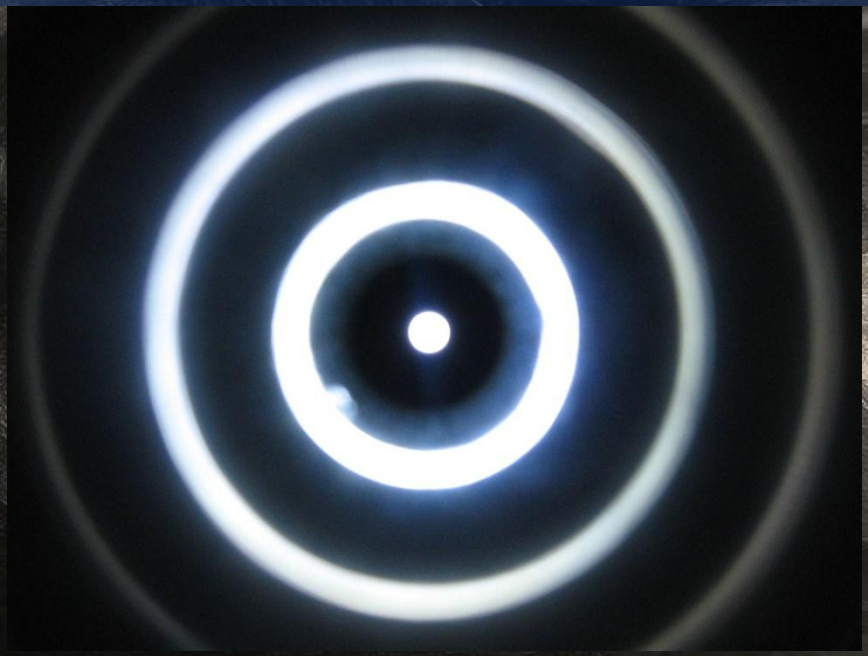
«Optical tube»

Presented by Belarusian team

Nankai University, 2009

Problem:

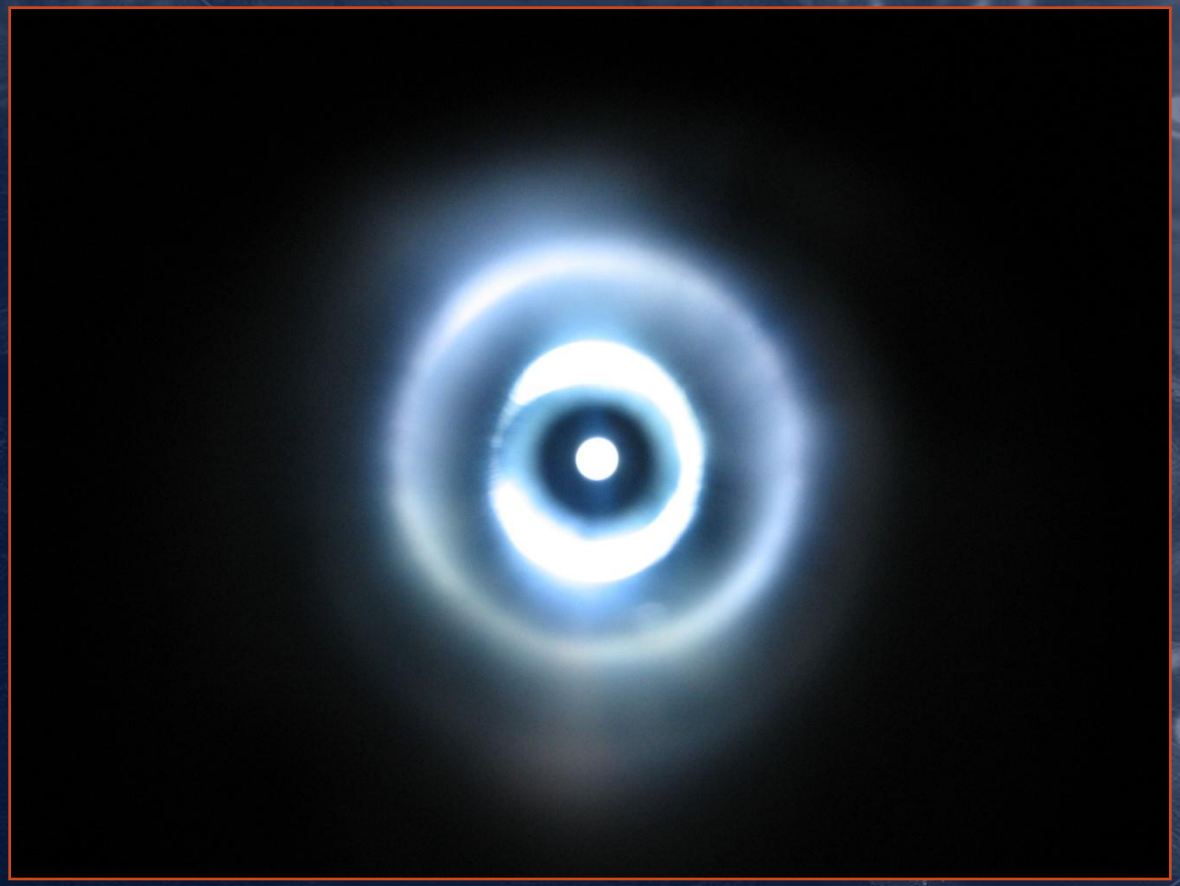
- Look down a cylindrical metal tube which is shiny on the inside. You will notice dark and light bands. Investigate the phenomenon.



Plan of investigations:

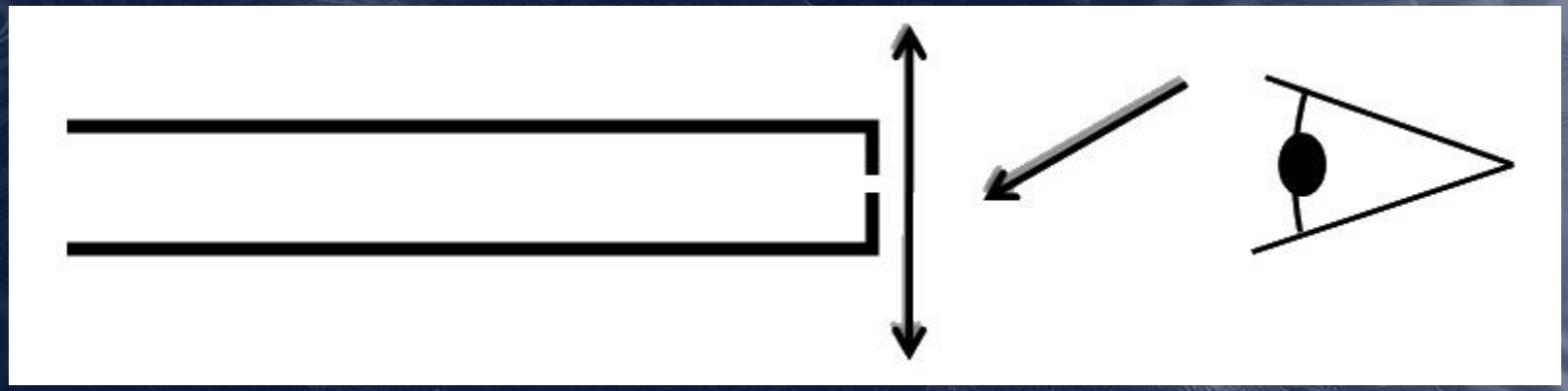
- Define, if the problem can be explained using just geometrical optics, without involving wave effects;
- Explain the formation of the bands;
- Find a way of obtaining an image;
- Investigate the features of the image both for the point lamp and the “real” image (many lamps);

Part 1: One Radiator



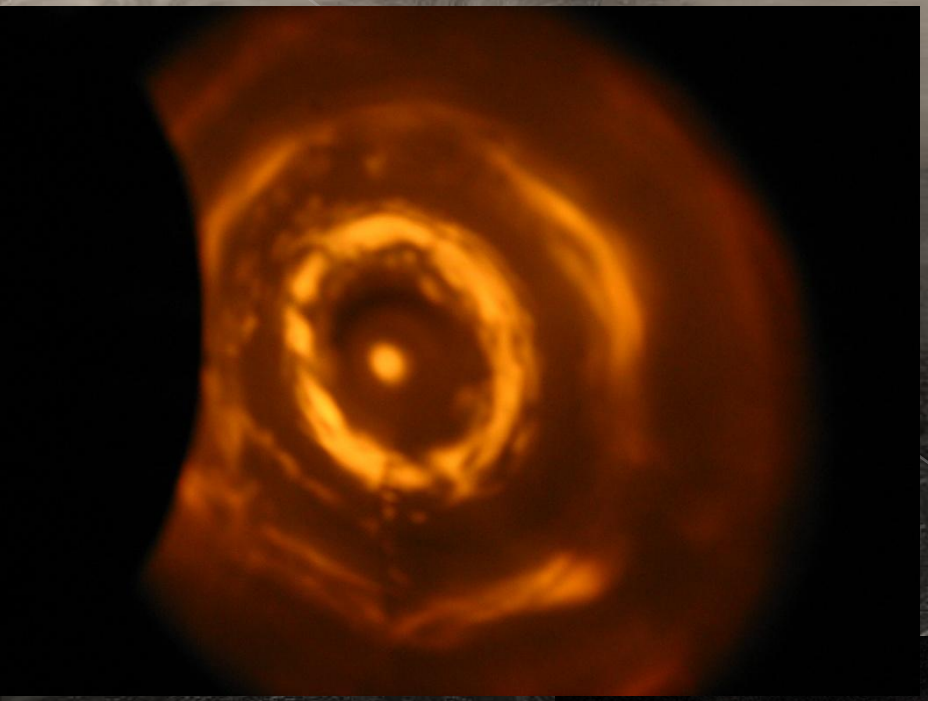
Obtaining an image

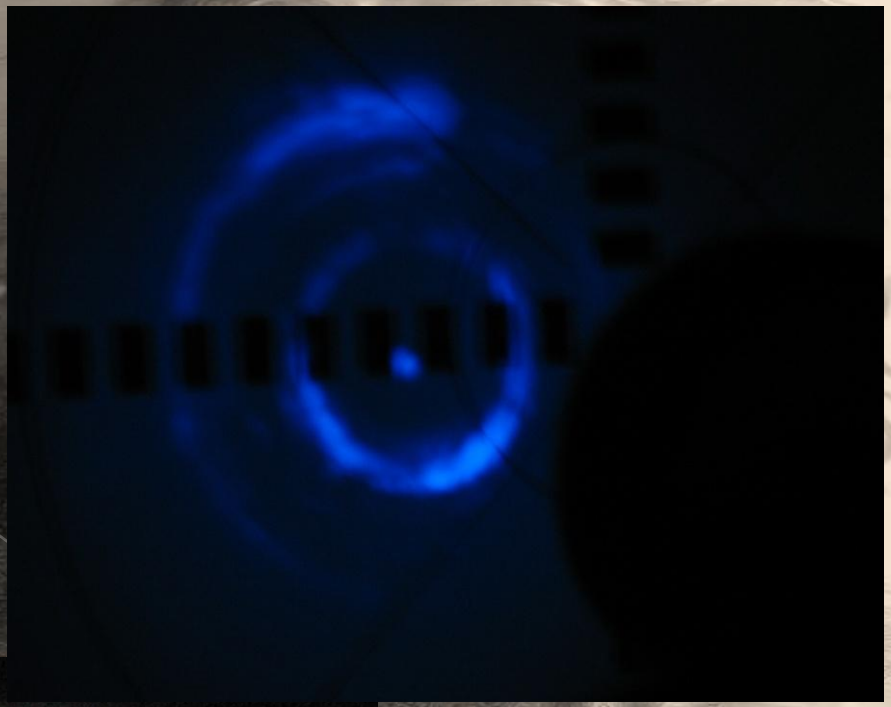
- To see the band we can use lens with a screen, use hole with a screen, or simply look with an eye.



