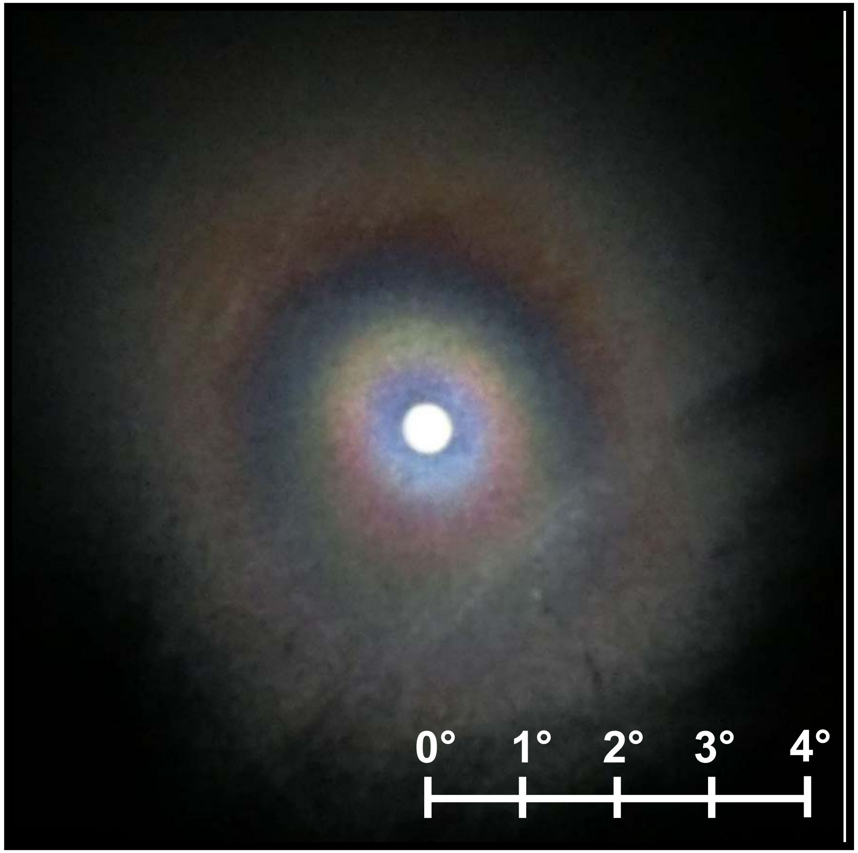
Misty glass

Breathe on a cold glass surface so that water vapour condenses on it. Look at a white lamp through the misted glass and you will see coloured rings appear outside a central fuzzy white spot. Explain the phenomenon.

Vyacheslav Matyunin, Russia

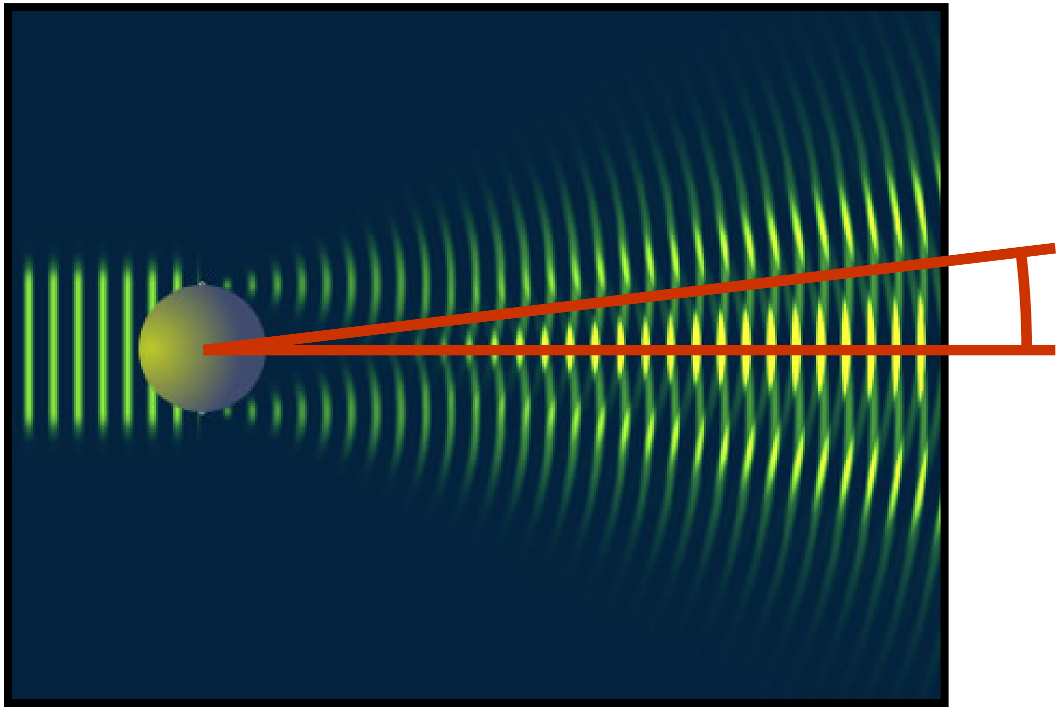
Corona as natural phenomenon

When a light from a bright compact source goes through a fog, clouds, dusty and misty glasses, we can observe some colored rings around a bright central spot. Those rings are called **coronae.**



A moon corona on a window glass

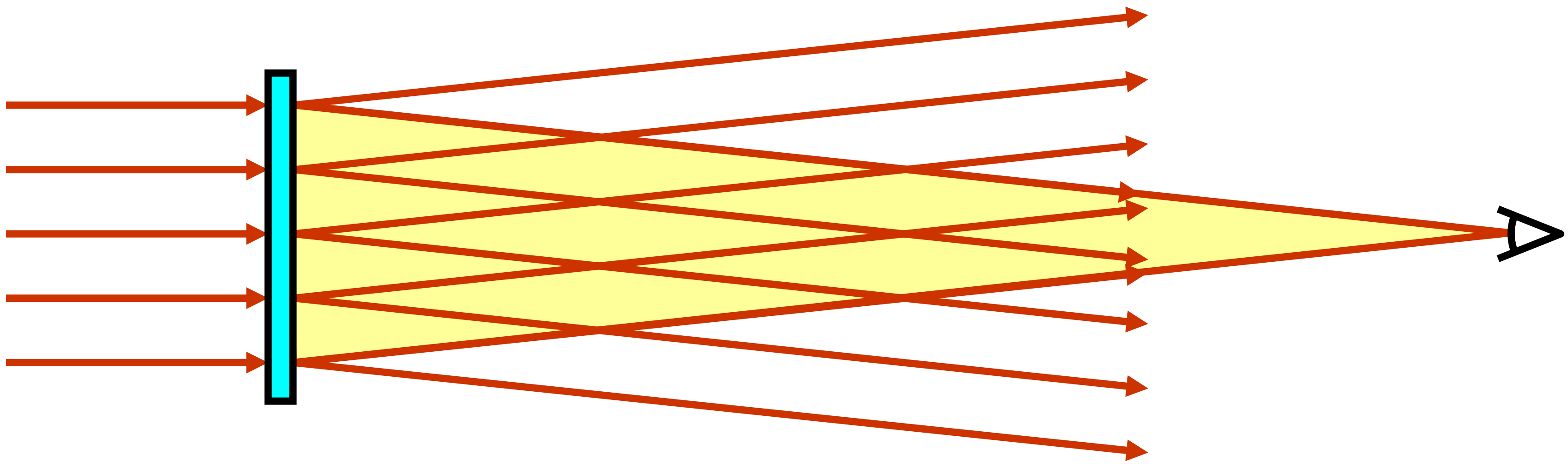
Diffraction of light



$$\theta \approx \frac{\lambda}{d}$$

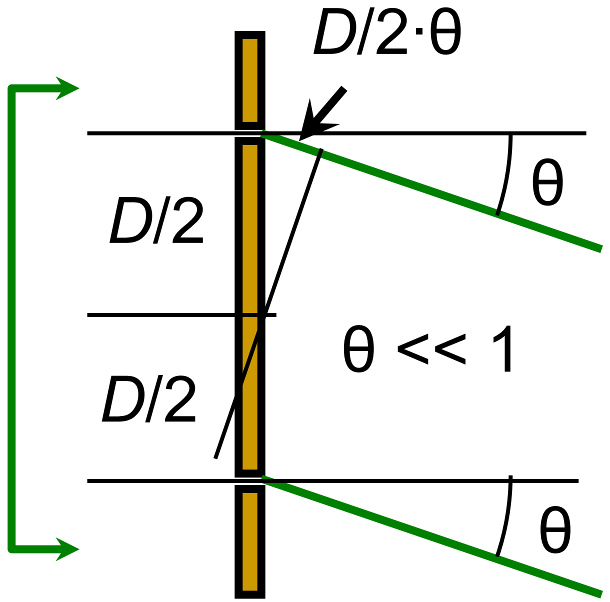
The phenomenon is based on the diffraction of light by small water droplets. Angular size of the rings is proportional to the wavelength and is inversely proportional to the diameter of the droplets.

