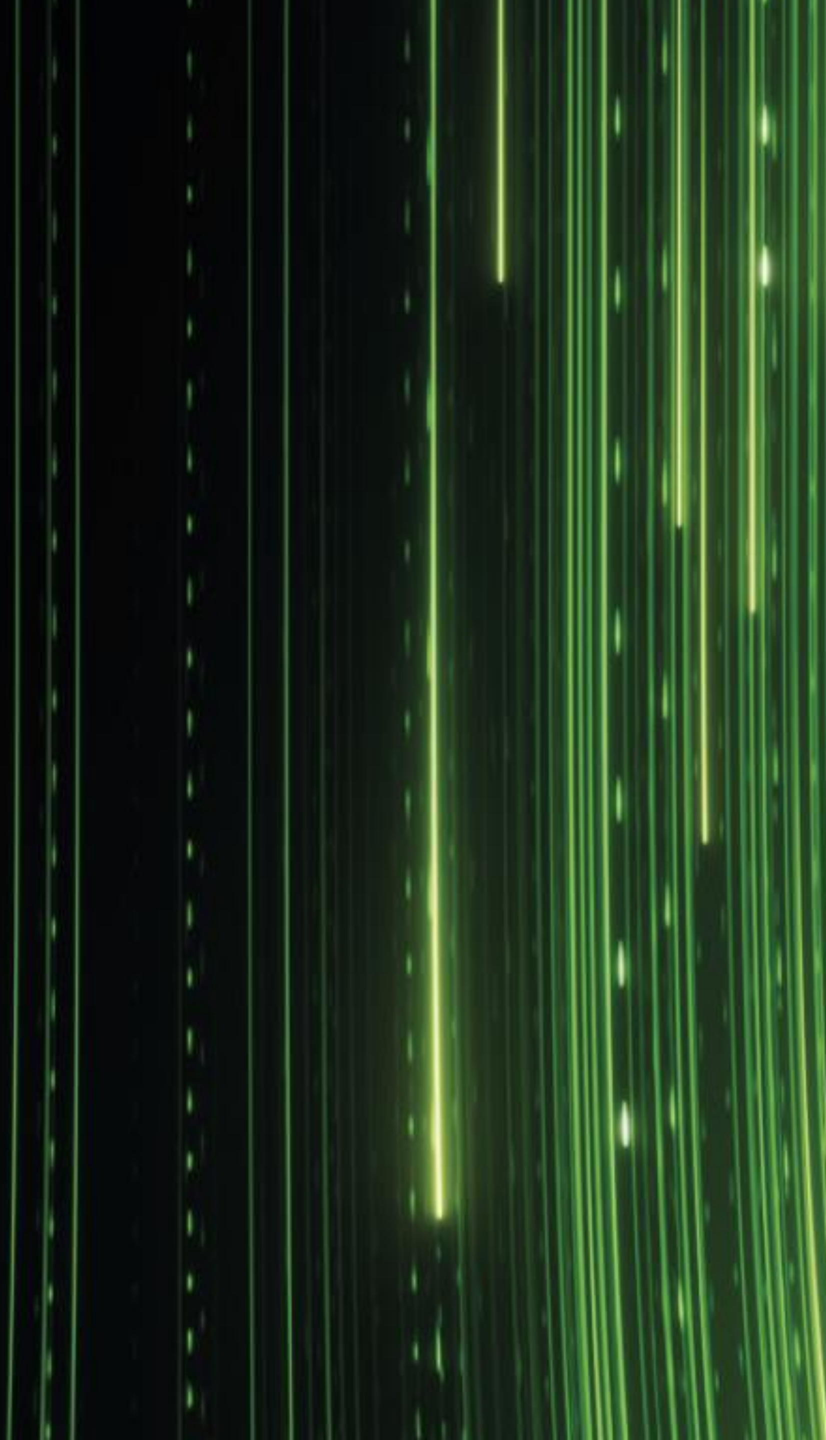
PULSE

Introduction to Photonics



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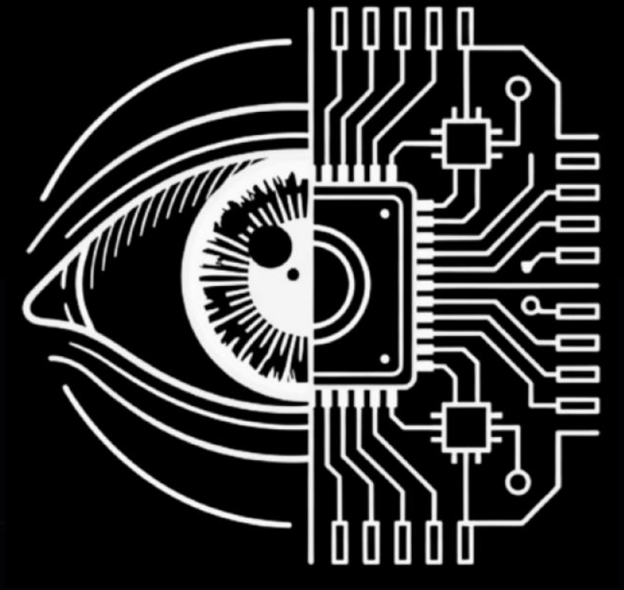
What is Photonics?

Generation ,manipulation,
and detection of light
particles (photons)



The backbone of modern
tech: moving data at the
speed of light

THE SCIENCE OF LIGHT

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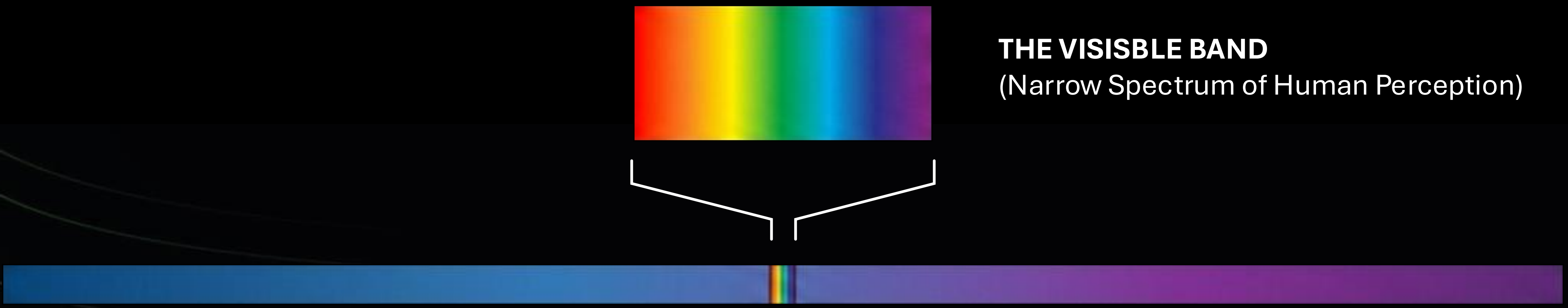
The Nature of Light

RAY
Explains propagation and reflection.
Assumes light travels in straight lines

WAVE
Explains electromagnetic phenomena: polarization, interferance, and diffusion

PARTICLE
Explains quantum phenomena: energy absorption, emisión, and the photoelectric effect

The Electromagnetic Spectrum



THE VISISBLE BAND
(Narrow Spectrum of Human Perception)