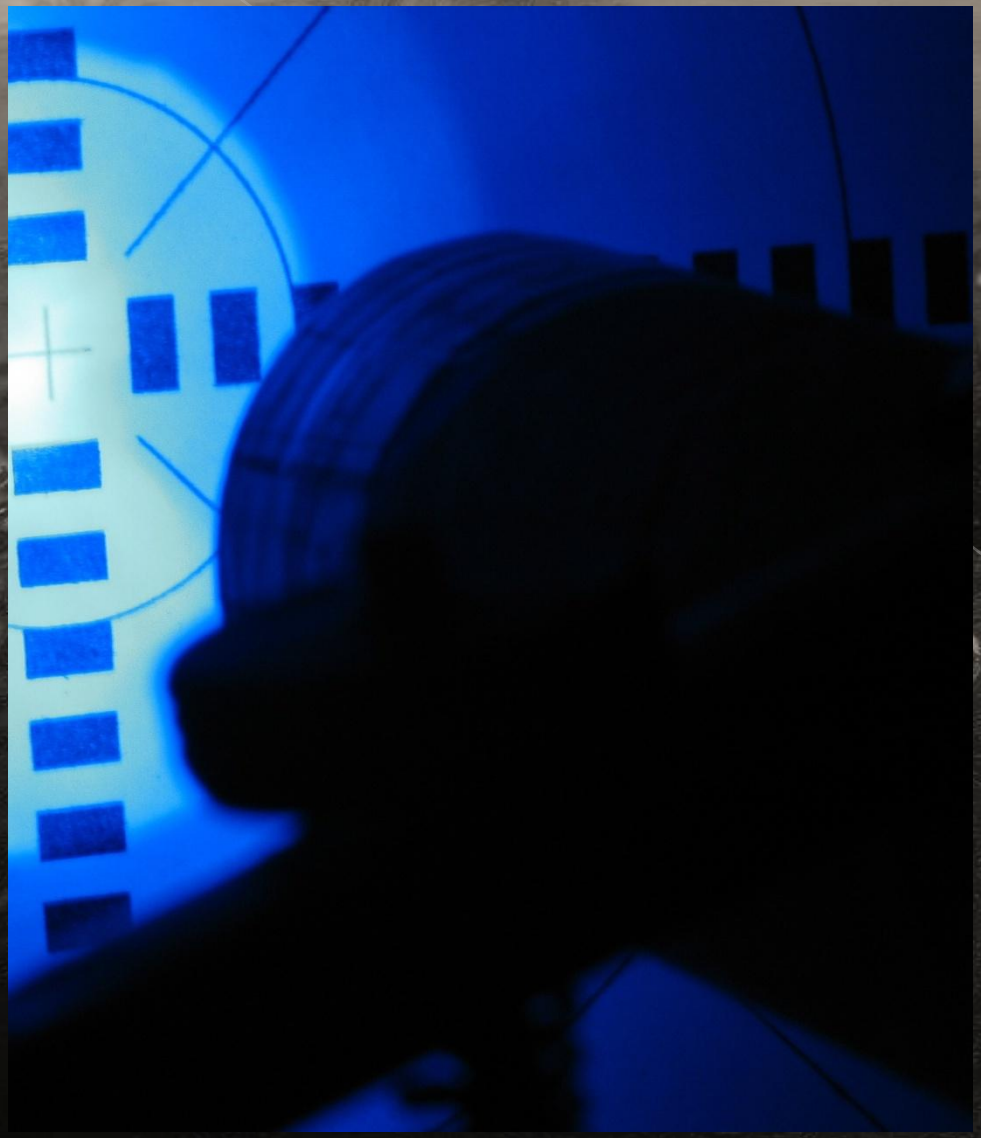
Setup №1: Hole

№1: Obtained images

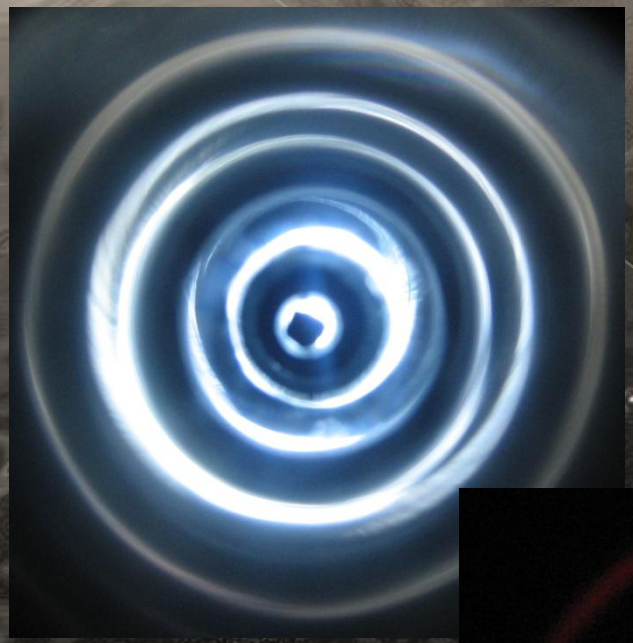


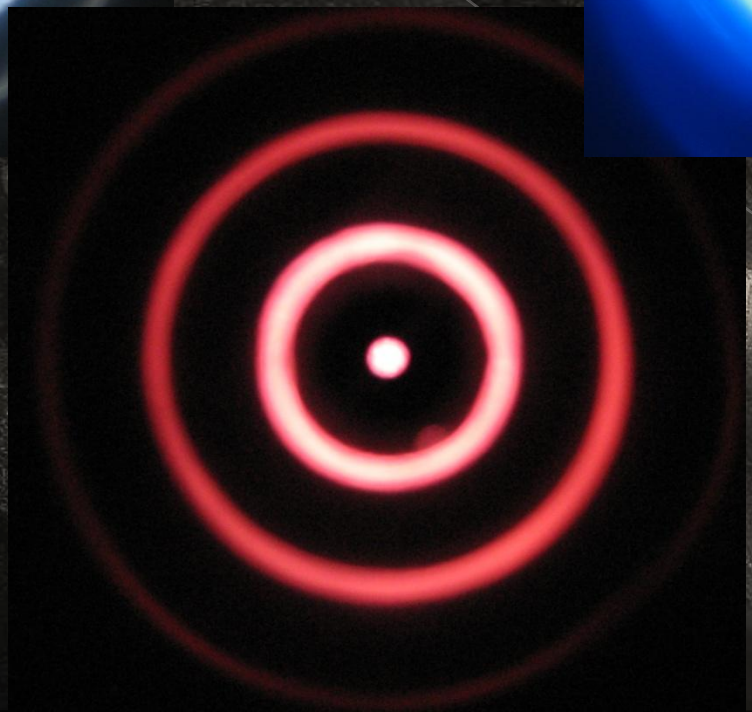


Setup №2: A lens

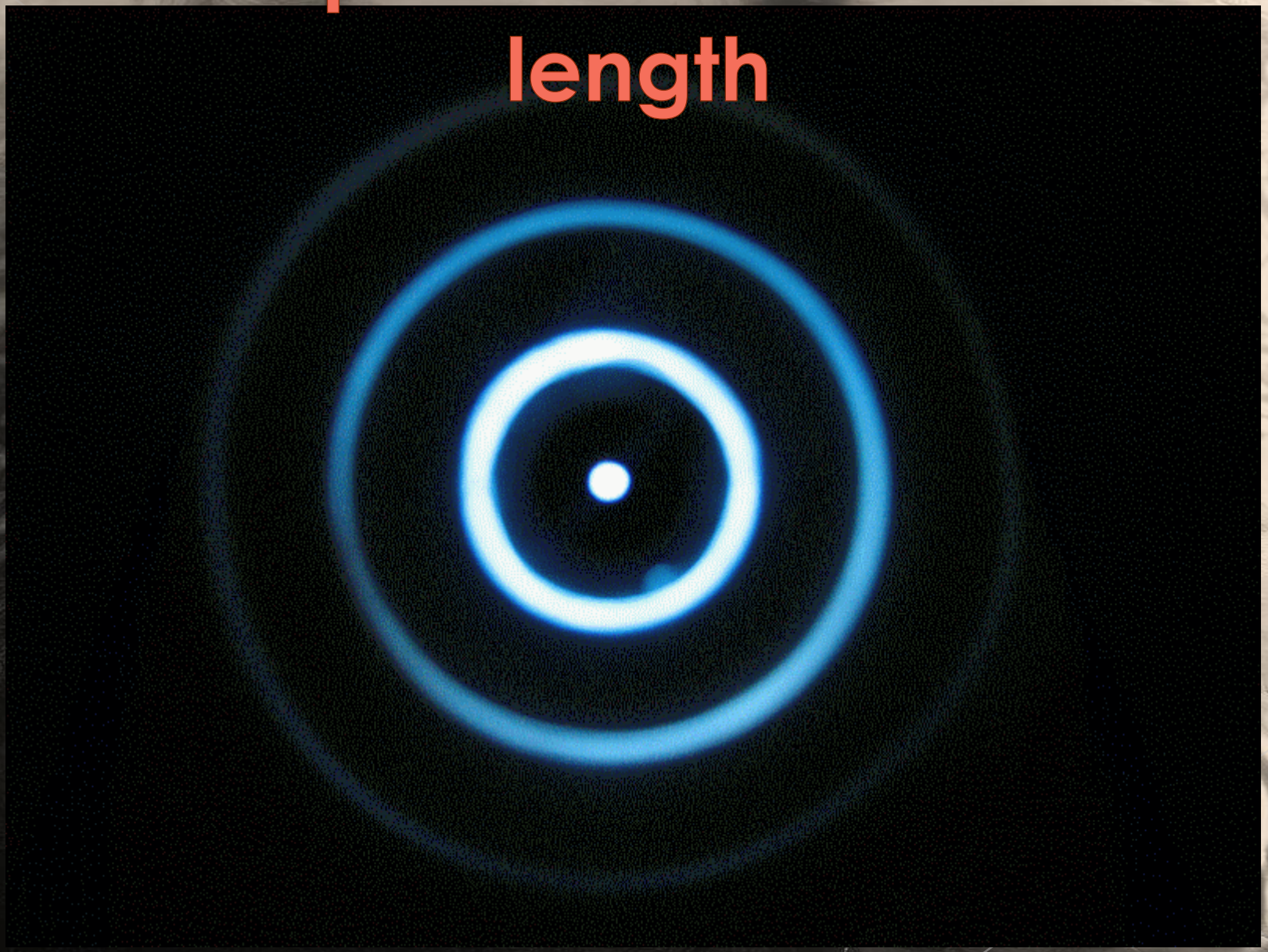


№2: Obtained images

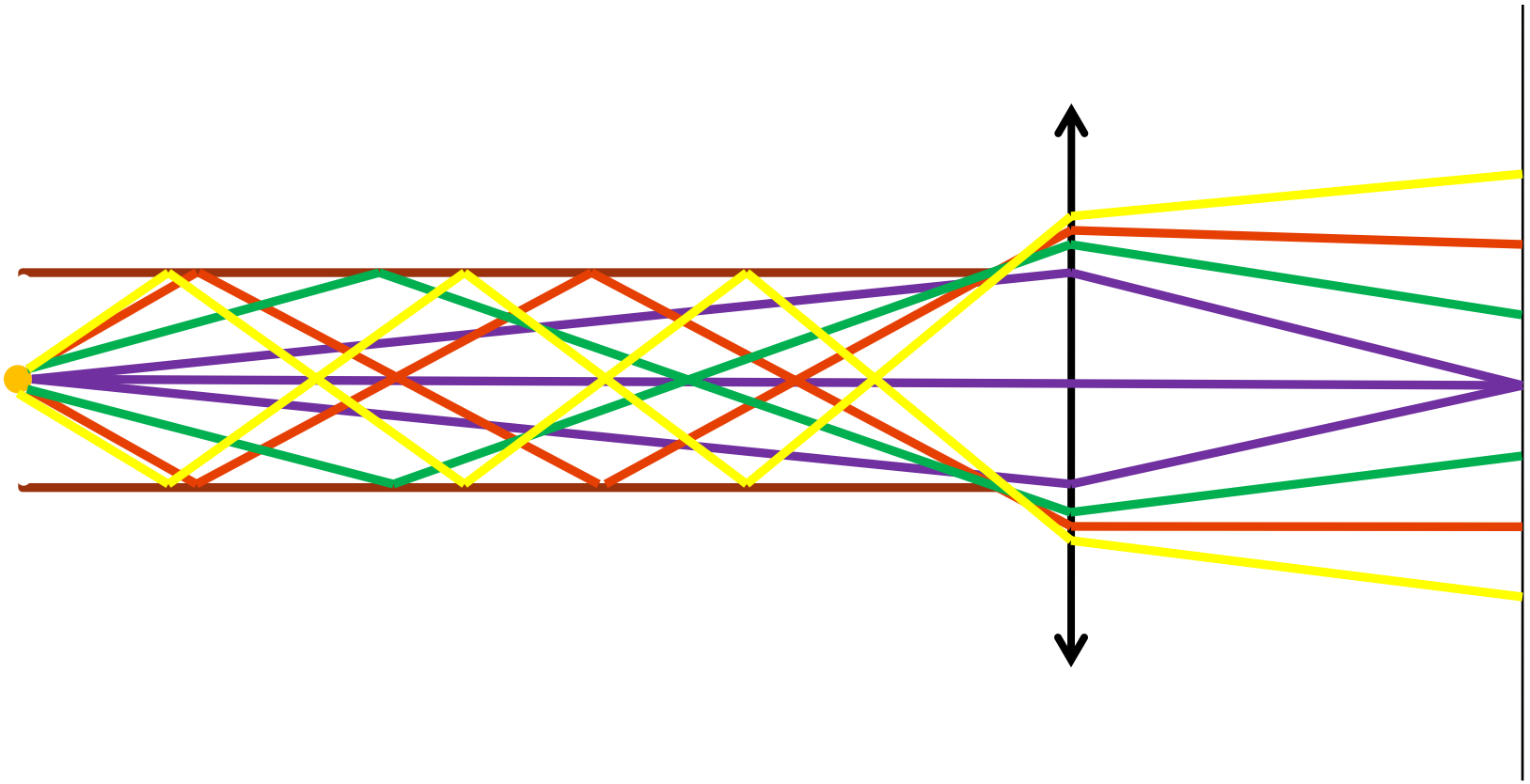




The dependence on a wave length

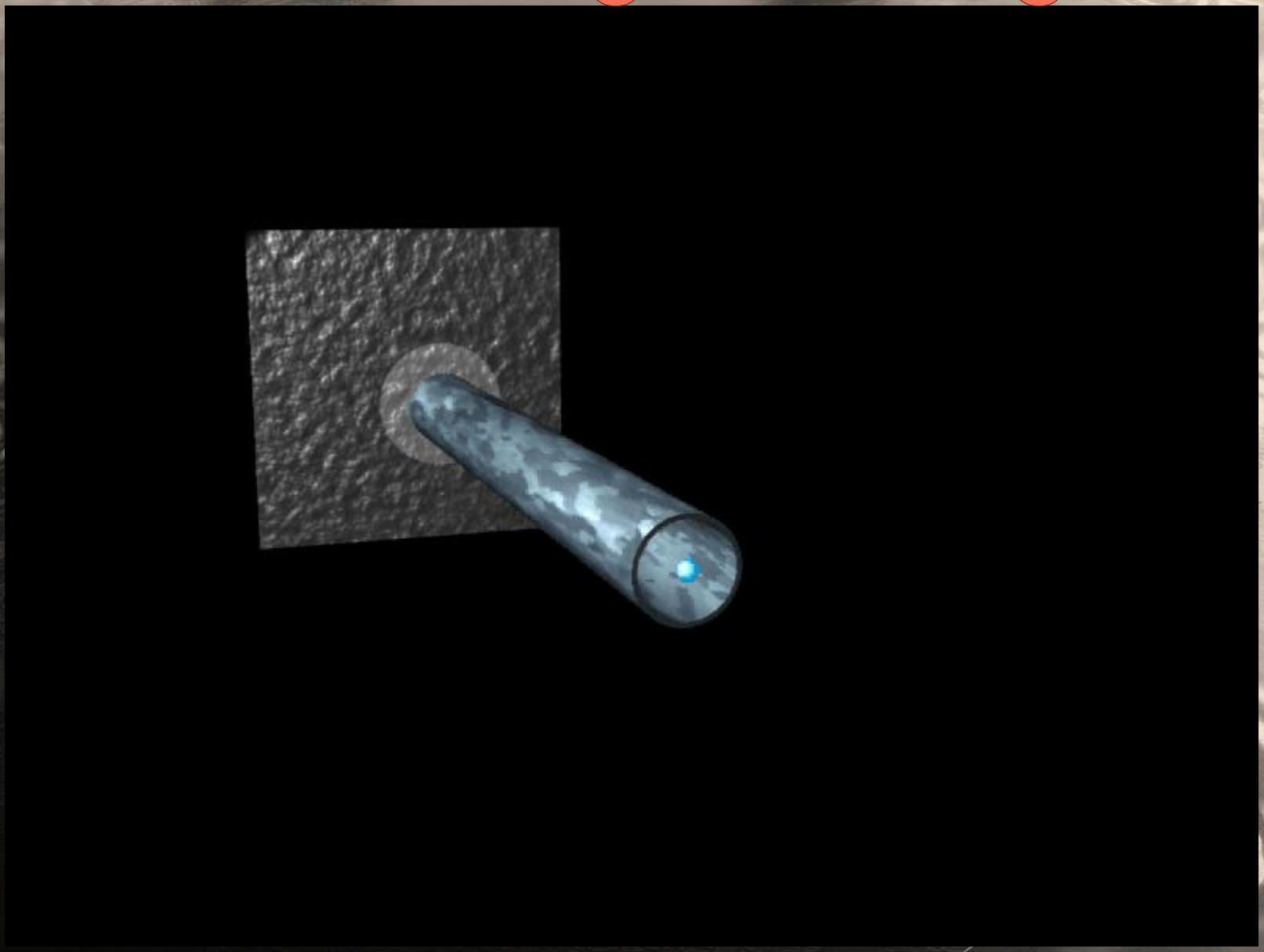


Ray tracing

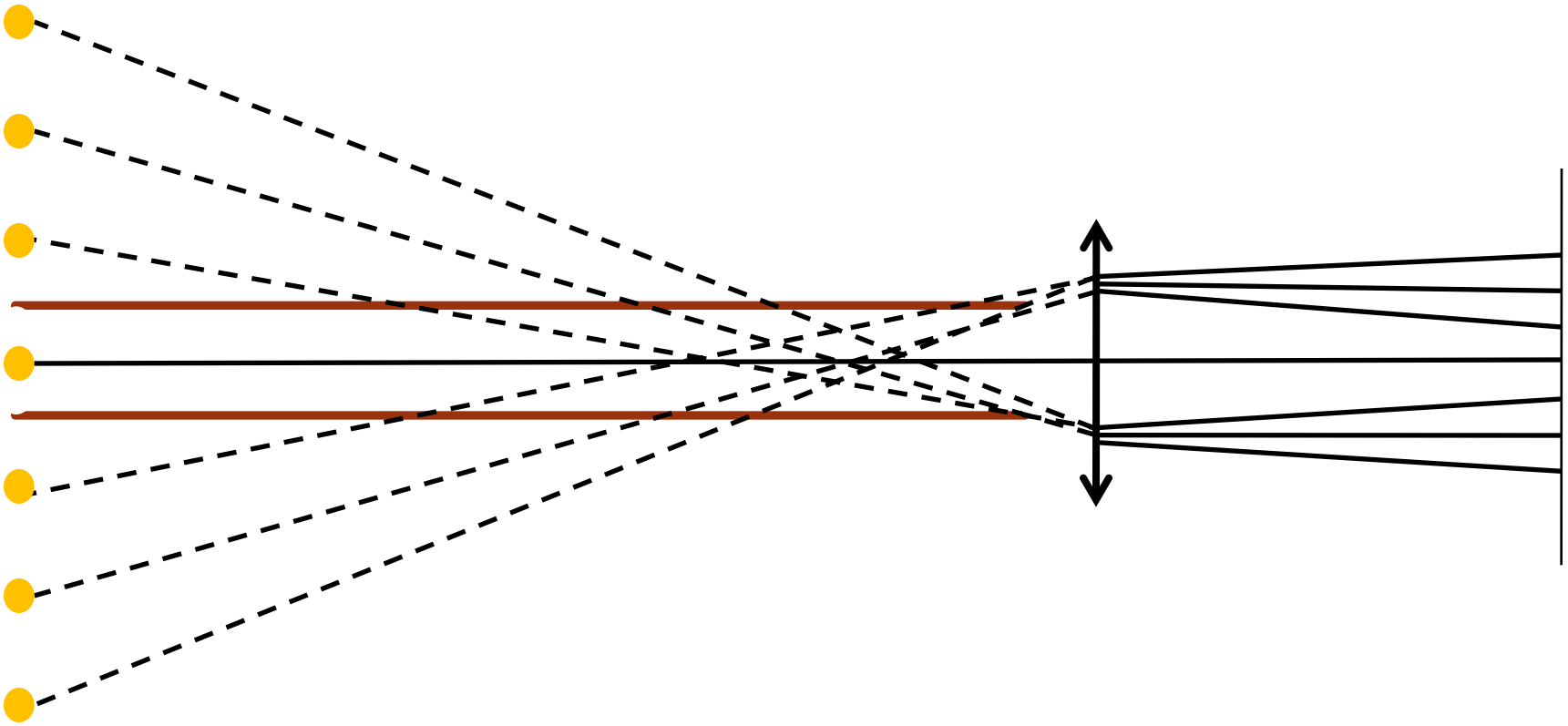


Visualizing the beams paths

The image building



Imaginary radiators



Visualizing the beams paths and imaginary radiators

Angular position