A model formation of a light ring



Light which falls onto the glass is scattered by every drop and goes along a divergent cones. Some rays of these cones create a convergent cone with an apex in a pupil of the observer, so we can see a light ring.

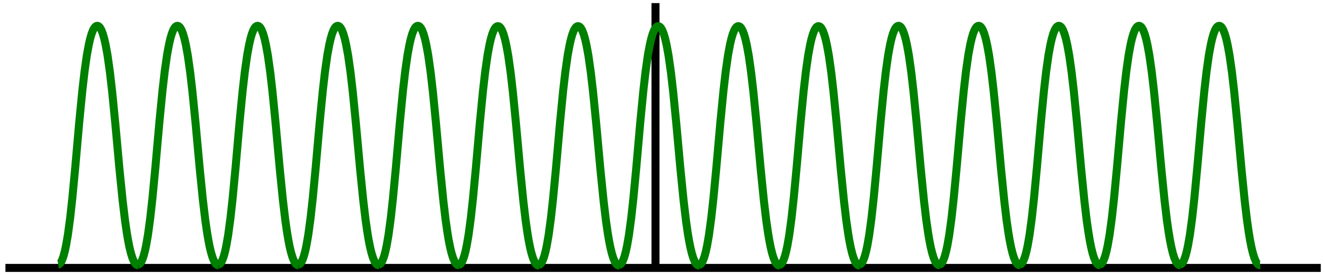
Fraunhofer diffraction on two “narrow” slits



$$\varphi = 2\pi \frac{(D/2)\cdot\theta}{\lambda}$$

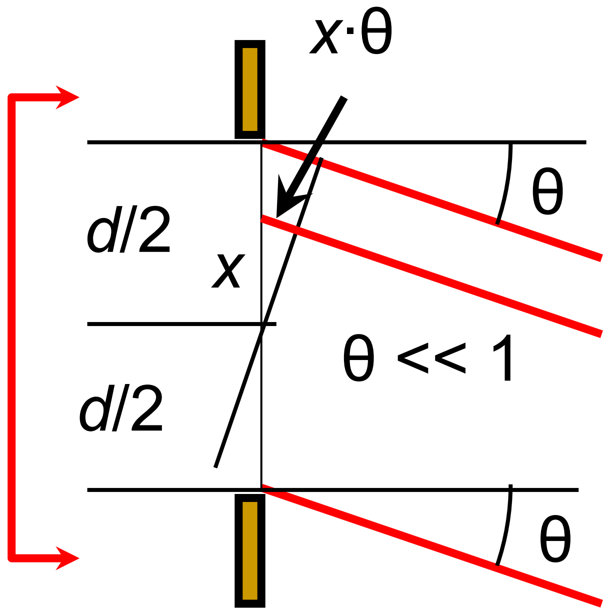
$$A = A_0\ \{\sin(\omega t + \varphi) + \sin(\omega t - \varphi)\} =$$
$$= 2A_0 \cdot \cos\varphi \cdot \sin\omega t$$

$$I = I_0 \cos^2\left(\pi \frac{D}{\lambda}\theta\right)$$



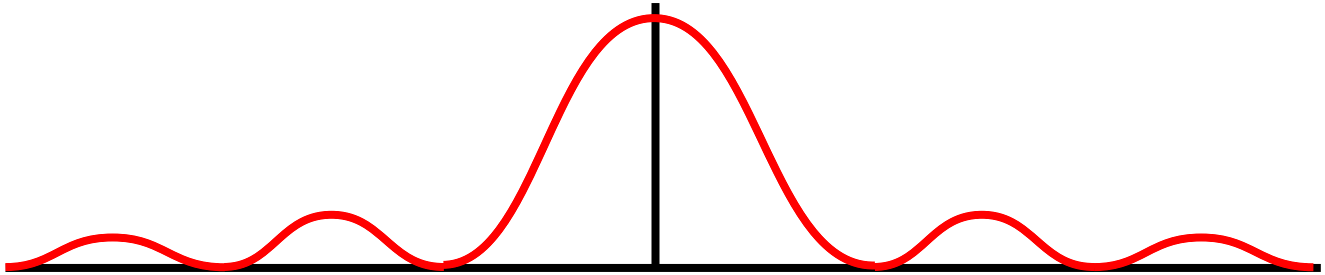
Light intensity distribution

Fraunhofer diffraction on a single "wide" slit



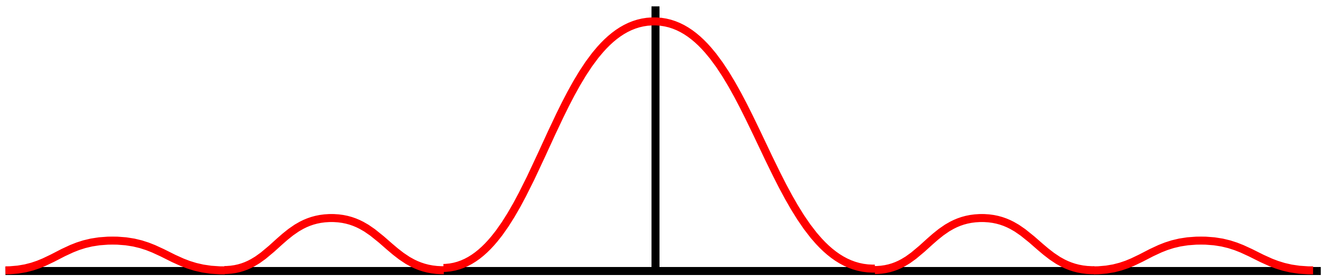
$$A = A_0 \int_{-d/2}^{d/2} \sin\left(\omega t + \frac{2\pi\theta}{\lambda}x\right)dx$$

$$I = I_0 \left\{ \frac{\sin\left(\frac{\pi d\theta}{\lambda}\right)}{\left(\frac{\pi d\theta}{\lambda}\right)} \right\}^2$$

