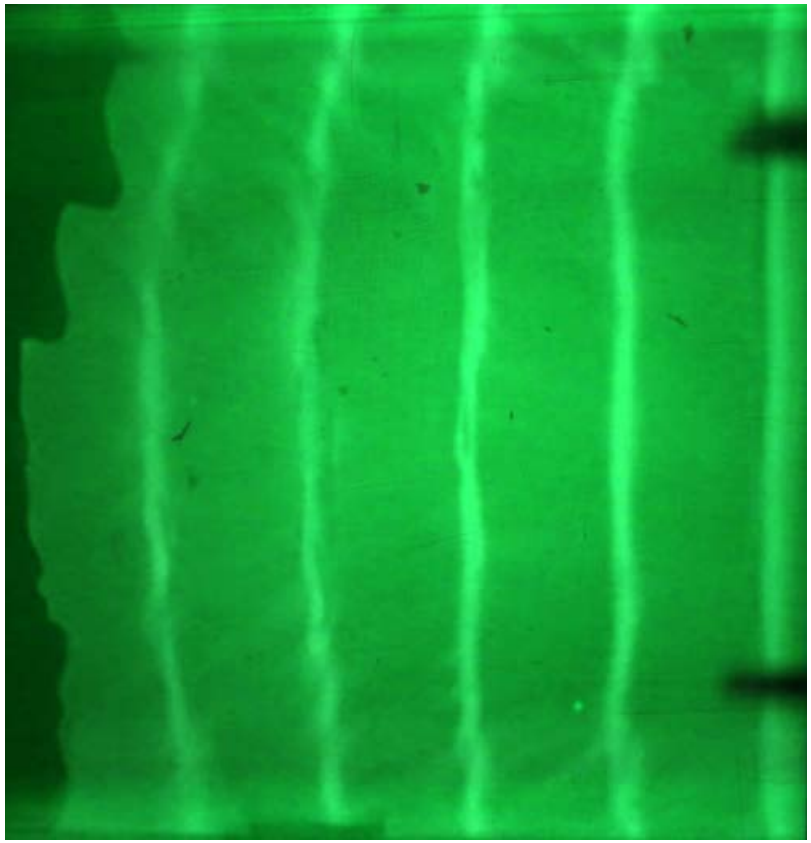


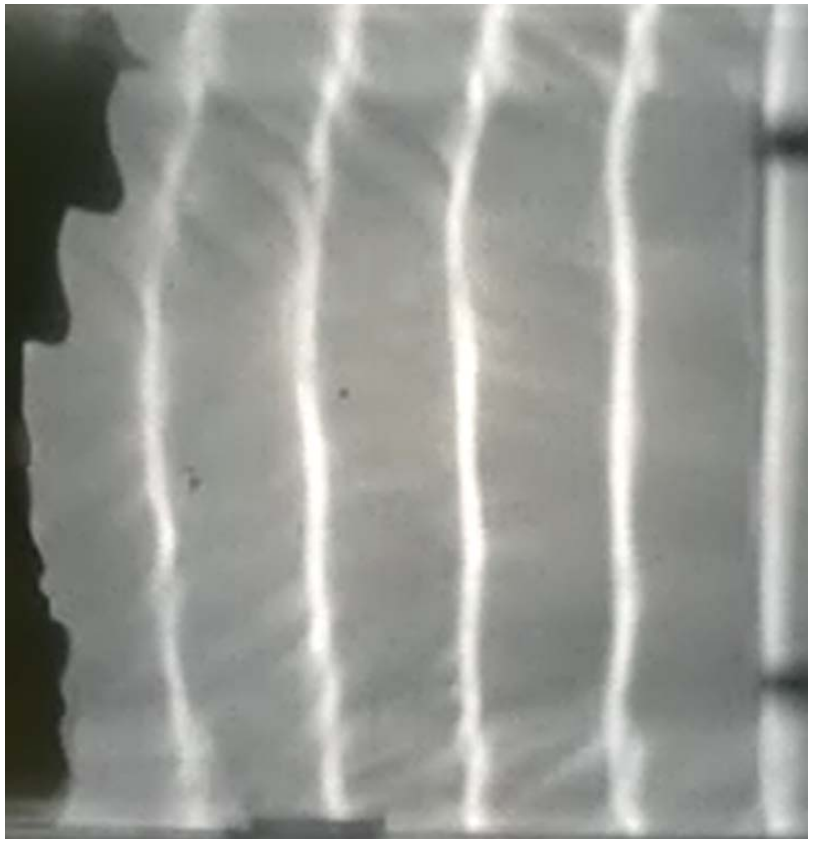
Conclusion


Theory
Experiment
Conclusion
Water Surface Modeling
Light Flux Density
Refraction
Analytical Prediction
Numerical Simulation
Lens Approximation
Acrylic Wave – Laser Experiment
Water Waves and Patterns
Bright Wave Pattern Predicted
Relationship between Amplitude & Focal Length