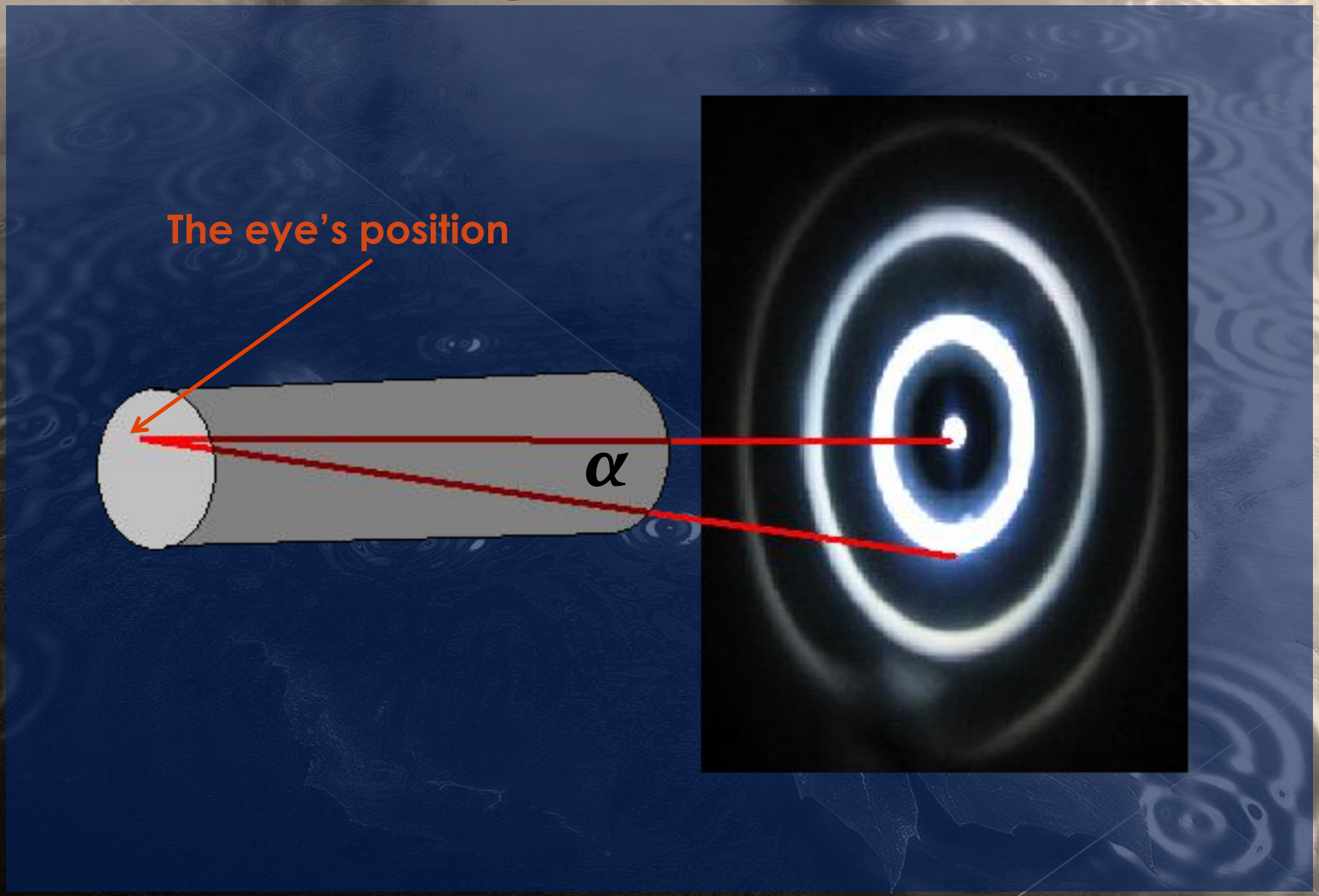


Image features

The angular position of the first ring according to the geometric optics:

$$\alpha = \arctan\left(\frac{2 \cdot R}{L}\right)$$

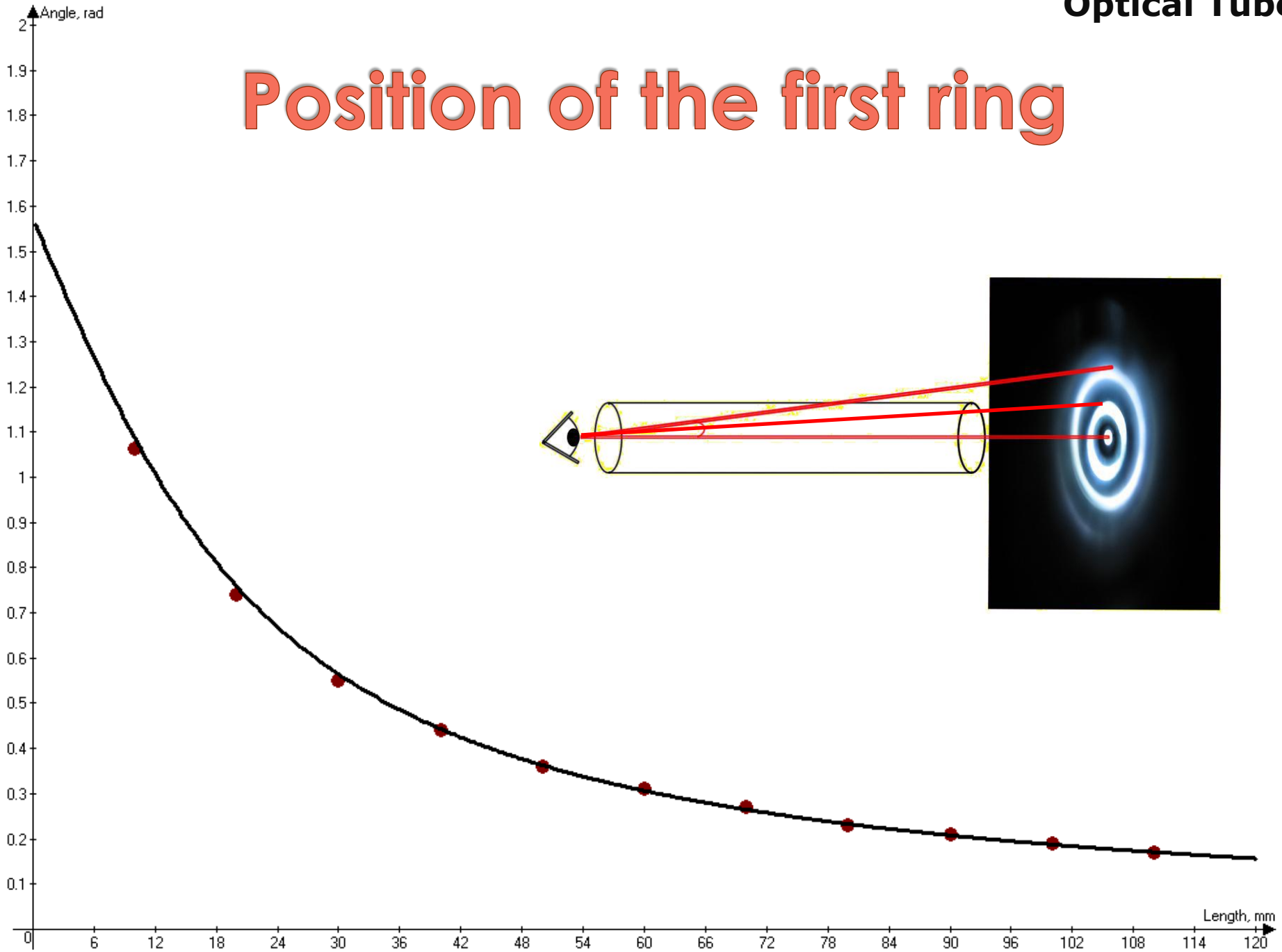
$$S = \frac{R}{L}$$

$$\alpha = \arctan(2 \cdot S)$$

Angular position of the nth ring:

$$\alpha = \arctan\left(2n \cdot S\right)$$

Position of the first ring



Non-point light source

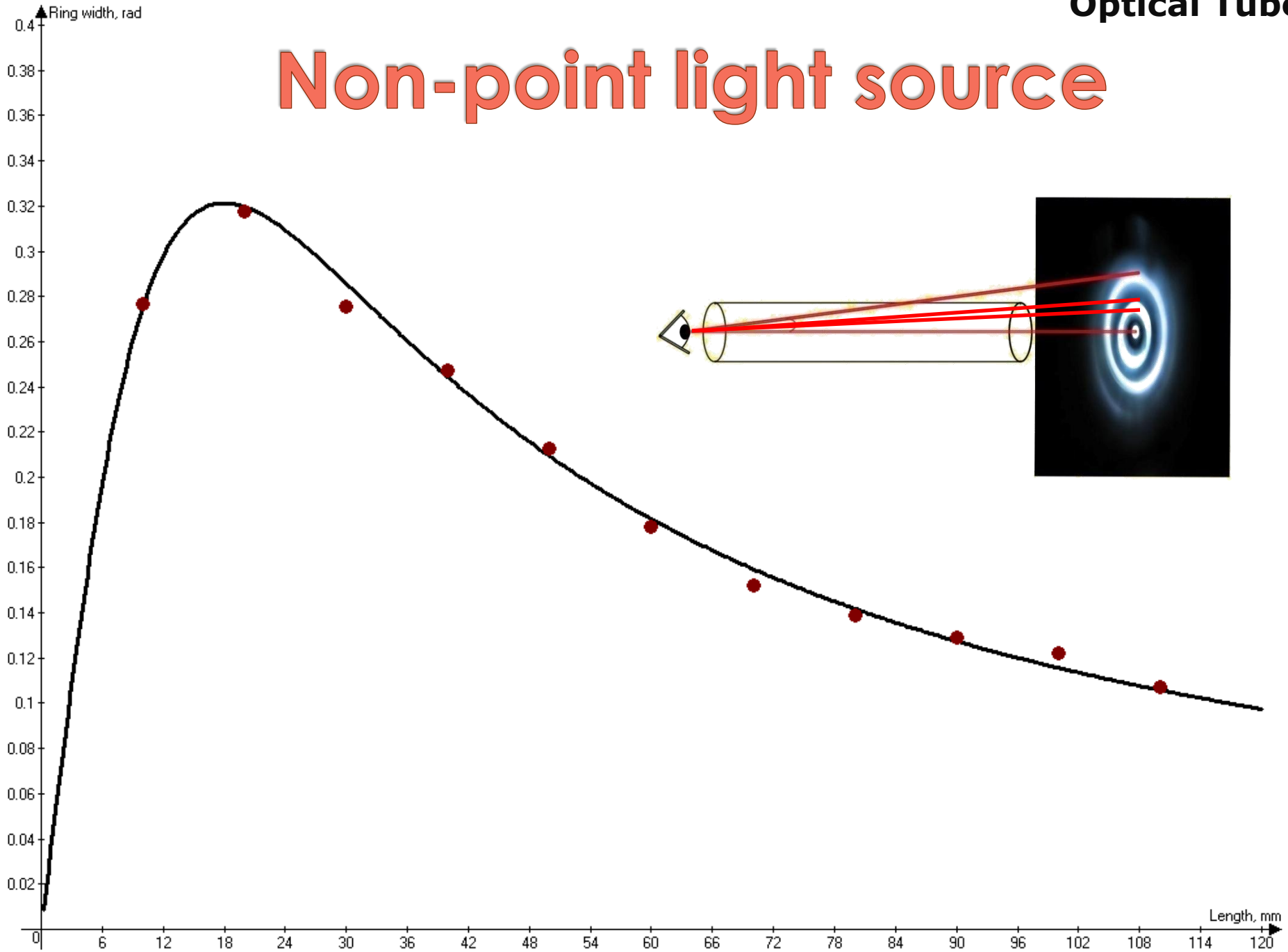
The angular "width" of the first ring:

$$\alpha = \arctan\left(\frac{2\cdot(R+r)}{L}\right) - \arctan\left(\frac{2\cdot(R-r)}{L}\right)$$