Radio & Microwaves
Low Energy / Long Wavelentth

X-Rays & Gamma
High Energy / Short Wavelentth

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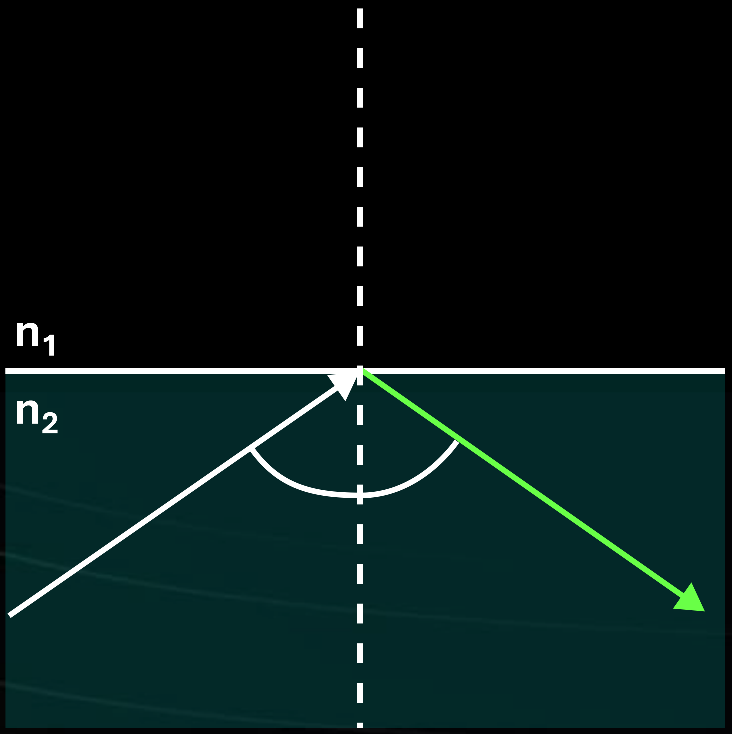
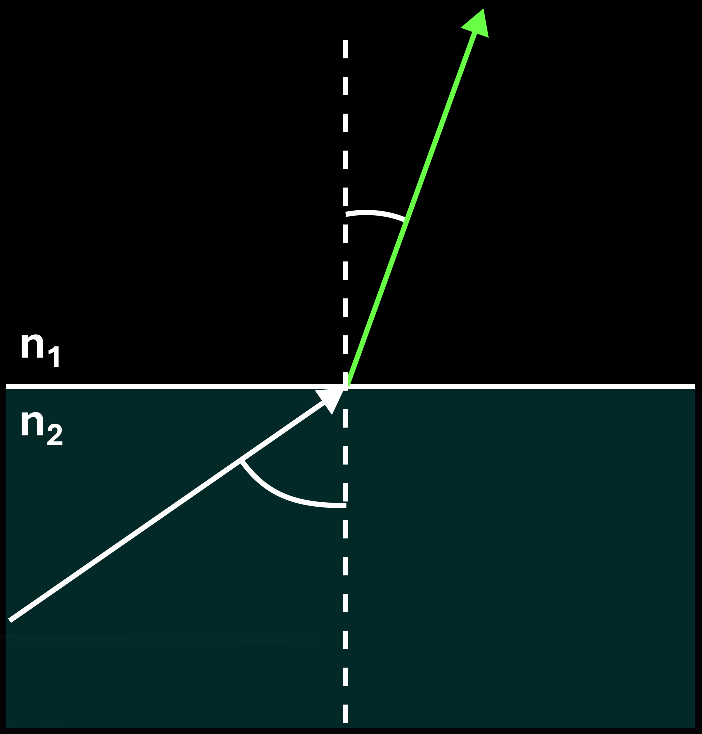
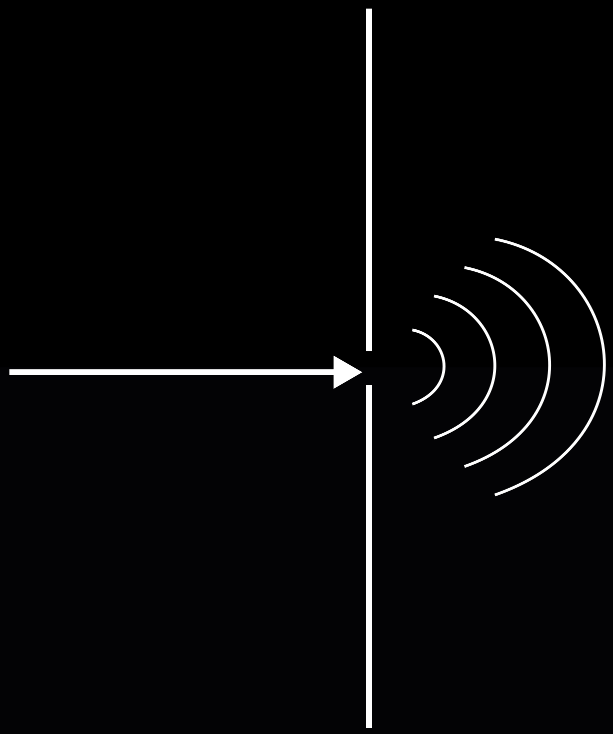
Fundamental of Optics