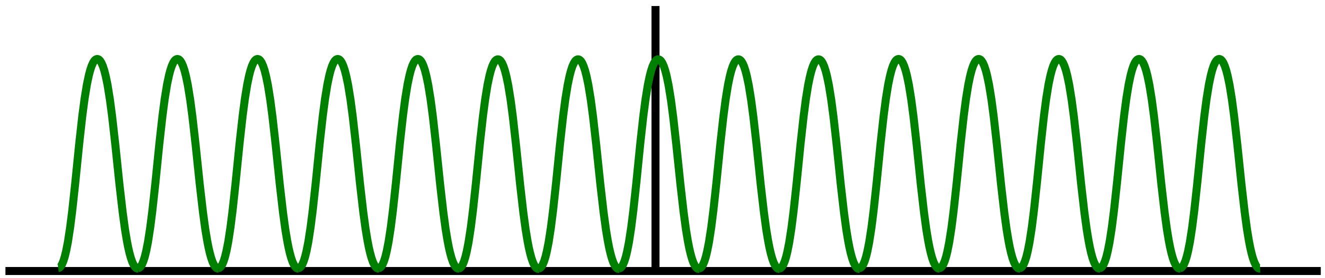


Light intensity distribution

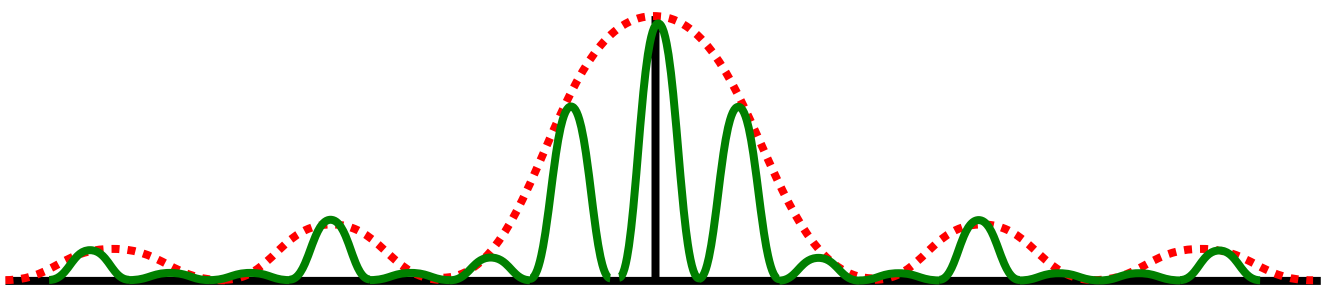
Fraunhofer diffraction on two “wide” slits



Diffraction factor — one “wide” slit

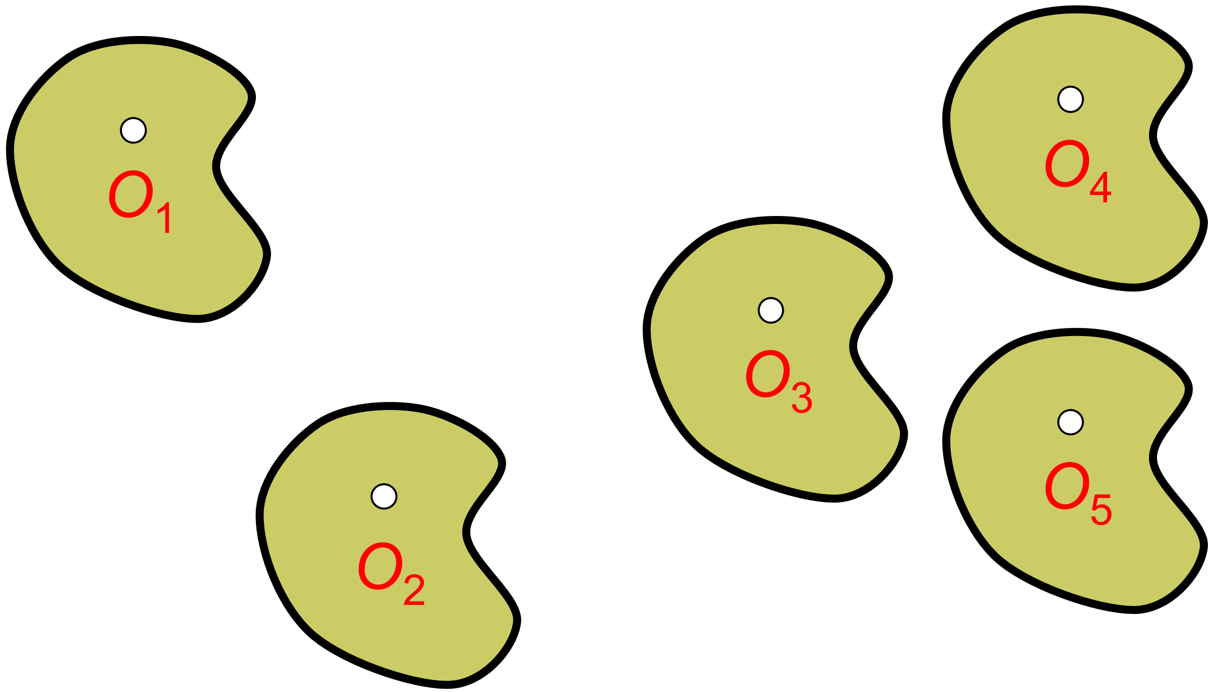


Structural factor — two “narrow” slits



The product of two factors

The array theorem

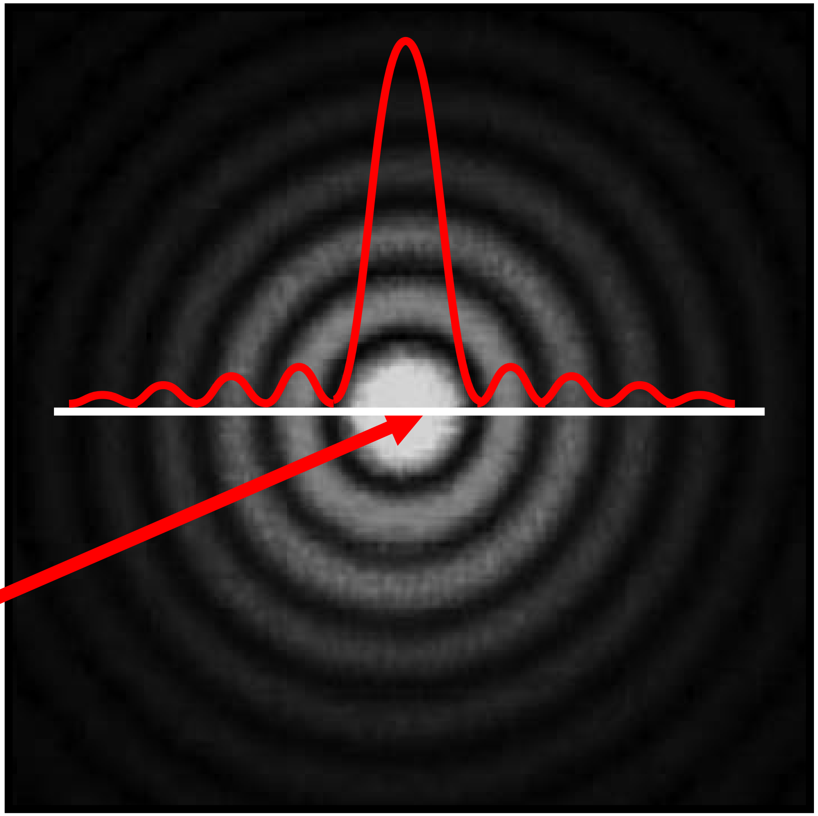


When monochromatic light is scattered on an array of identical and similarly oriented apertures, the distribution of its intensity in far field will be a product of two factors: **diffraction factor**, which is obtained by a diffraction from any one aperture, and **structural factor**, which is obtained by an interference of many similarly located point sources.