But the imaginary width is constant:

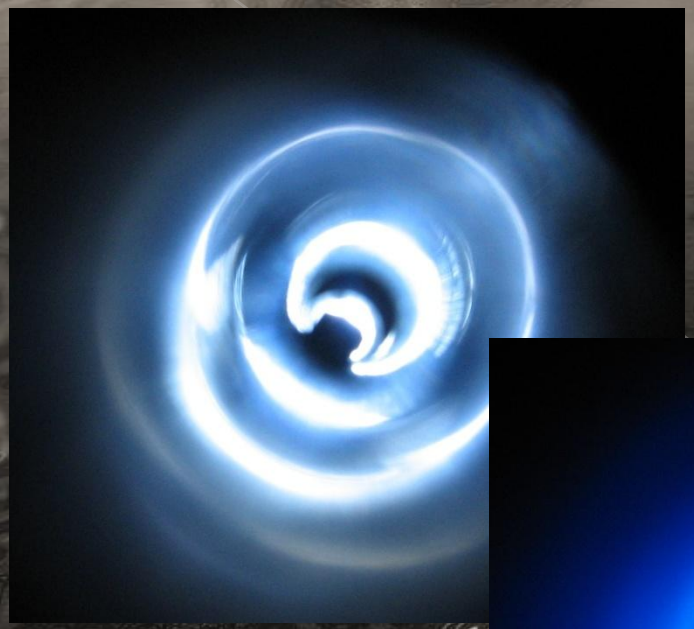
$$h = const = 2\cdot r$$

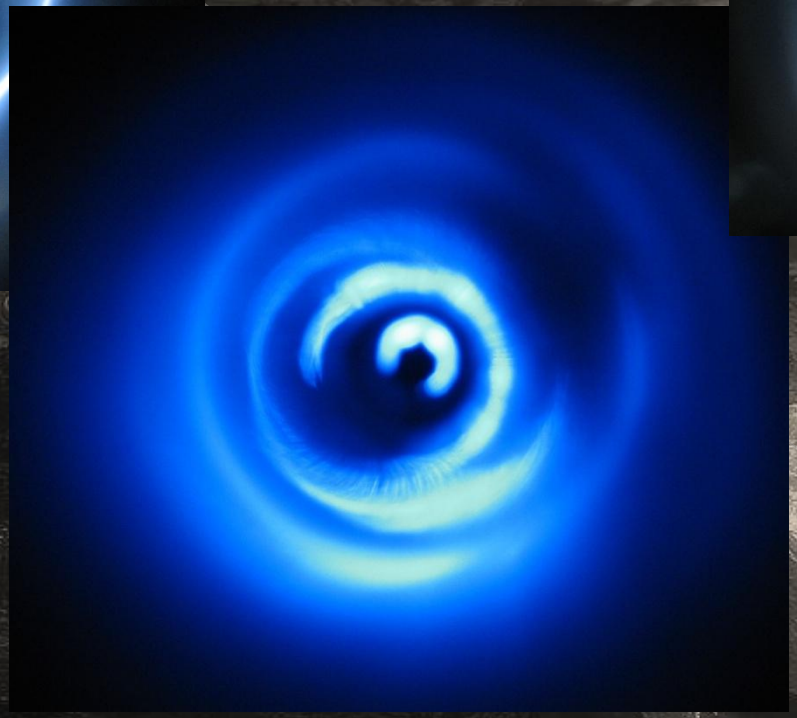
Non-point light source

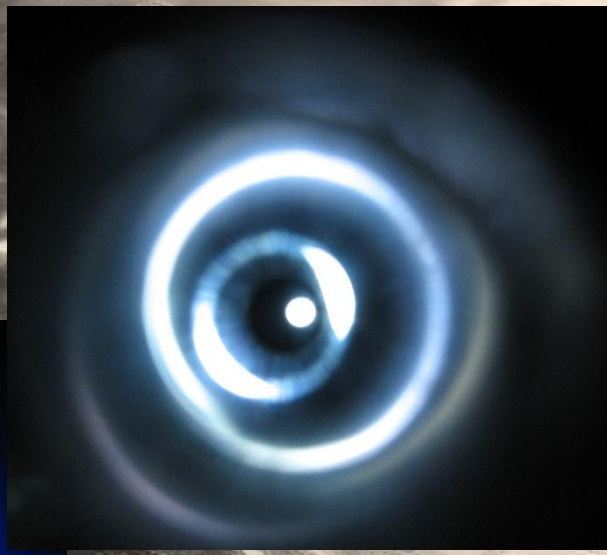


Changing the tube length

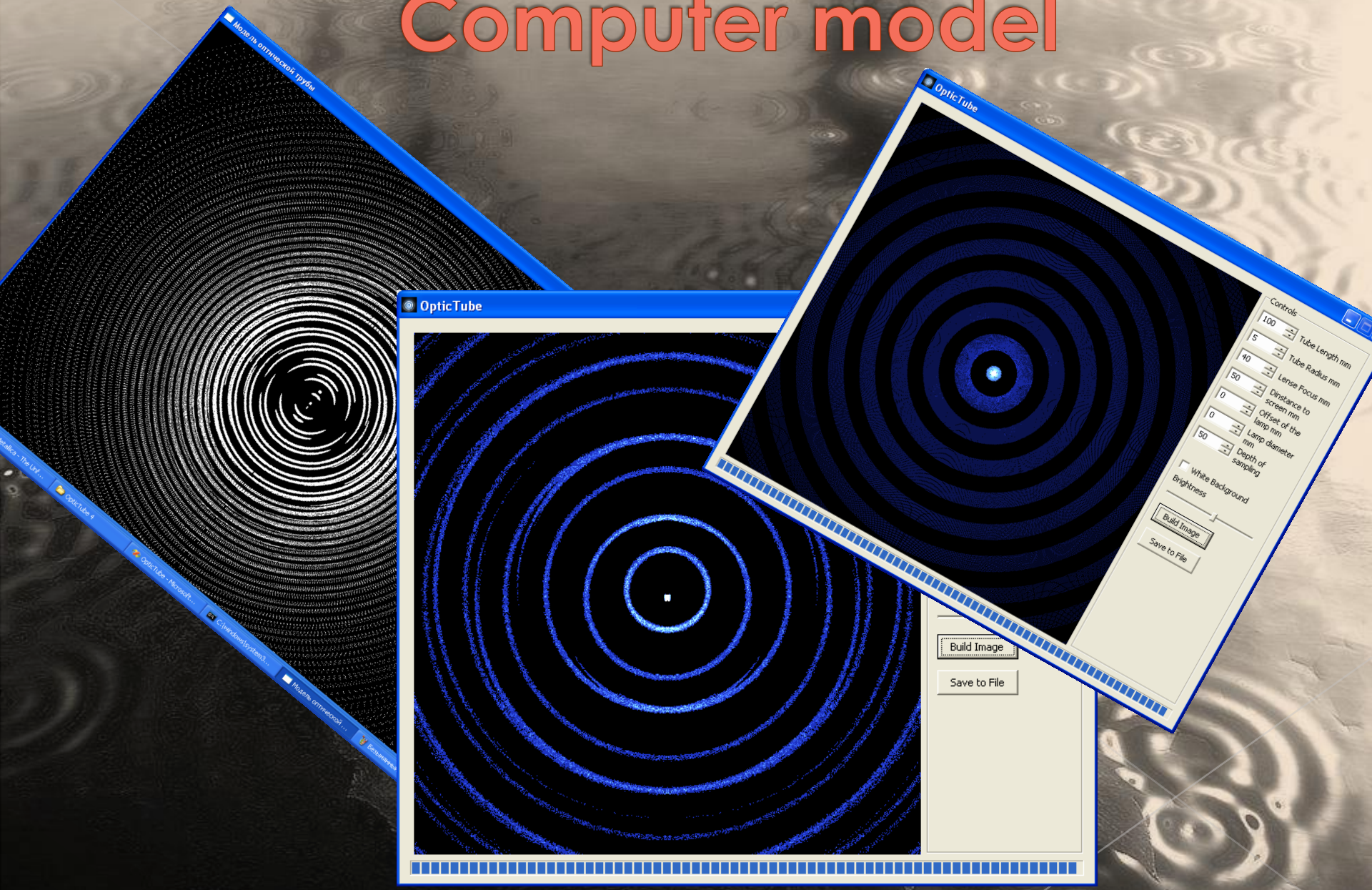
The lamp out of axis



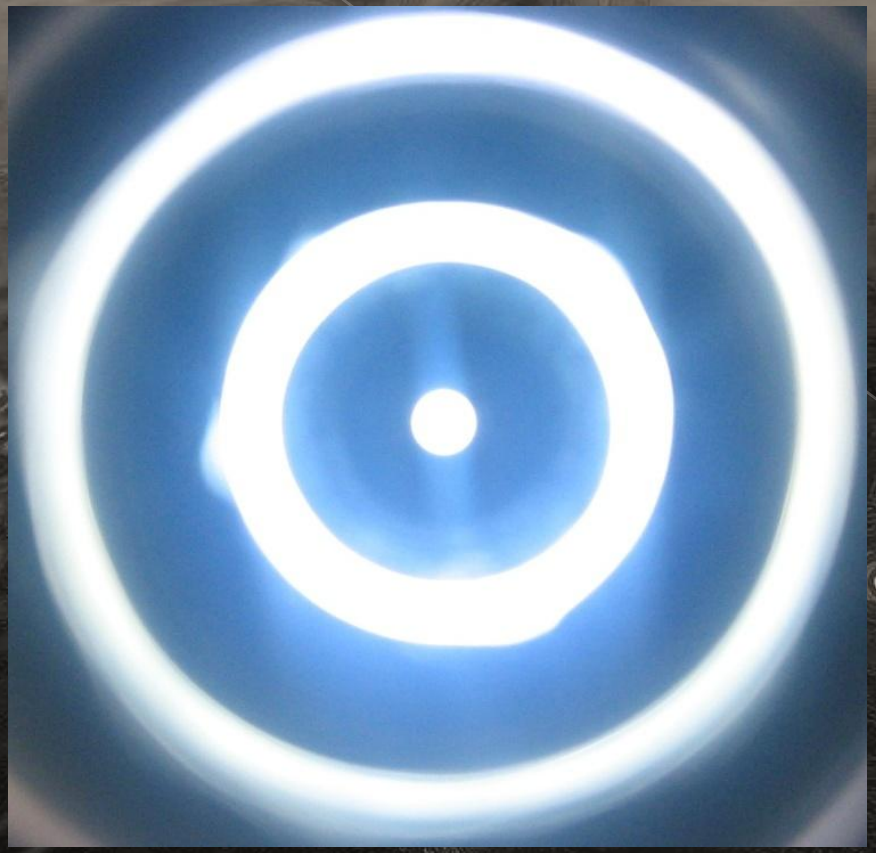


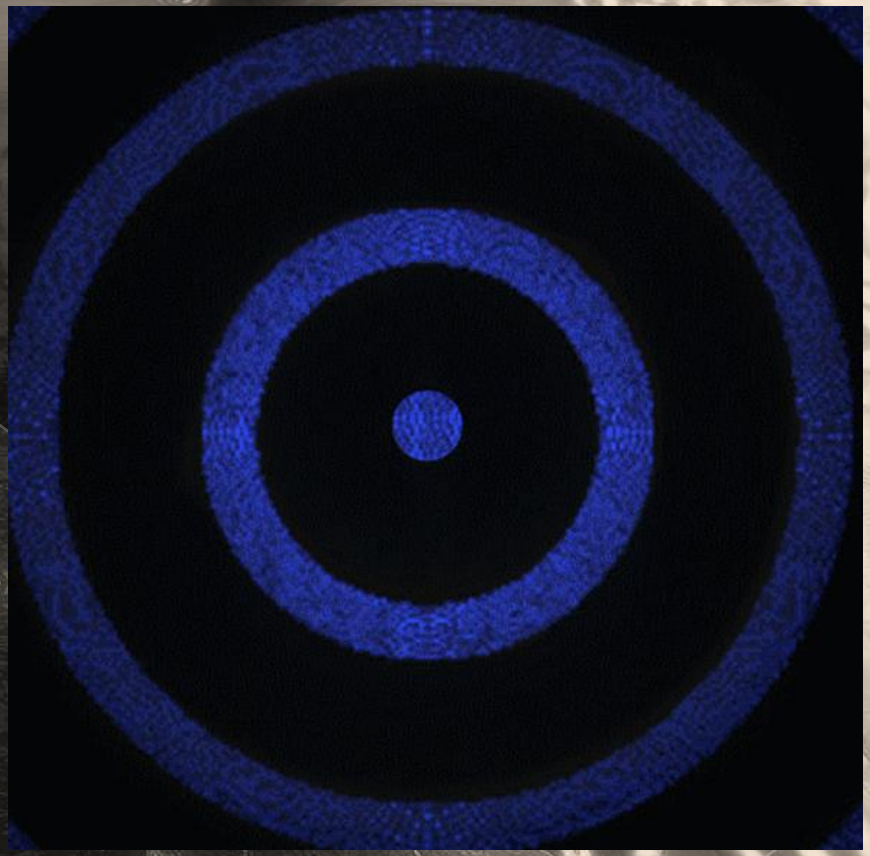