Actual Waves Interference Lip-Shape

THANK YOU

Monochromatic Light?





Capillary Wave Function

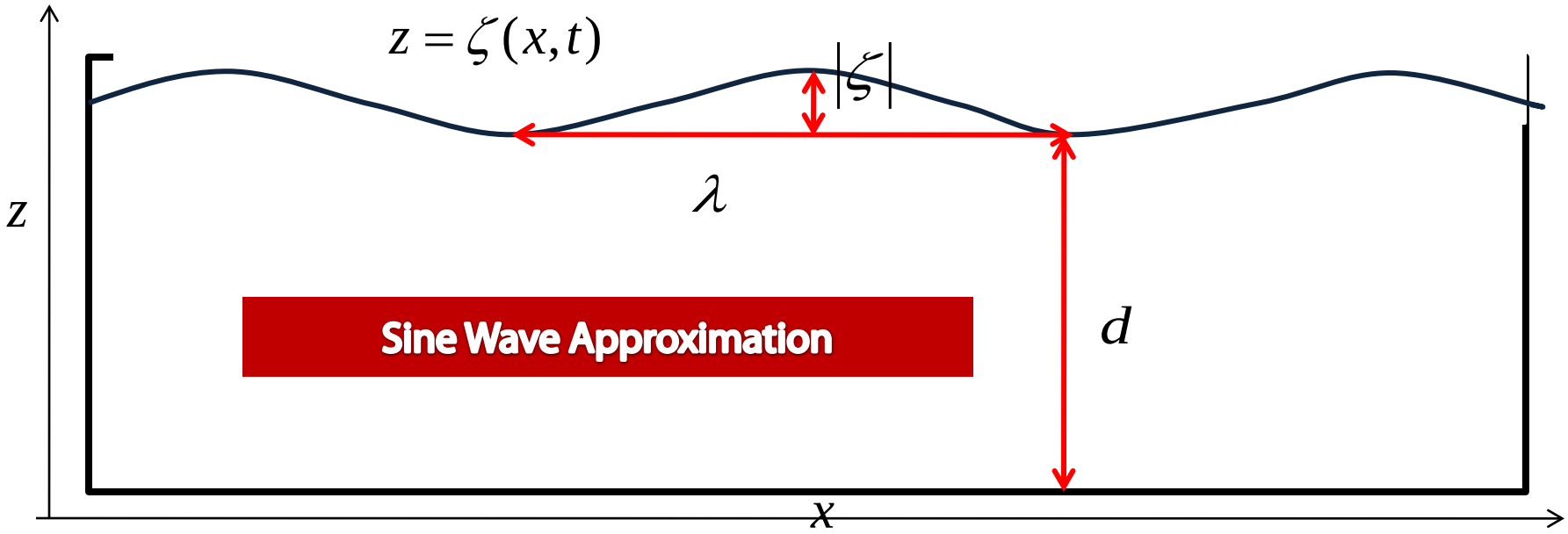
Bernoulli Equation for Unsteady Potential Flow

$$p + \rho\left(\frac{1}{2}q^2 + gz + \frac{\partial u}{\partial t}\right)$$

$$\zeta = -\frac{ka_0}{\omega}\sin(kx - \omega t)$$

when

$$|\zeta| << \lambda << d$$



Final Remark