Fraunhofer diffraction on an opaque disk

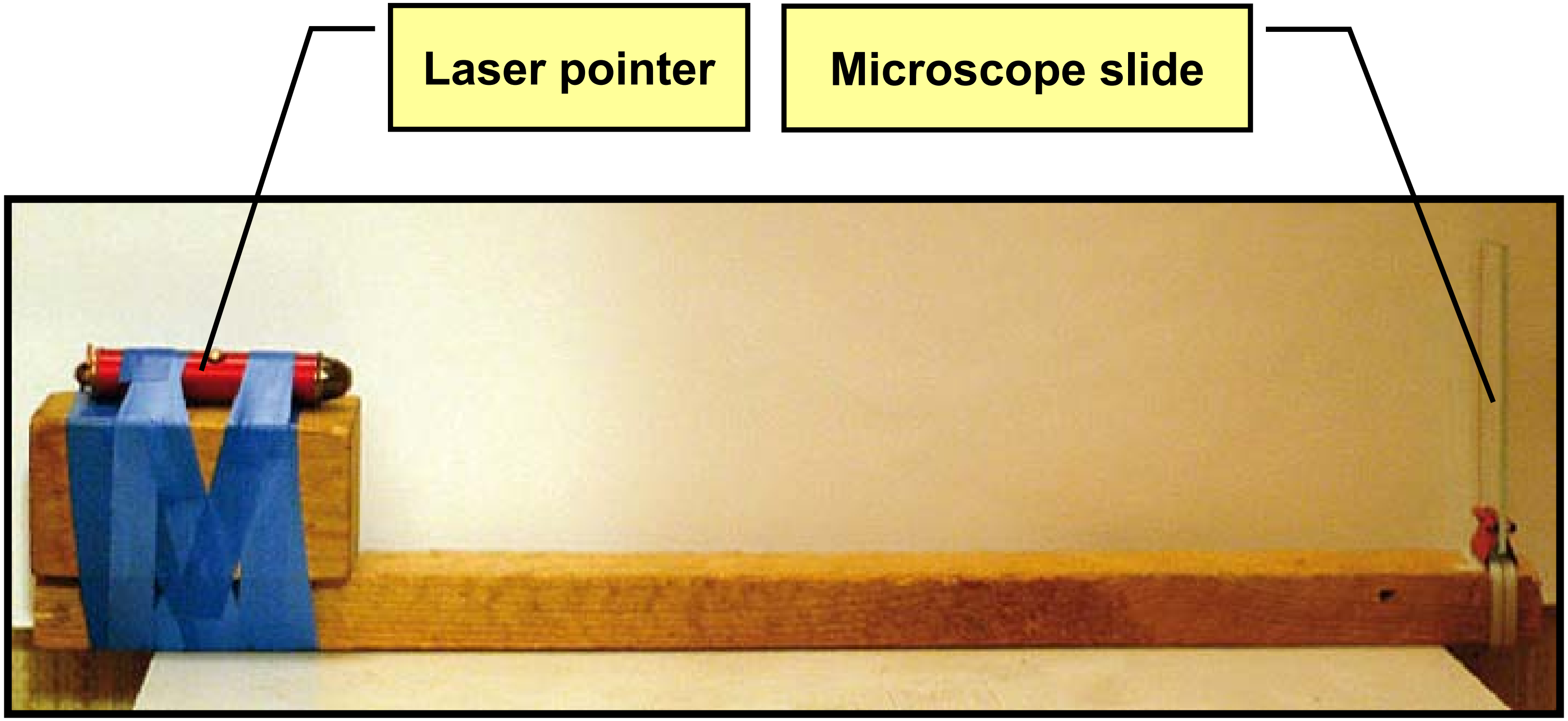
$$I(\theta) = 4\left(\frac{J_1\left(\frac{\pi D\theta}{\lambda}\right)}{\frac{\pi D\theta}{\lambda}}\right)^2$$

84% of energy

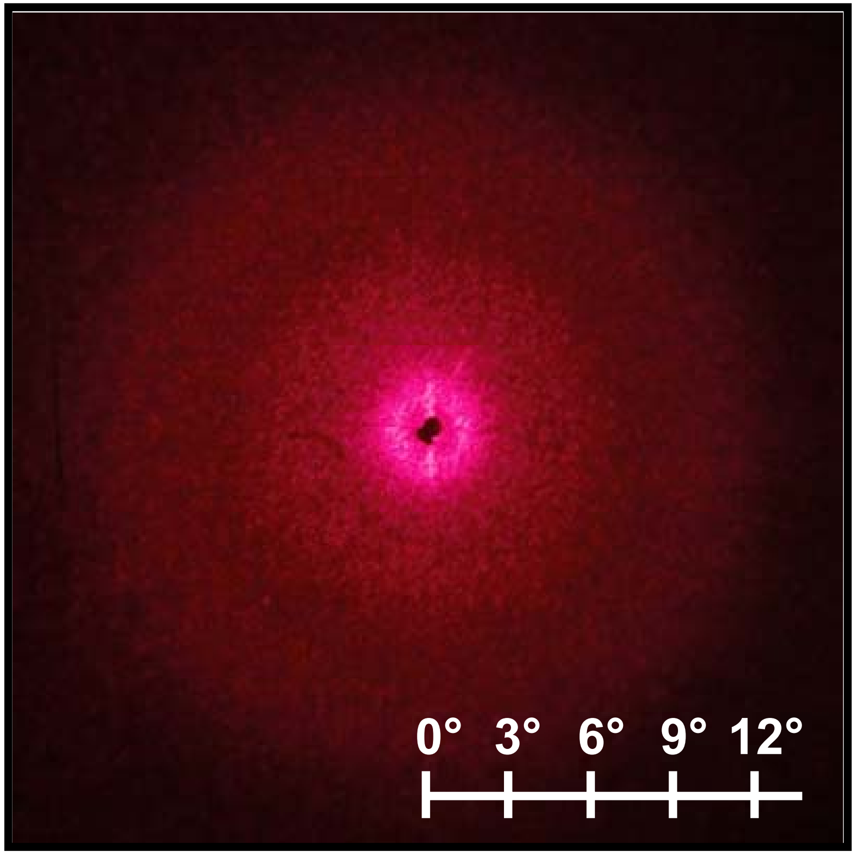


In our observations of coronae such a bright central spot was absent.