Computer model

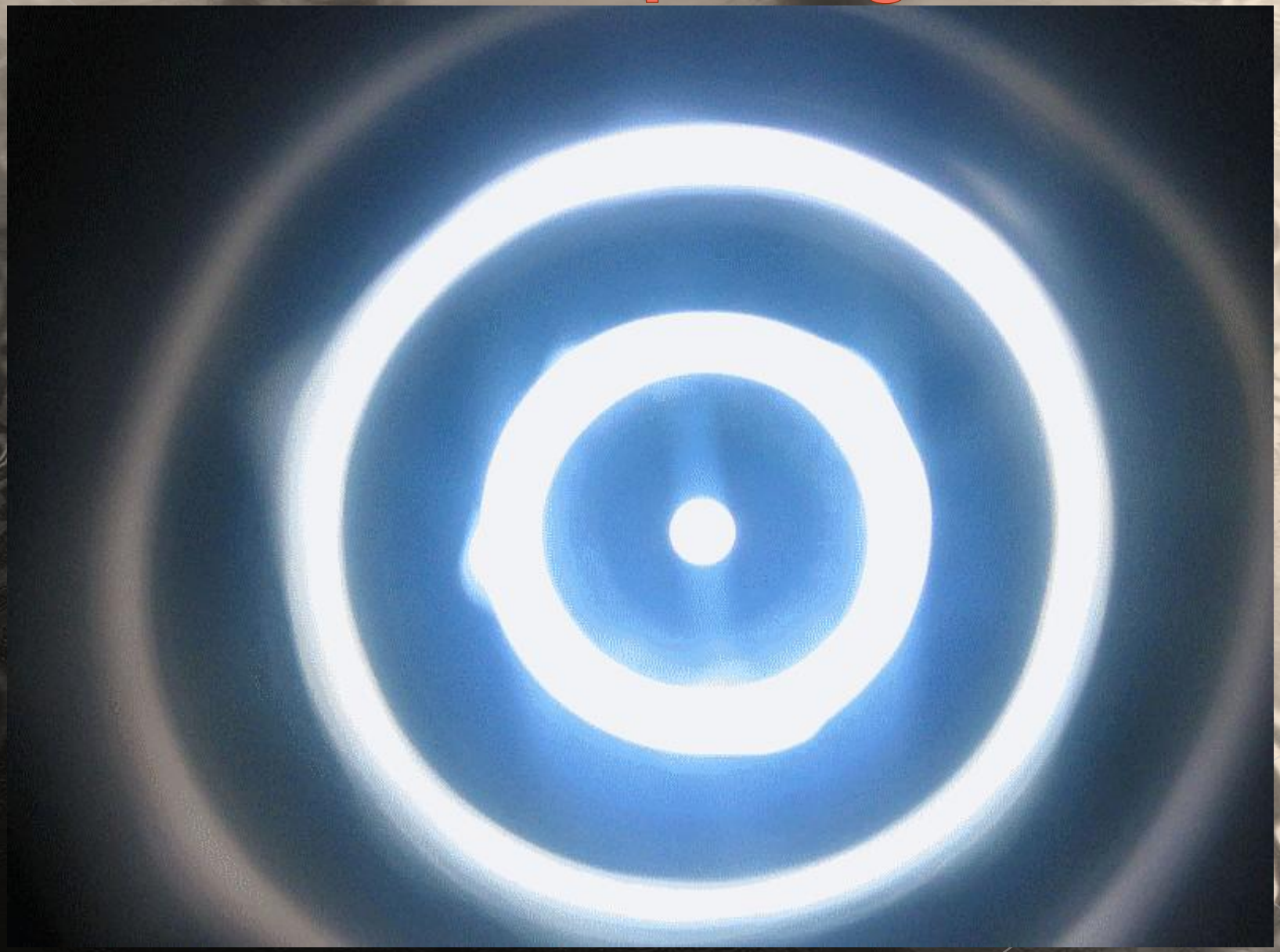


Comparing

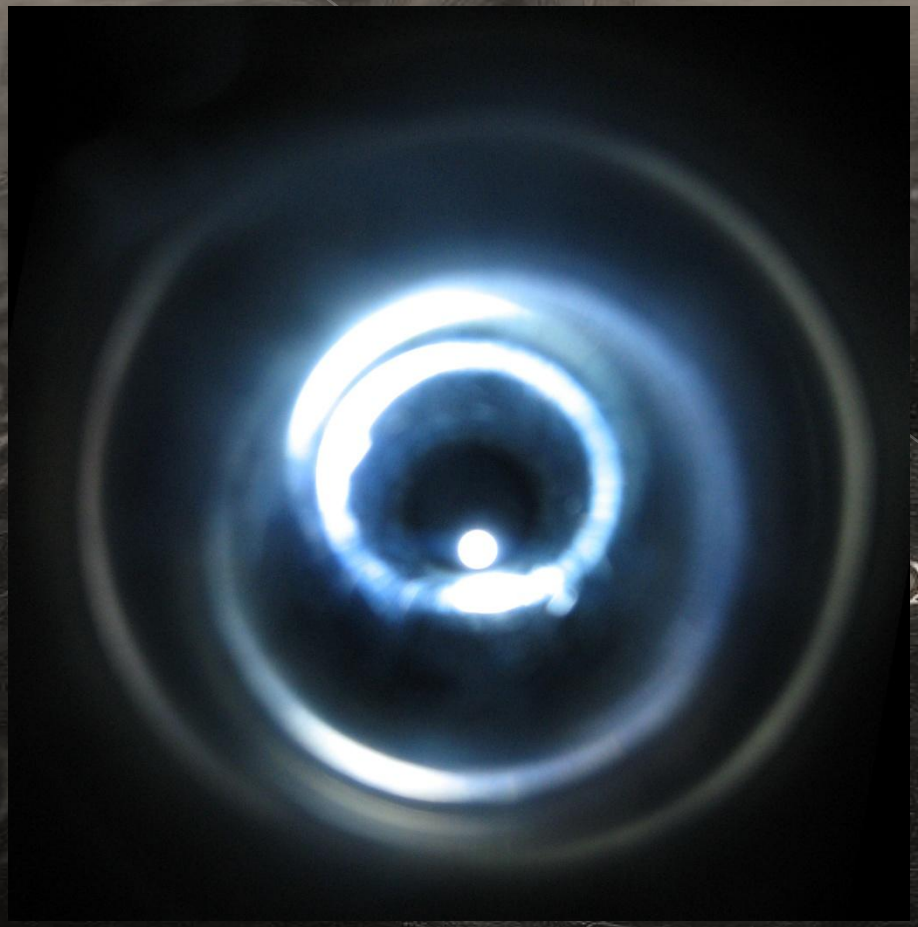


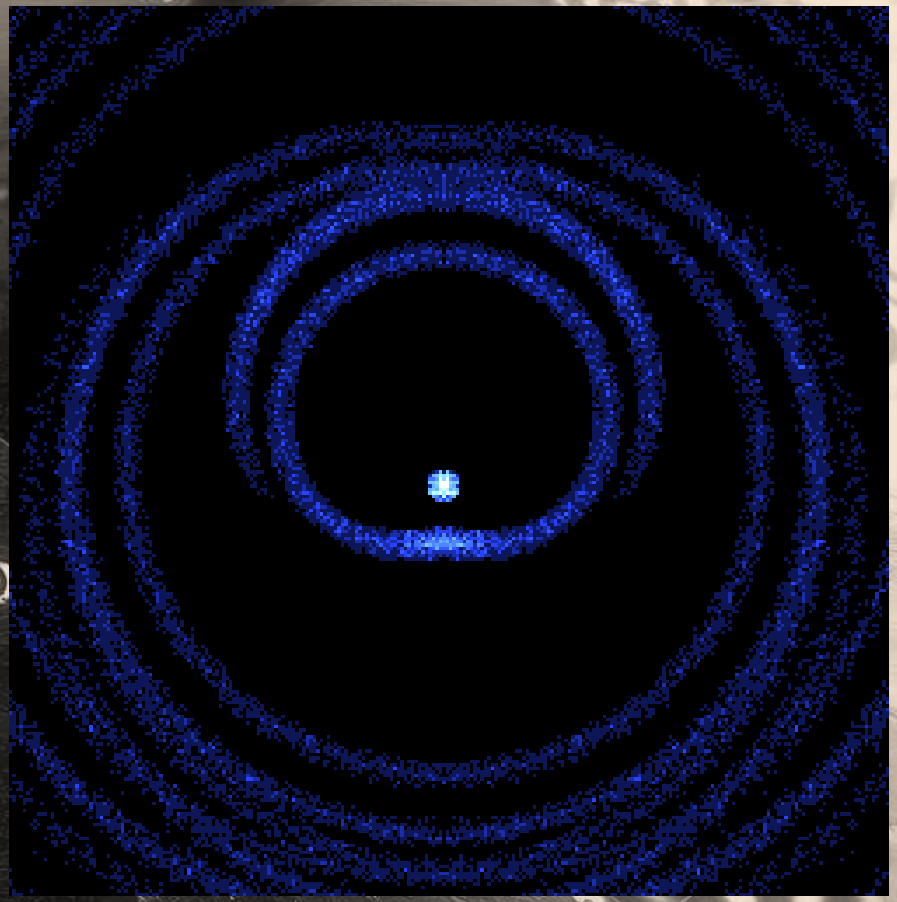


Comparing



Comparing



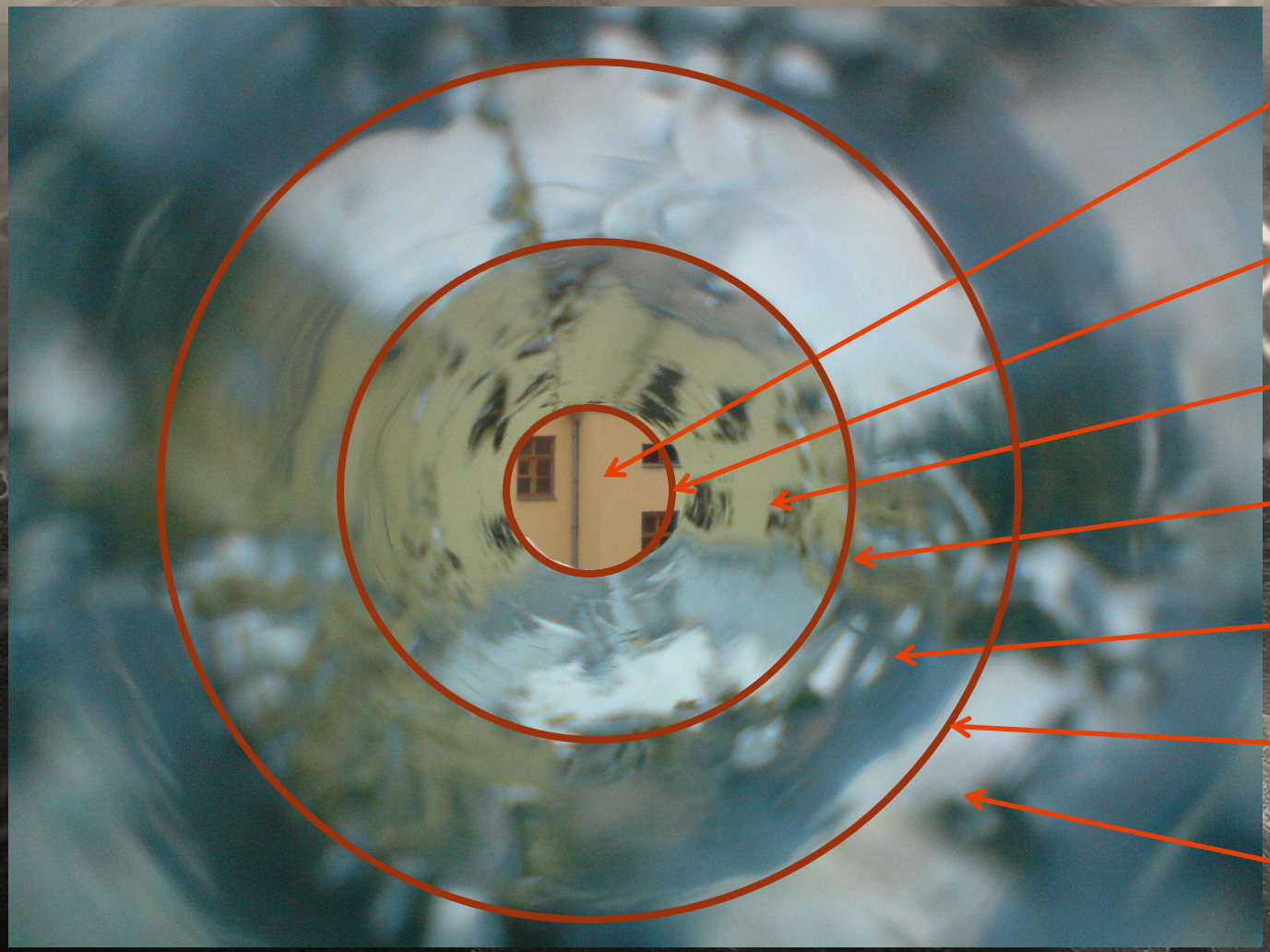


Changing lamp's position

Boundaries

Part 2: Image

The real image



Zones

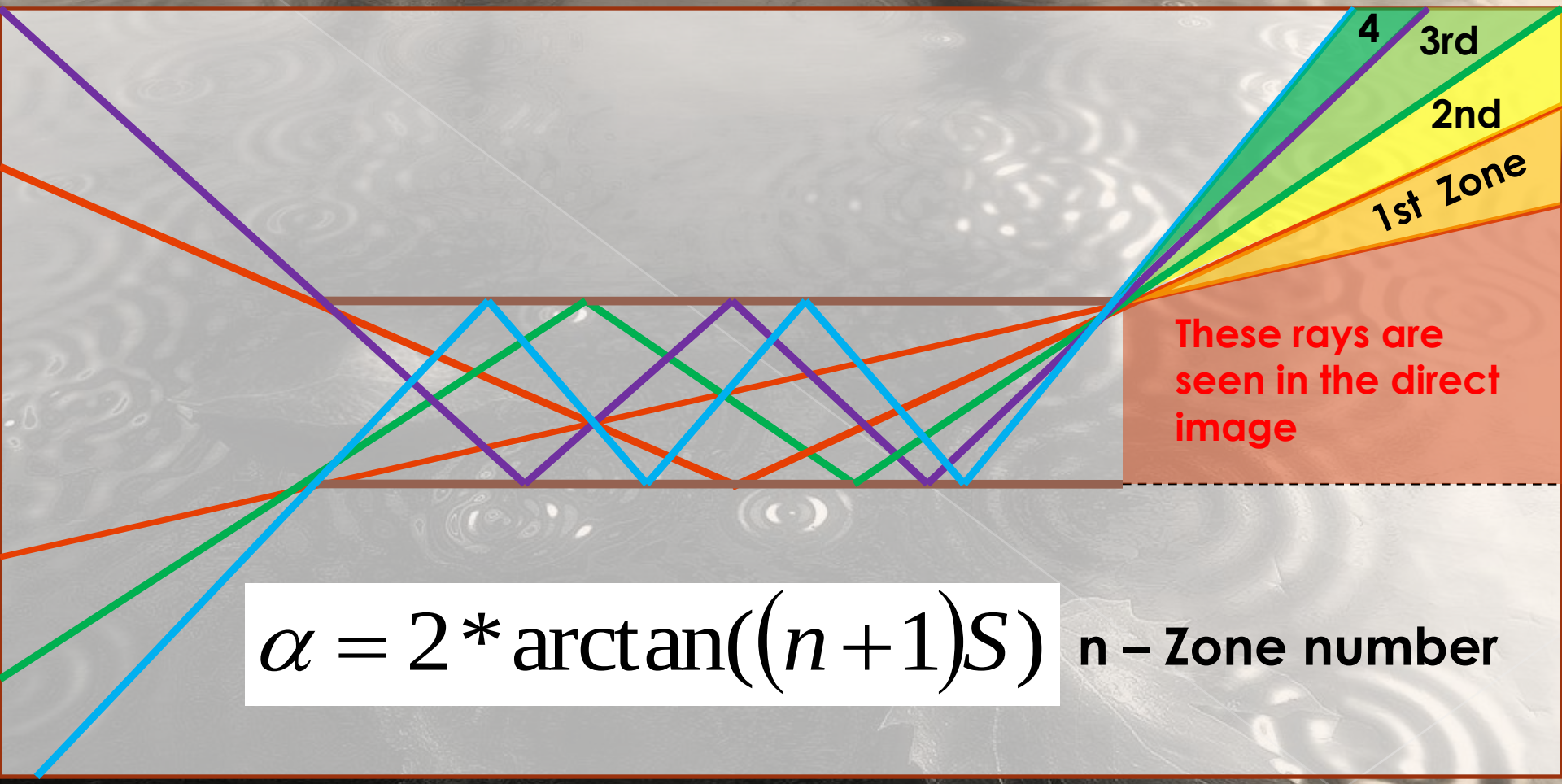
$$\alpha = \arctan\left(\left(2 \cdot n + 1\right)S\right)$$