Experimental setup

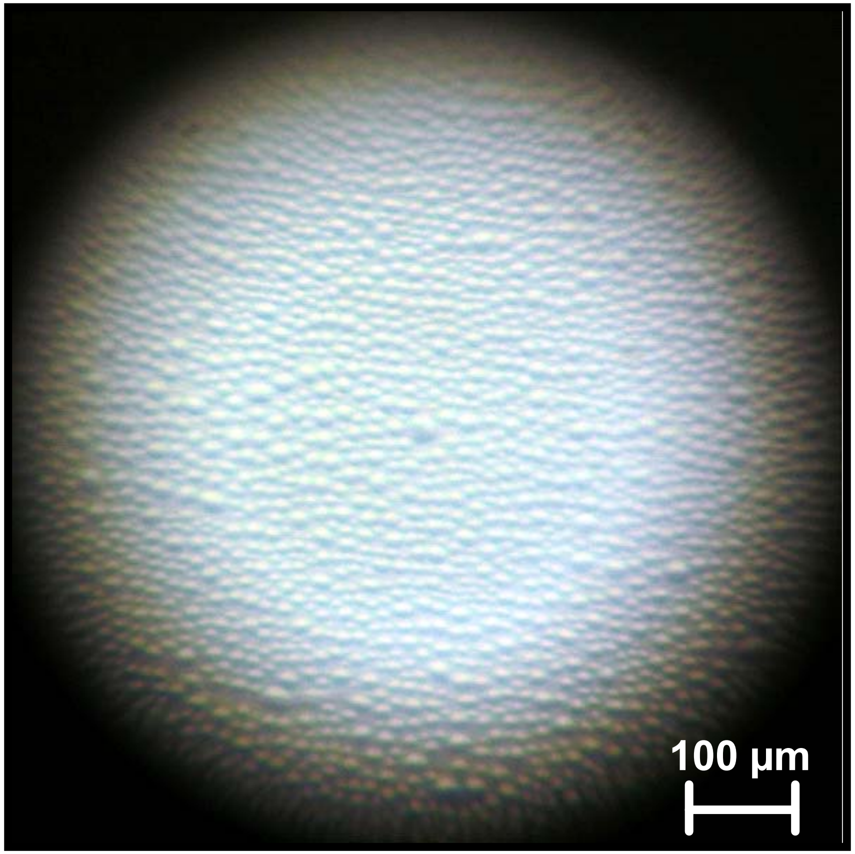


Diffraction of a laser beam from a misty glass



Radius of the central ring θ ~ 2°
For this radius λ / θ ~ 15 μm

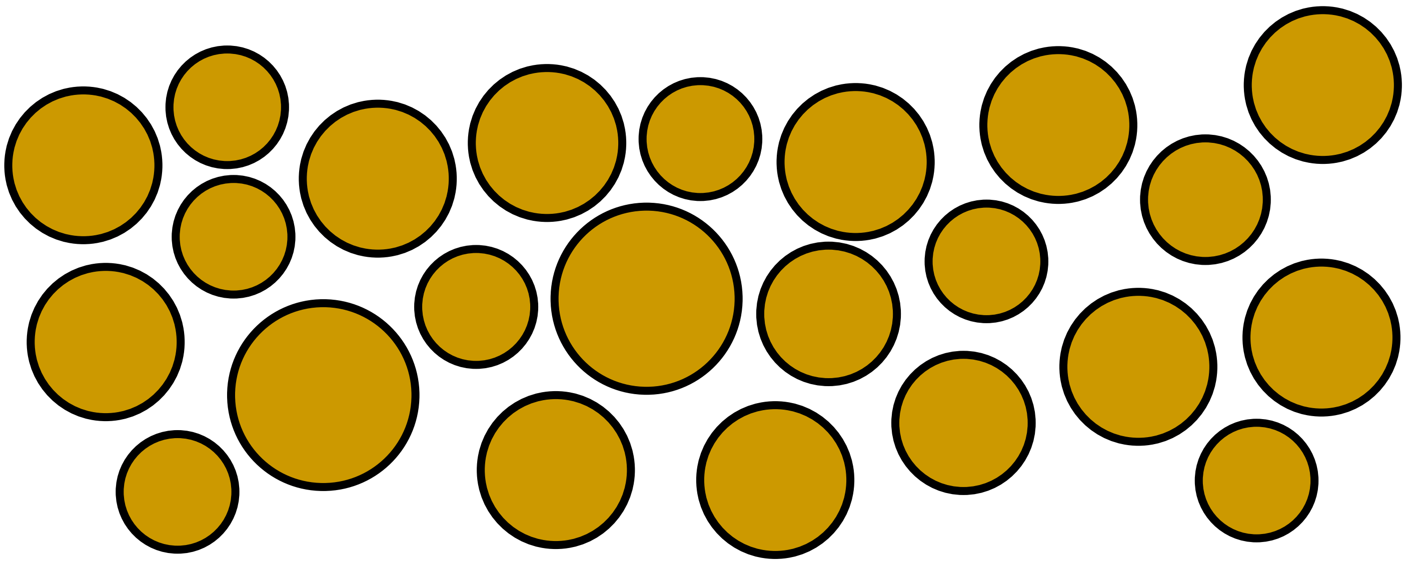
Misty glass under a microscope



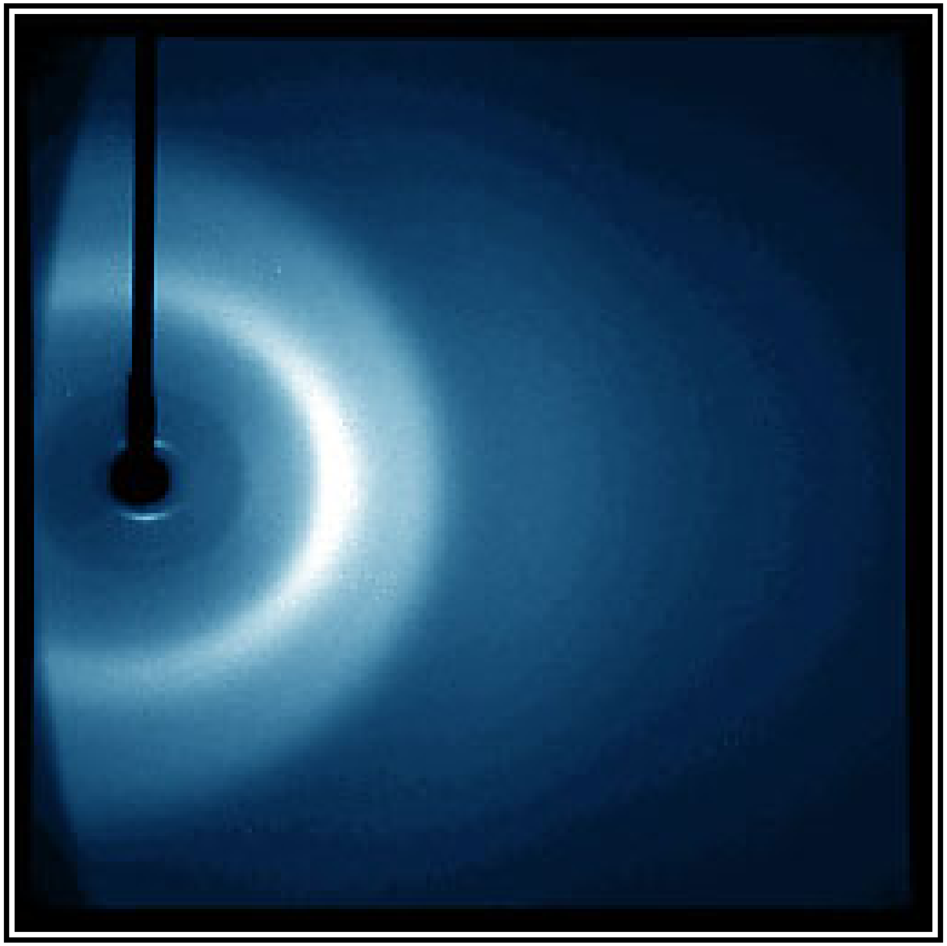
Water droplets are situated closely one near another.
Diameter of the droplets is about 10–20 µm.

Main feature of misty glasses

- **A location of water droplets is not completely random and has a short-range order.**
- The gaps between neighboring droplets are comparable with their diameters.

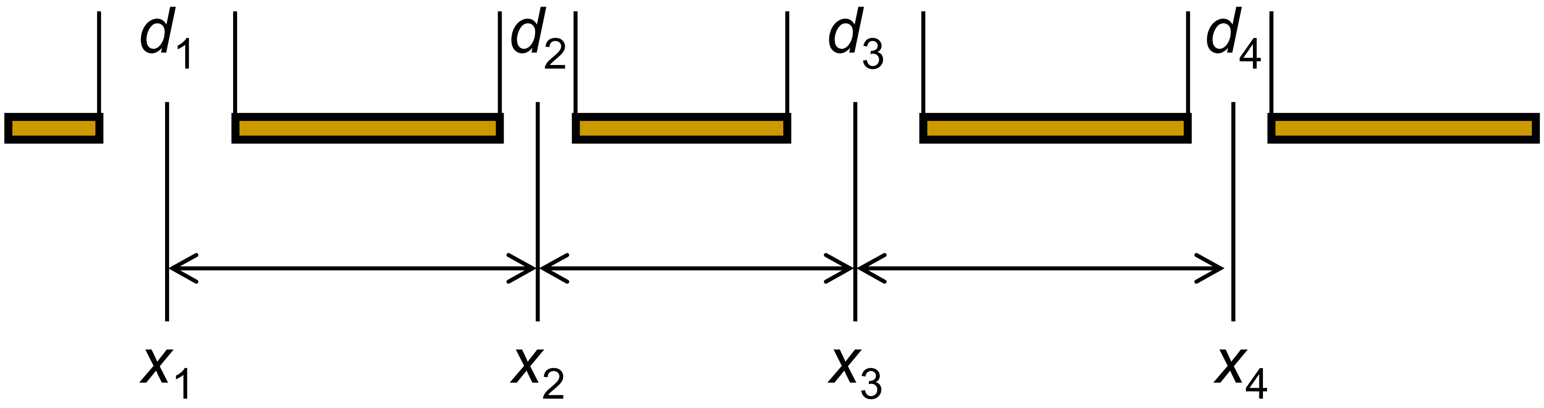


Analogy: X-ray diffraction on amorphous solids and liquids



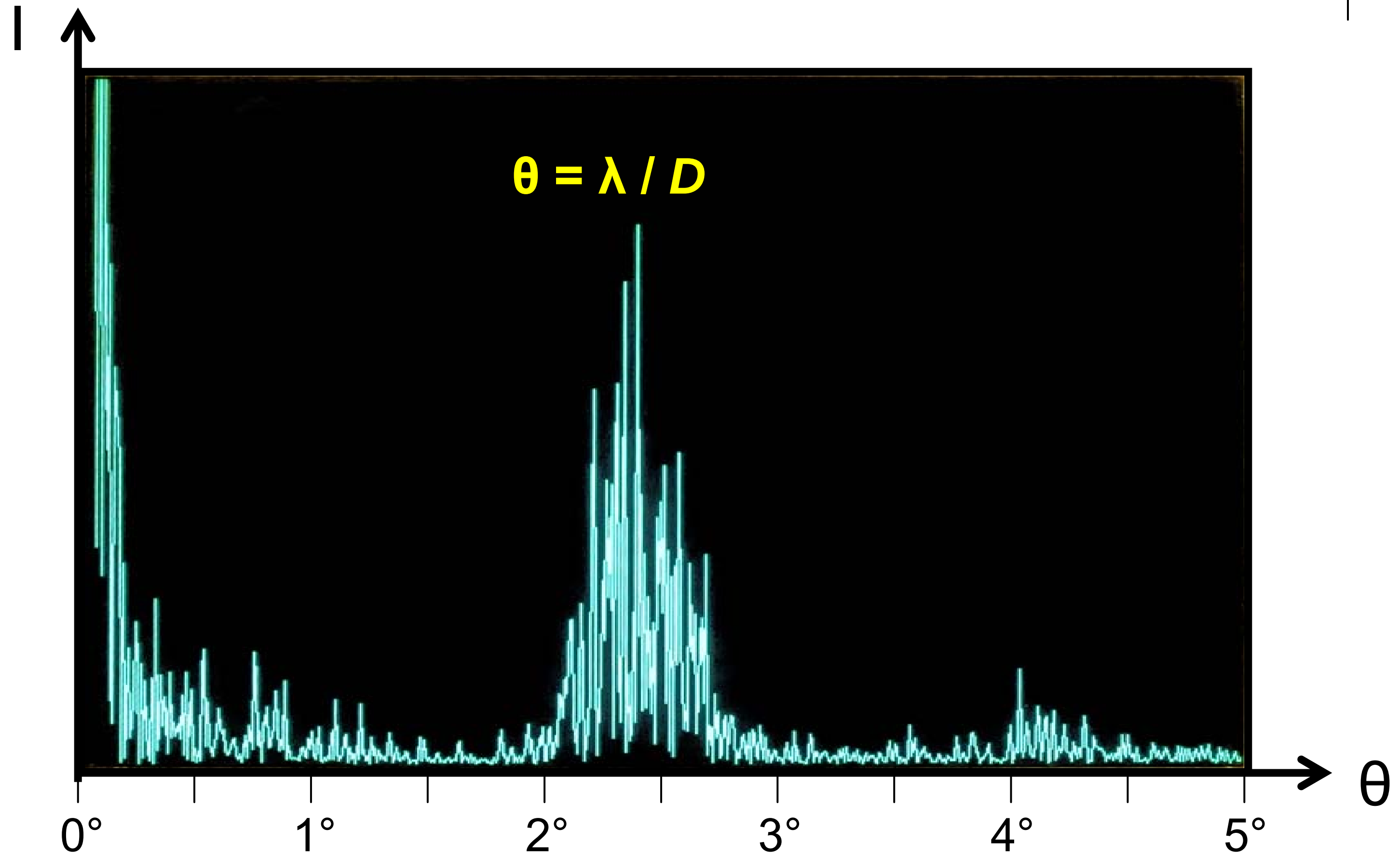
X-ray scattering pattern of water
Lawrence Berkeley National Laboratory

Diffraction grating with irregularly spaced slits



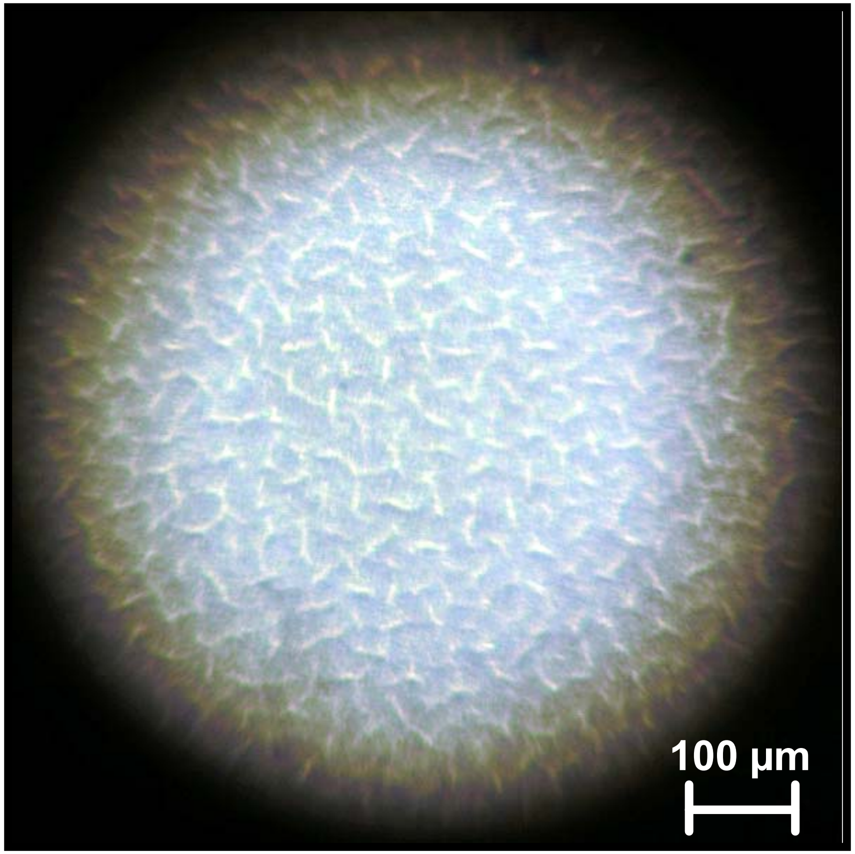
$$I(\theta) = \left(\frac{A\lambda}{\pi\theta}\right)^2 \cdot \sum_{i=1}^{N}\sum_{j=1}^{N} \sin\left(\frac{\pi d_i \theta}{\lambda}\right) \sin\left(\frac{\pi d_j \theta}{\lambda}\right) \cos\left(\frac{2\pi(x_i - x_j)\theta}{\lambda}\right)$$

Computer simulation



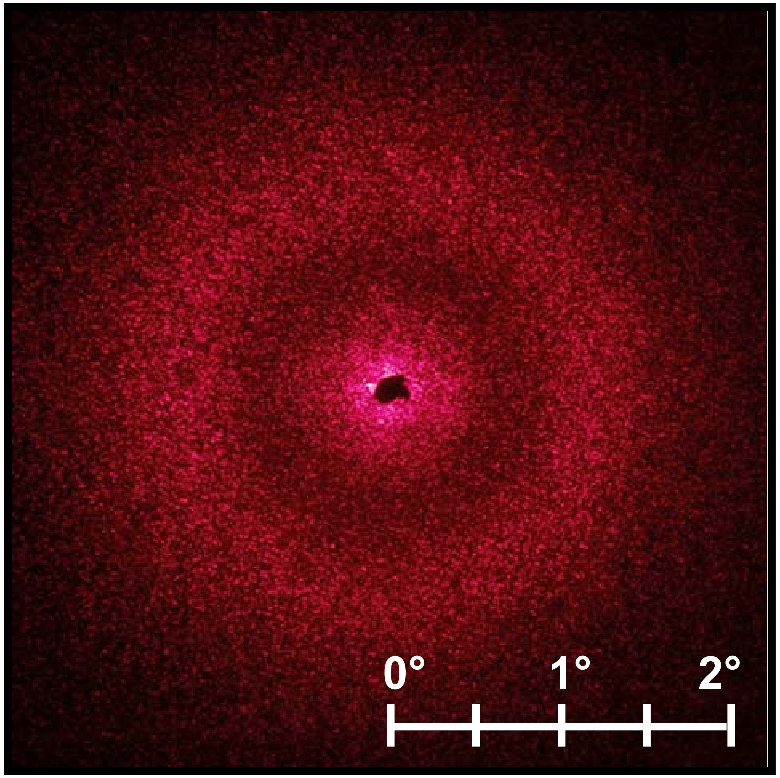
D = 12 ± 3 μm, *d* = 9 ± 1 μm, *N* = 200 , λ = 0,5 μm.