Zone end

Zone beginning

$$\alpha = \arctan\left(\left(2 \cdot n - 1\right)S\right)$$

Angle of view increase



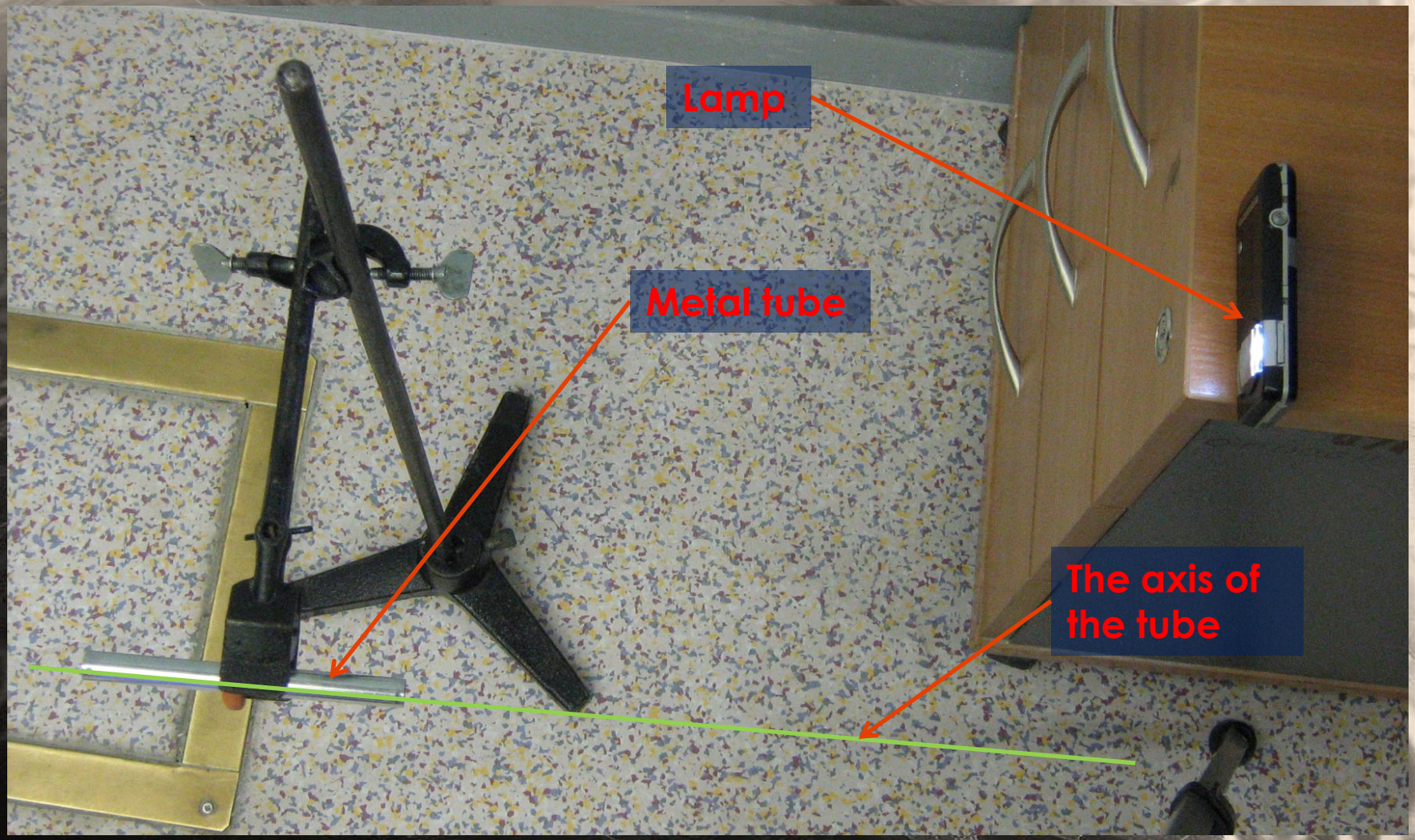
$$\alpha = 2 * \arctan((n+1)S)$$

n – Zone number

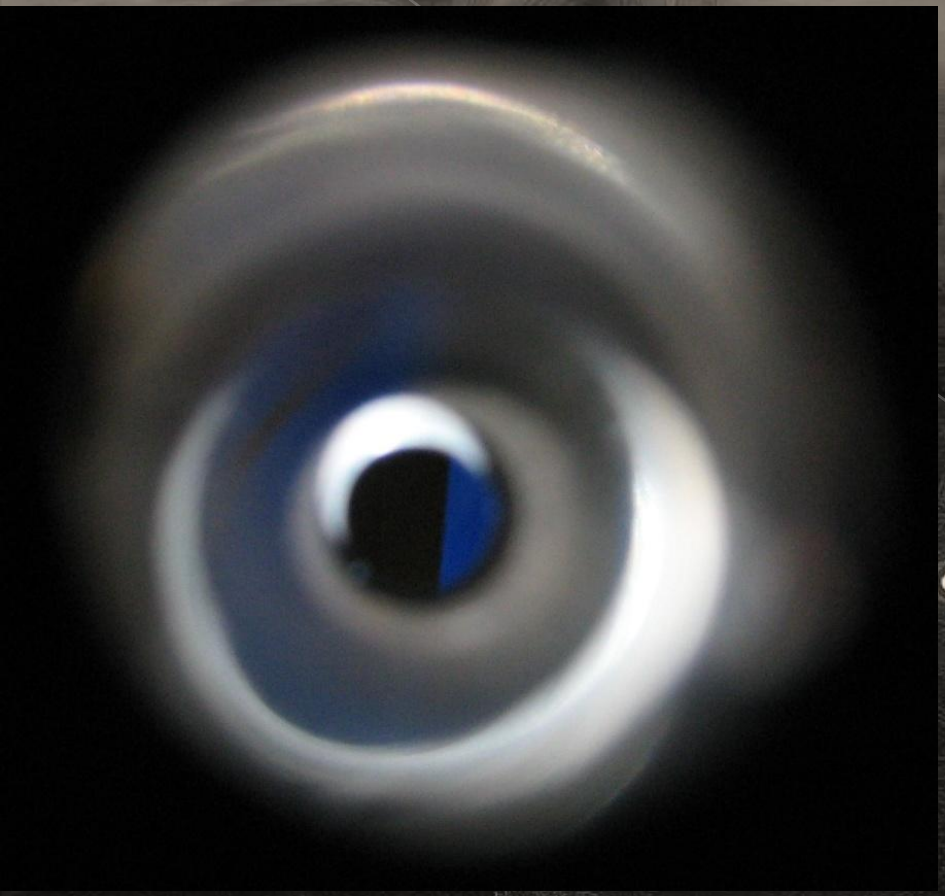
For our case a_1=0,36 rad

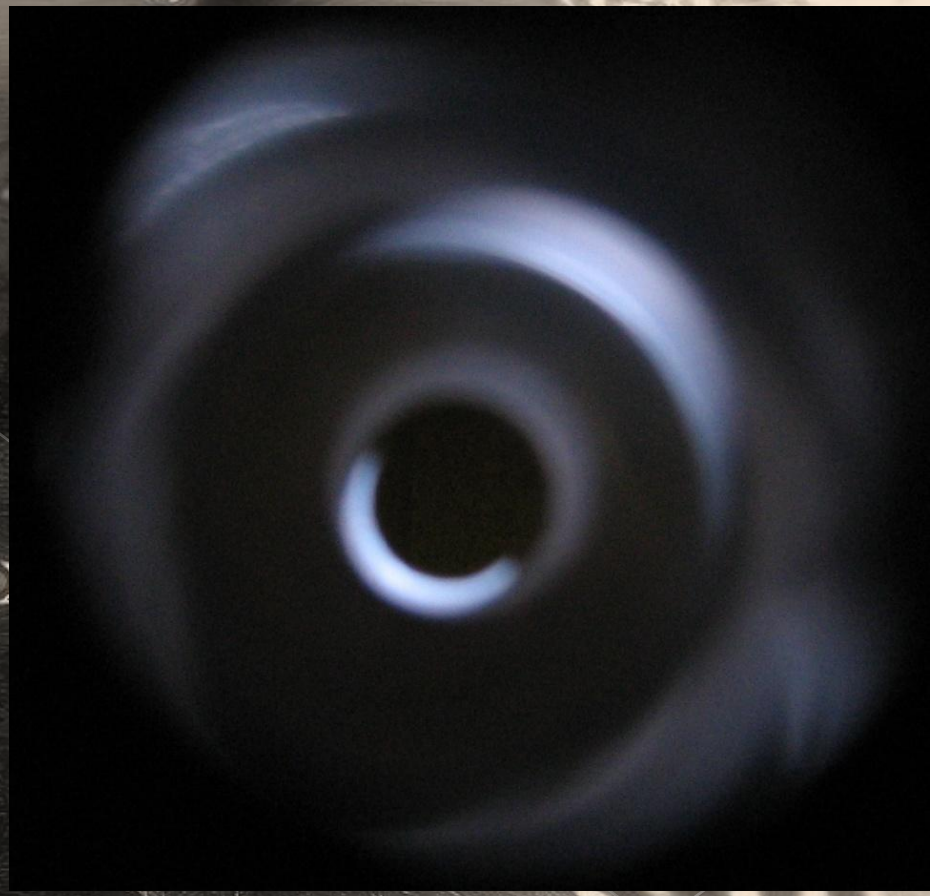
Angle of view increase

Angle of view increase

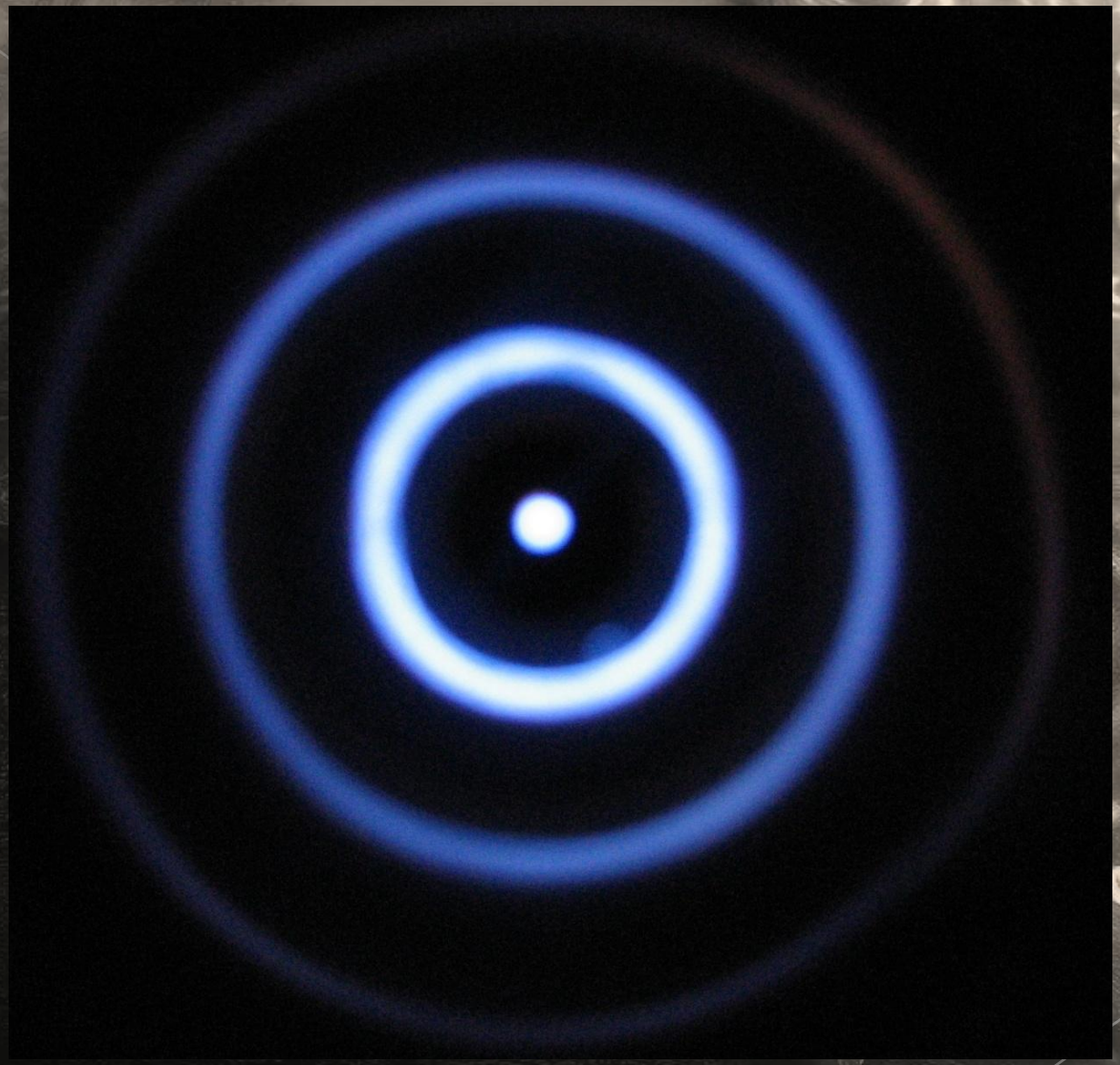


Angle of view increase





Observed number of zones



Human's vision

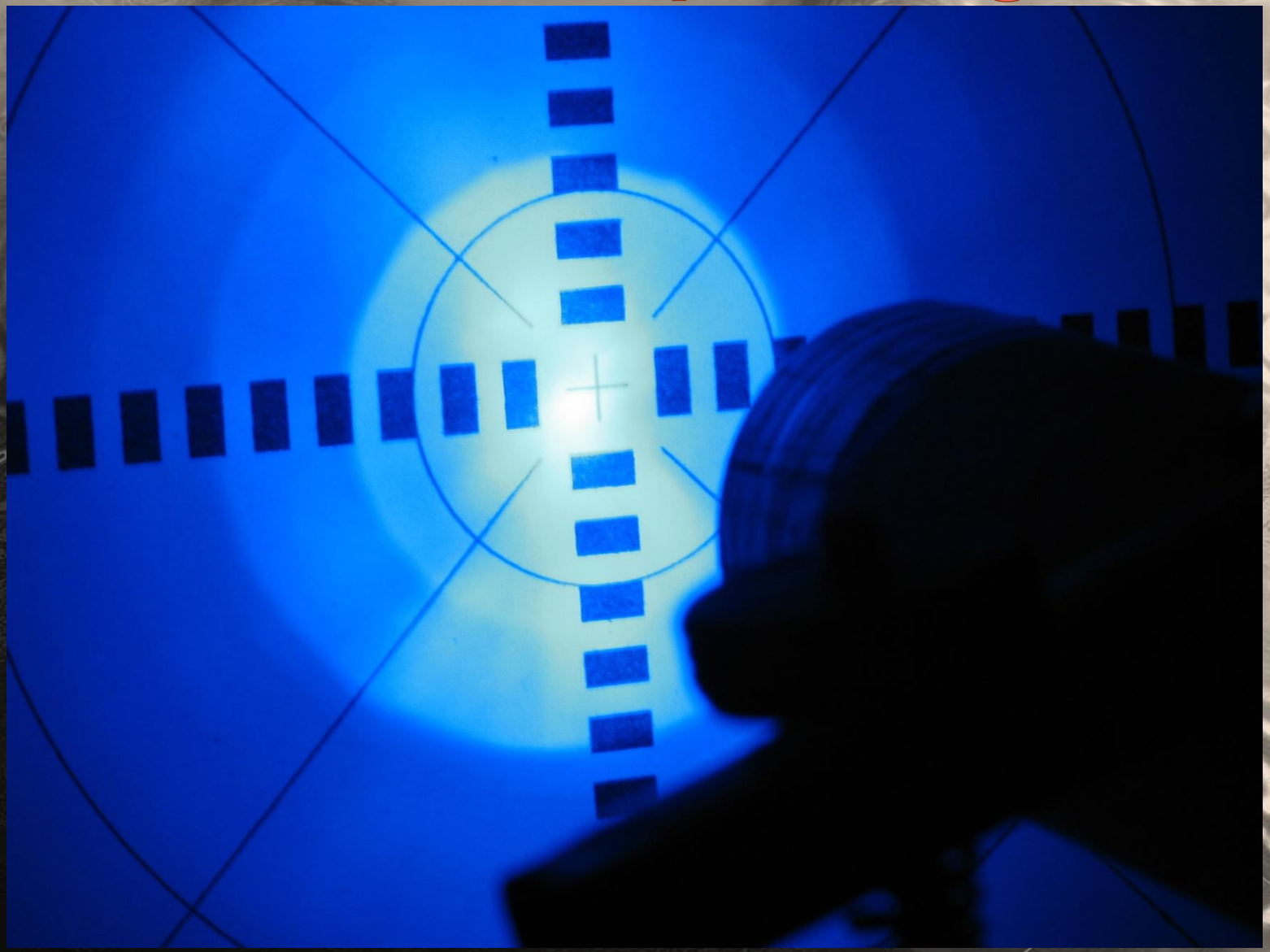
Because of the human's vision properties we cannot see object outside the zone of 35 degrees. The angle on the nth ring (for central point lamp):

$$\alpha = \arctan\left(2n \cdot S\right)$$

So, the number of rings:

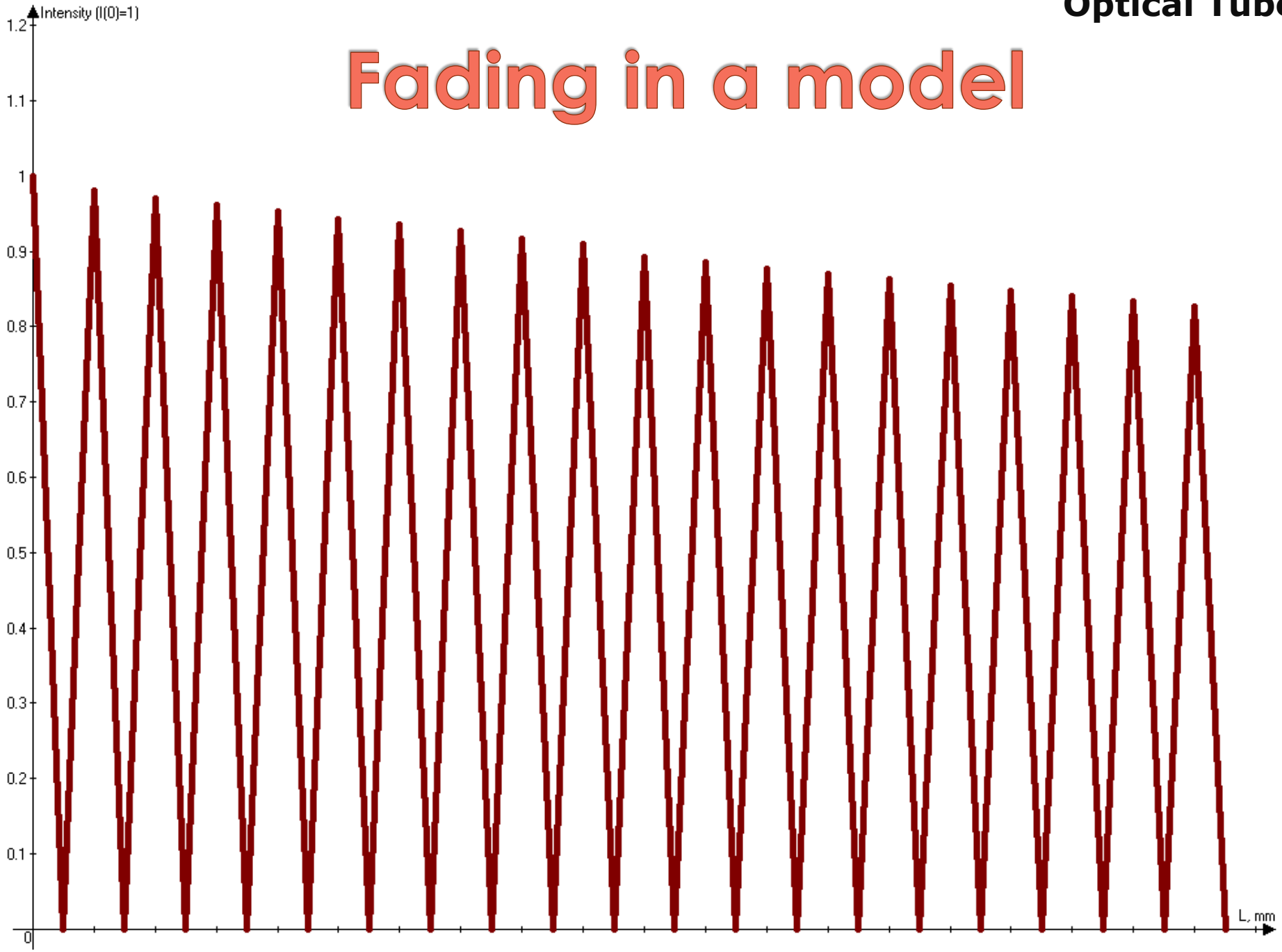
$$n = 0.32 \frac{1}{2 \cdot S}$$

Intensity fading

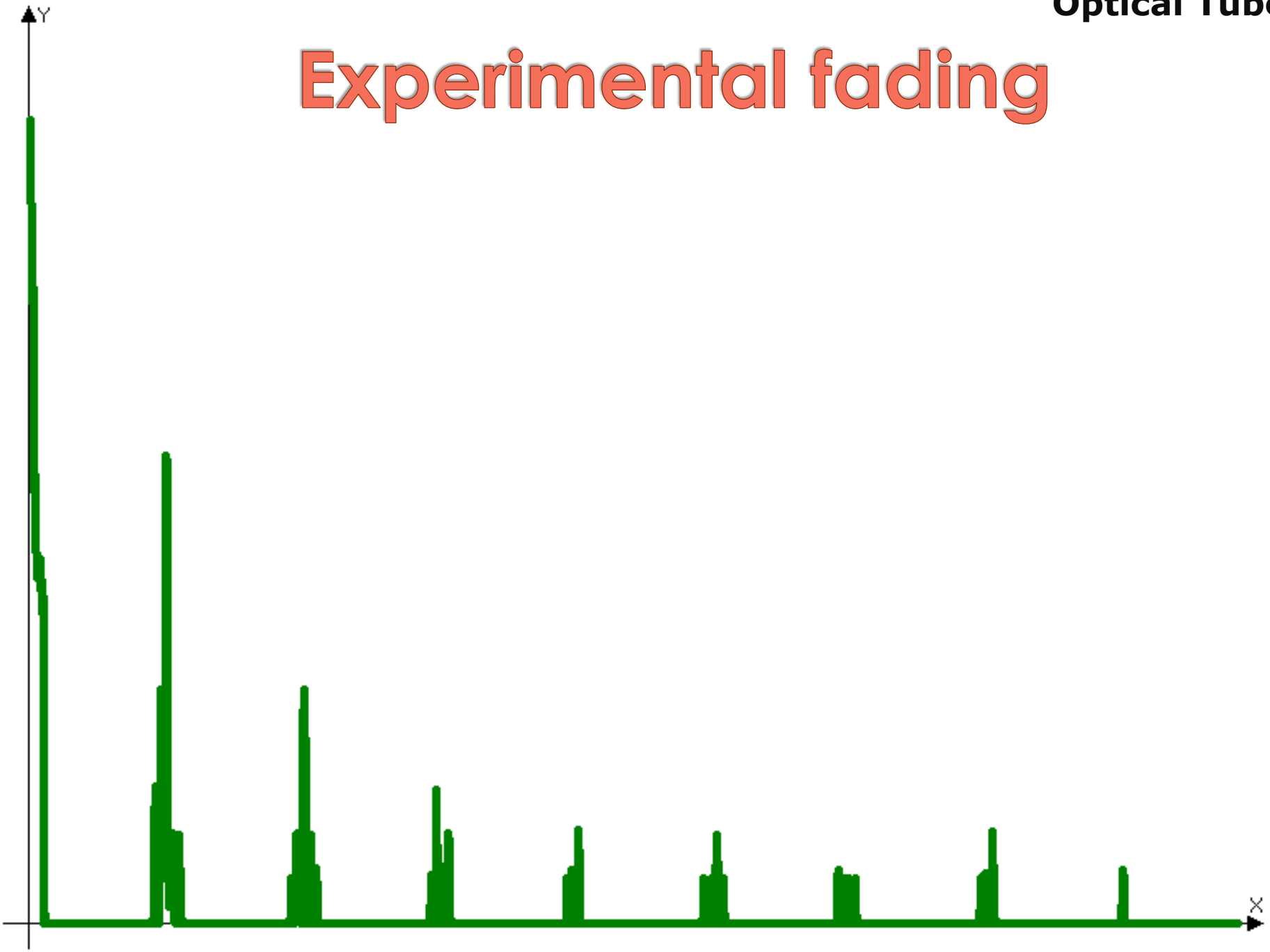


Fading in a model

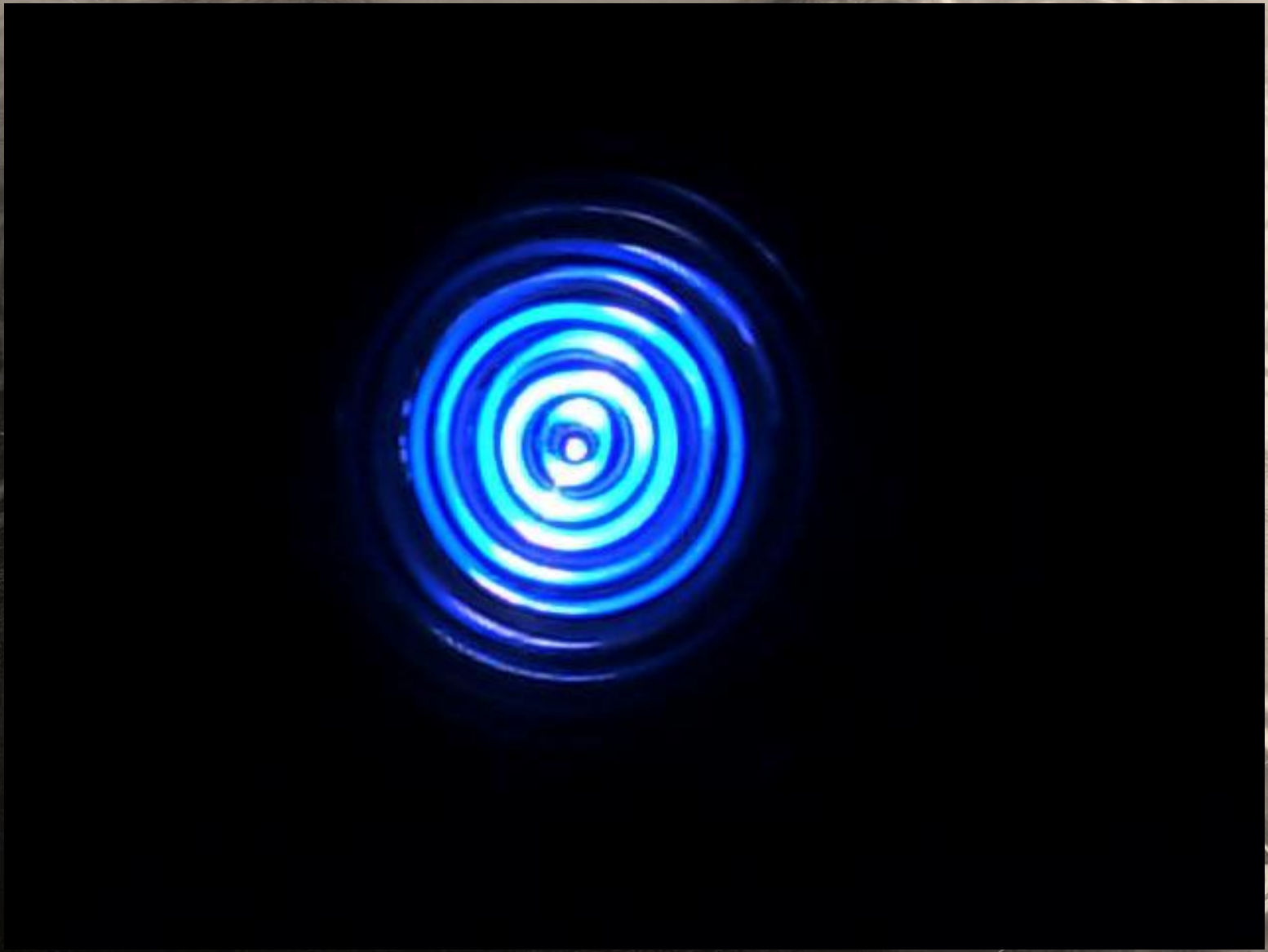
Fading in a model



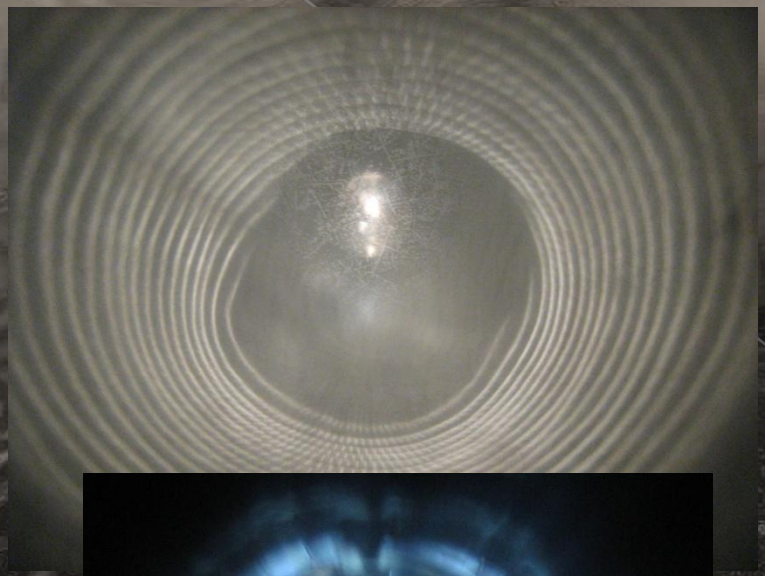
Experimental fading

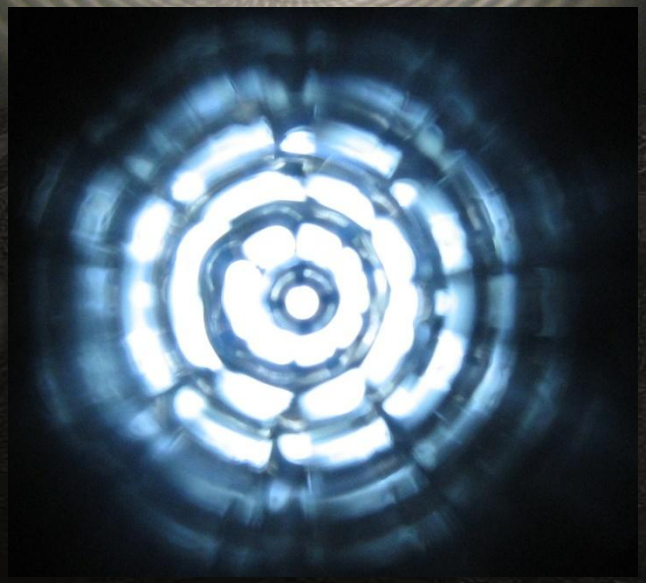


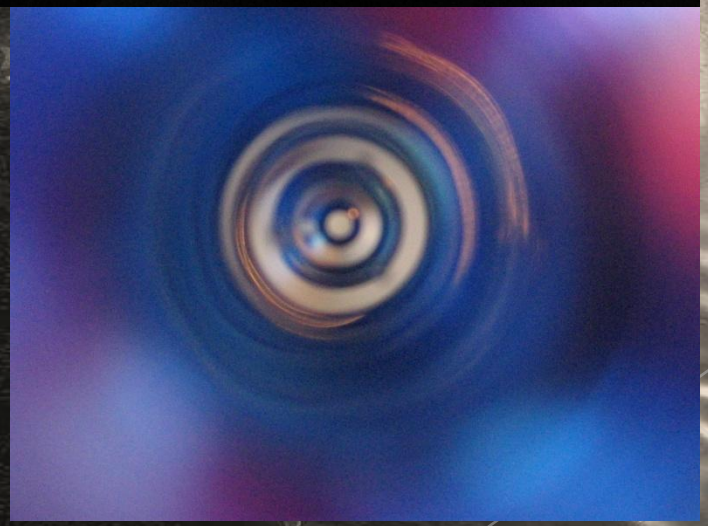
Glass Tube



Interesting effects







Conclusions

- The bands formation can be explained without involving wave effects.
- The bands are formed because of reflection on the inner side of the tube.
- We can divide an obtained image into zones. Each zone is formed by rays, which reflected same times.
- The boundary between zones is an image of the tube boarder.
- We cannot observe all the image zones due to the low intensity.

Results

- The formation of the bands is explained.
- The computer model, which can count the image for different parameters of the tube is created