Processed photographic film with reticulation effect

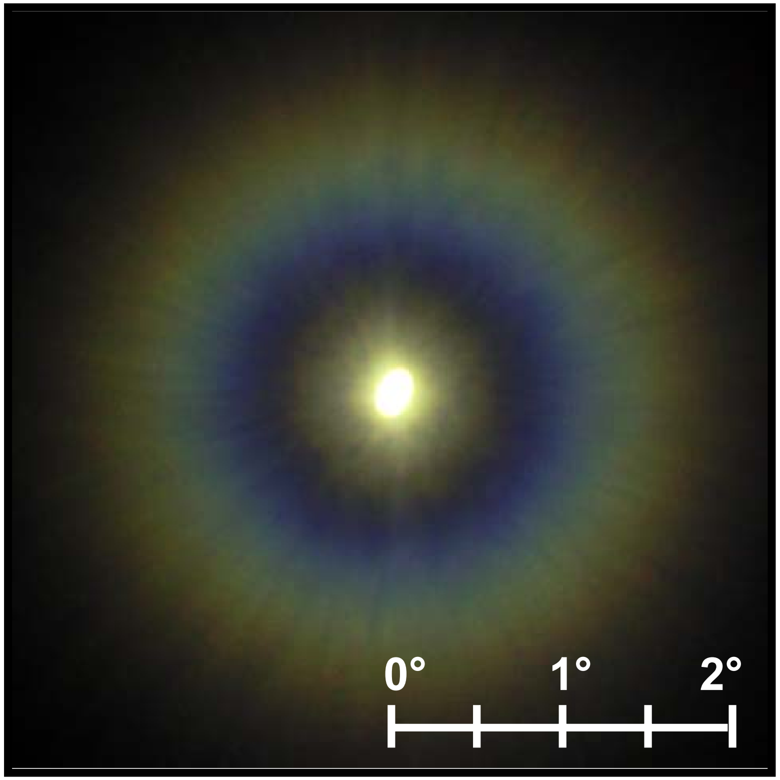


Reticulation is the worm-liked pattern of the photo emulsion caused by an incorrect procession. Width of a “worm” is about 25 μm.

Observation of coronae through reticulated film



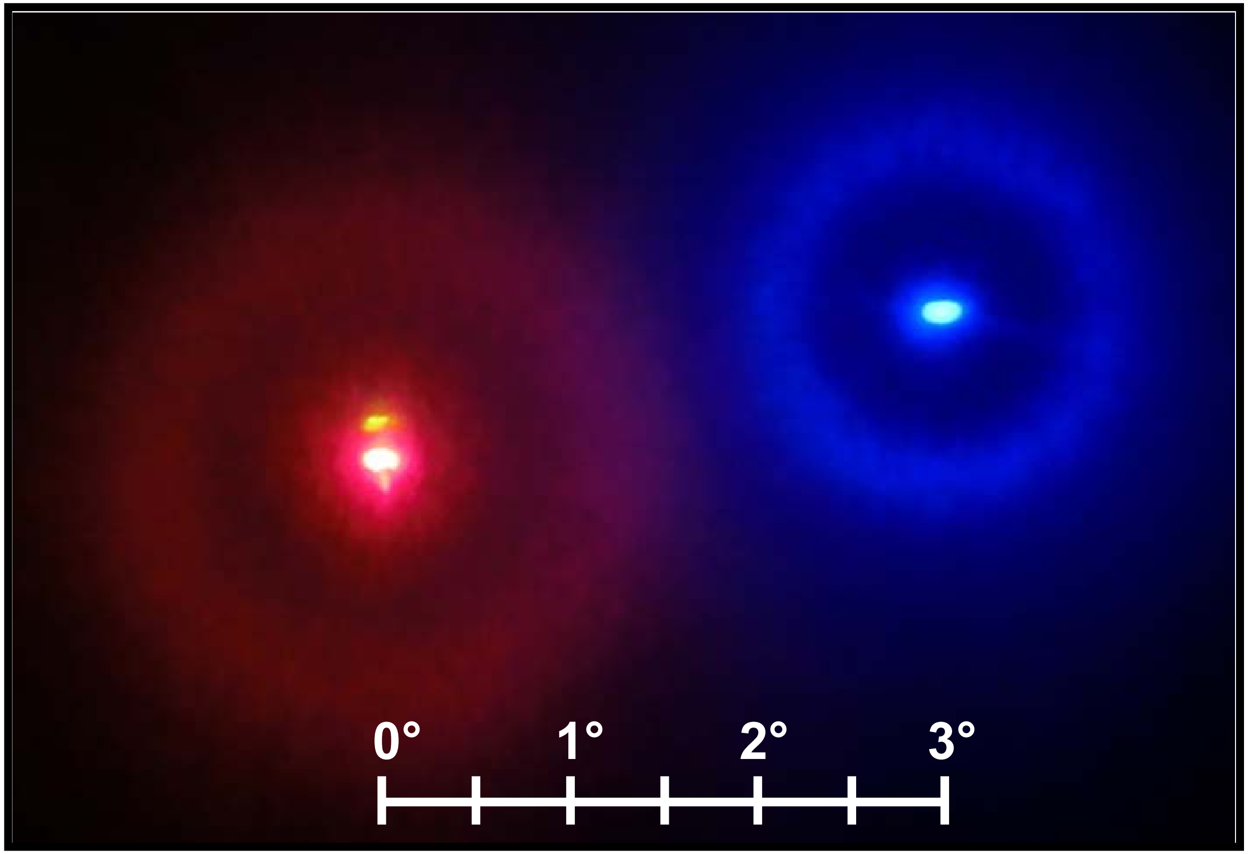
Corona of a laser beam



Corona of a street lantern

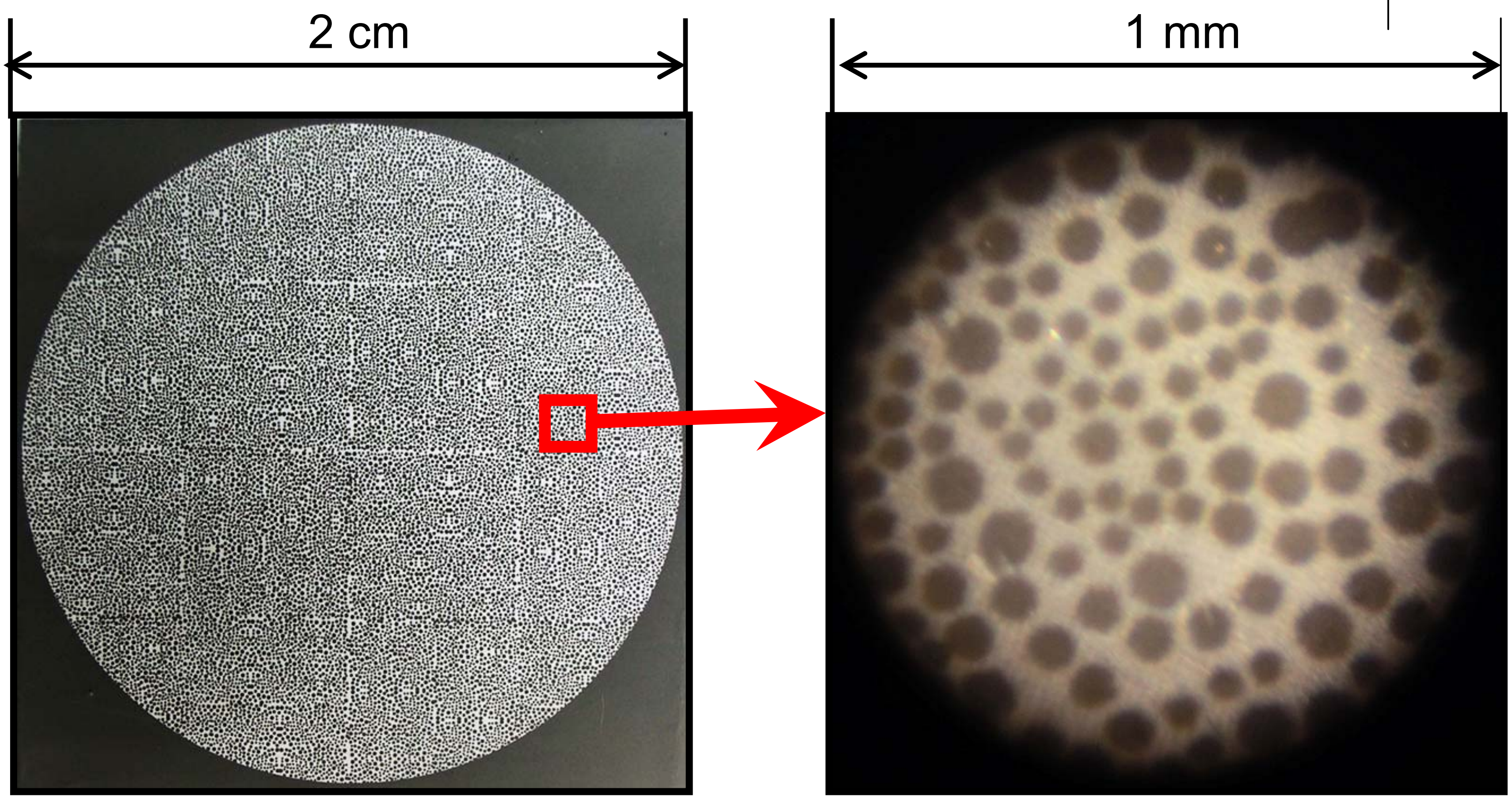
Radius of the main ring $\theta \sim 1.3°$.
For this radius $\lambda / \theta \sim 25$ μm.

Two sources of different light color



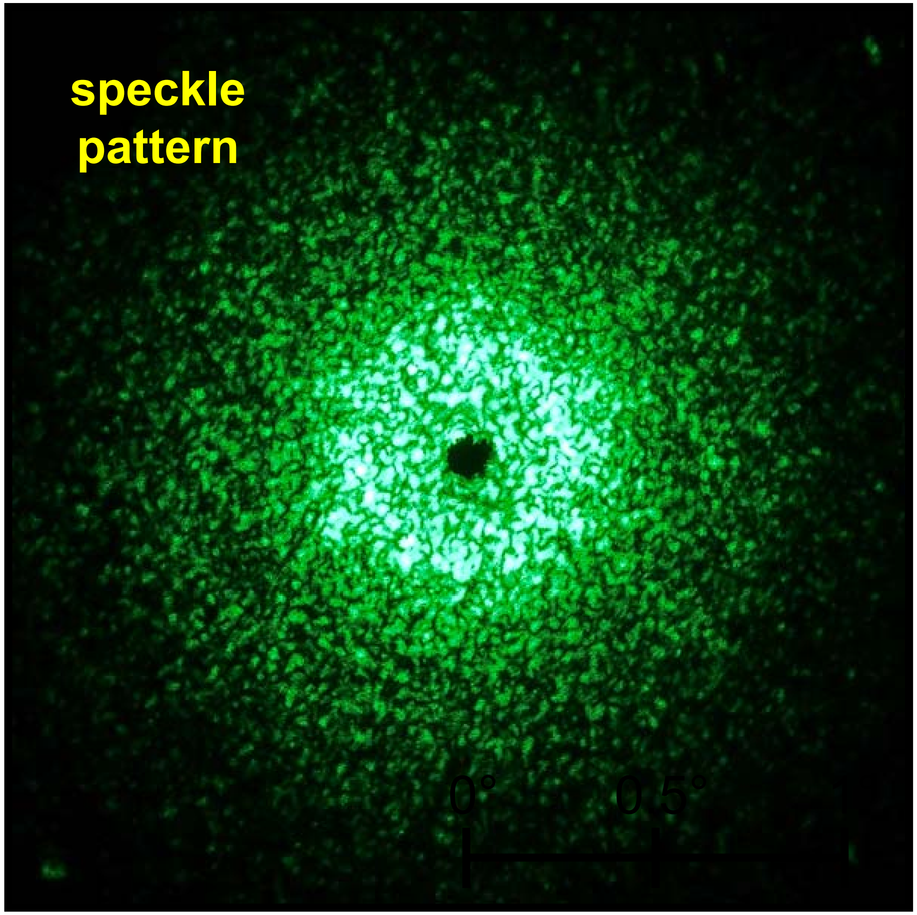
Two coronae around two photodiodes.
Red rings are visibly wider than blue ones.

An artificial model of misty glass



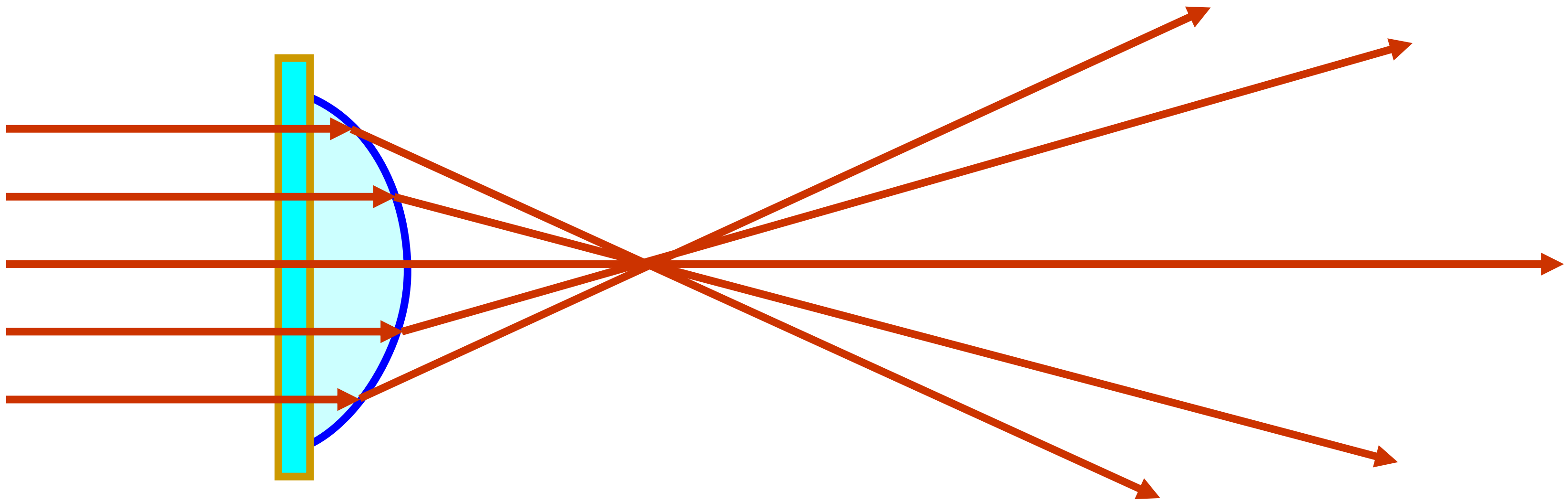
Diameter of circles ~ 50÷100 μm
Distance between the circles ~ 100 μm

Diffraction of a laser beam from artificial “droplets”



Radius of the central ring θ ~ 0.3°.
For this radius λ / θ ~ 100 μm.

Why can we consider the droplet as an opaque disk?



The droplet is not opaque. But it refracts light rays, and the cone of refraction is much wider than the cone of diffraction. So an intensity of refracted light is much lower than an intensity of diffracted light.

Summary

- Fraunhofer diffraction of light on water droplets as a basis of the phenomenon
- Absence of central bright spot (main feature!)
- Short-range order of water droplets
- Analogy with X-ray diffraction
- One-dimensional computer model
- Observations with a reticulated film
- Artificial model of misty glass
- Role of refraction

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