- The equations for counting the “zones” are obtained

Literature

- Wikipedia: Whispering galleries
- Slobodjanuk A. I. “Advance high school physic”
- Slobodjanuk A. I. “Computer model of physical processes for high school students”
- Landsberg “Optics”

Thanks for your attention!

Some data

- Best vision zone 1.5 degrees.
- Clear vision zone 15 degrees.
- Maximum vision zone 35 degrees.

- The first ring= 0,19 rad

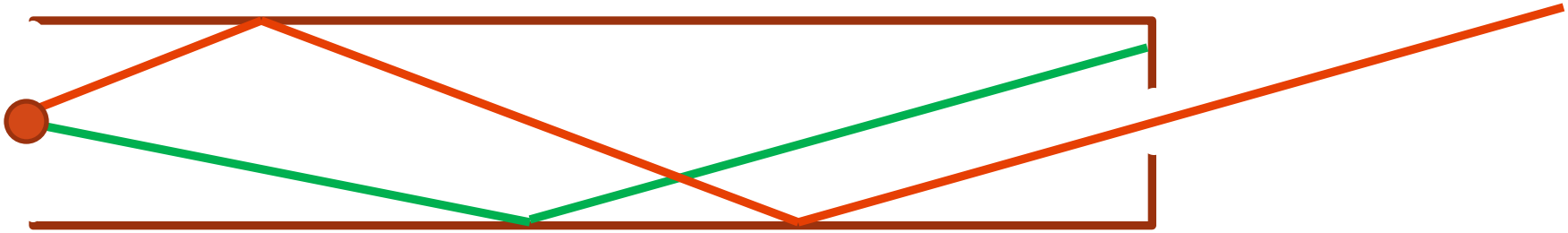
- S = 3mm

- First zone= 0,095 rad
- Second zone= 0,3 rad

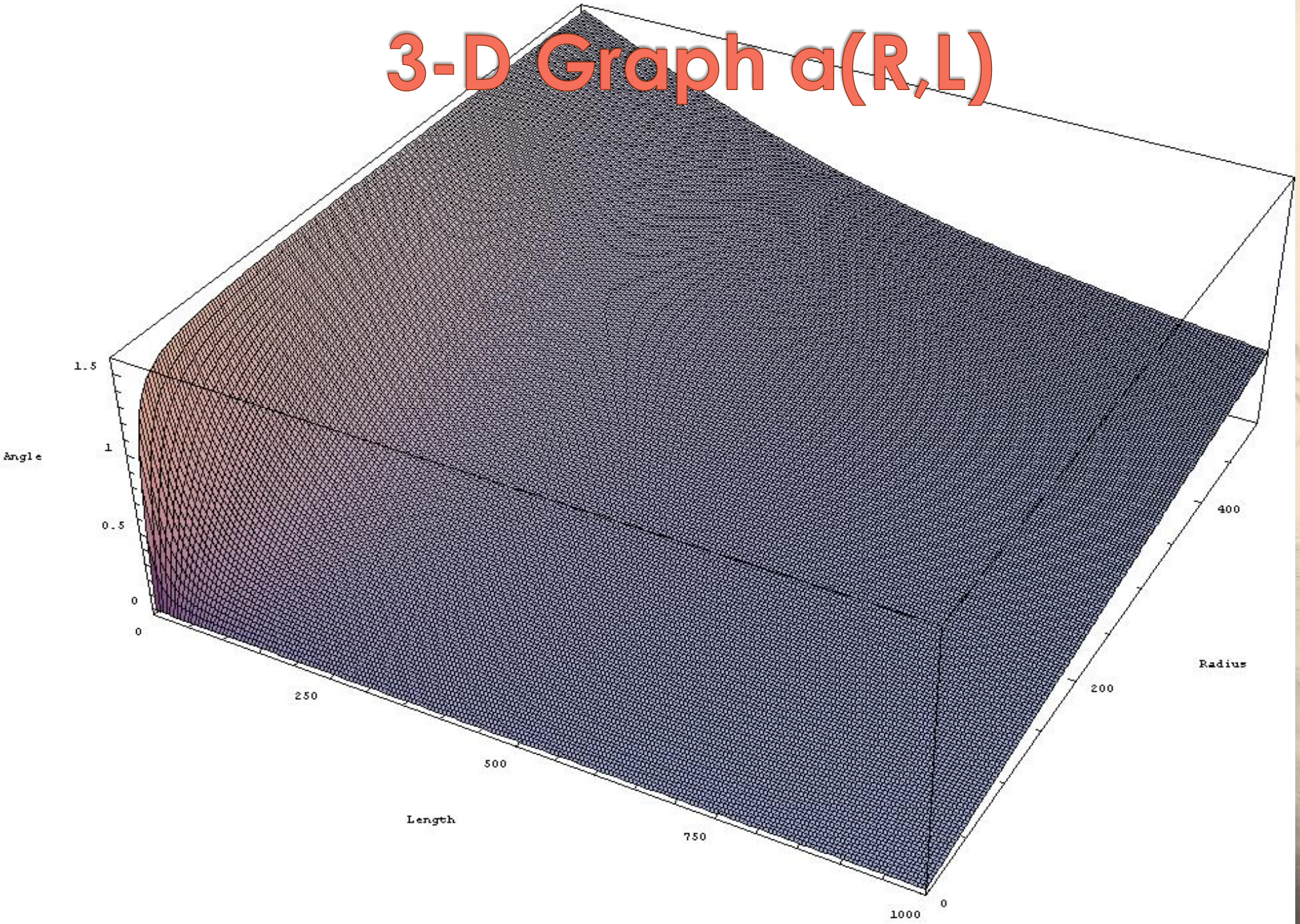
The most common equation

$$\alpha = \arctan\left(\frac{2 \cdot R \pm r}{L + l}\right)$$

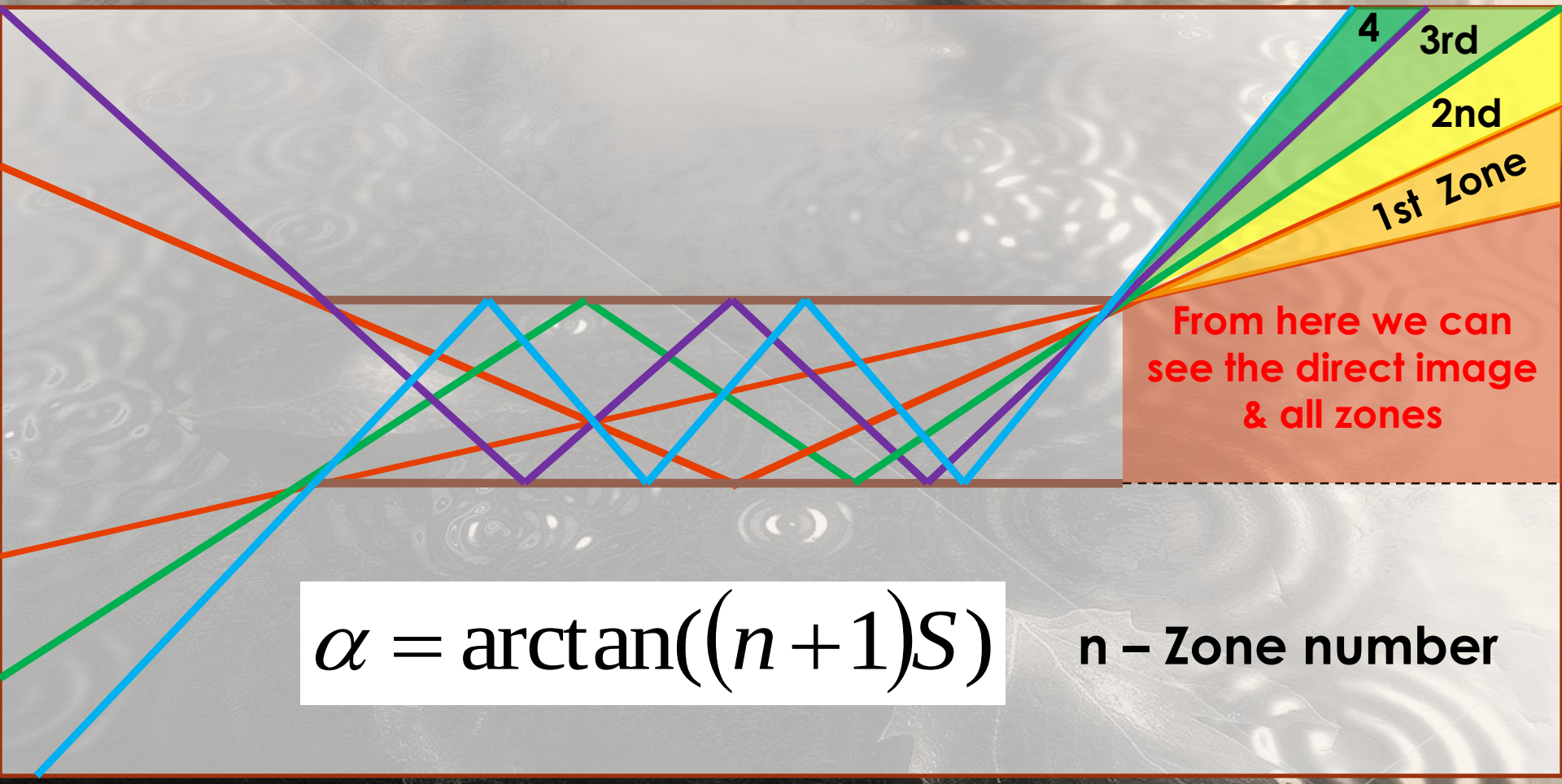
The hole



3-D Graph a(R,L)



From where can we see it?



$$\alpha = \arctan((n+1)S)$$

n – Zone number

If we are away from tube

$$N = \frac{l}{(l+L)} - 1$$

$$35 > \arctan\left(\frac{R}{l}\right)$$