Reflection
The incident ray and reflected ray mirror each other



Refraction
The bending of light as it shifts between mediums



Diffraction
The spreading of a wave as it passes through an obstacle

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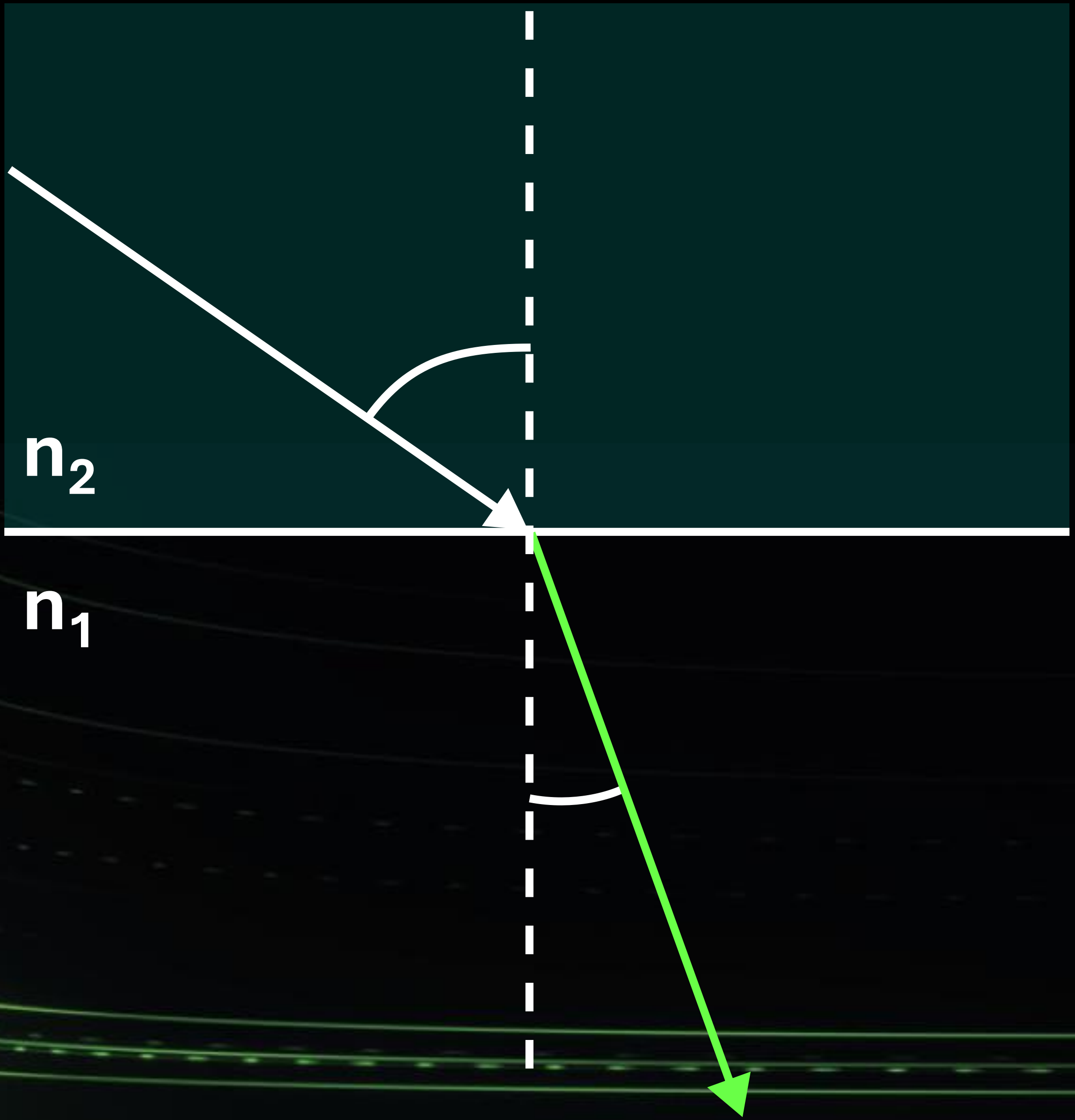

REFRACTION

LIGHT CHANGES SPEED

When a wave shifts between materials of different dielectric densities, its velocity changes, causing the beam's trajectory to bend

Refractive Index (n) : n = c/v
(Speed of light in vacuum vs. speed in the medium)

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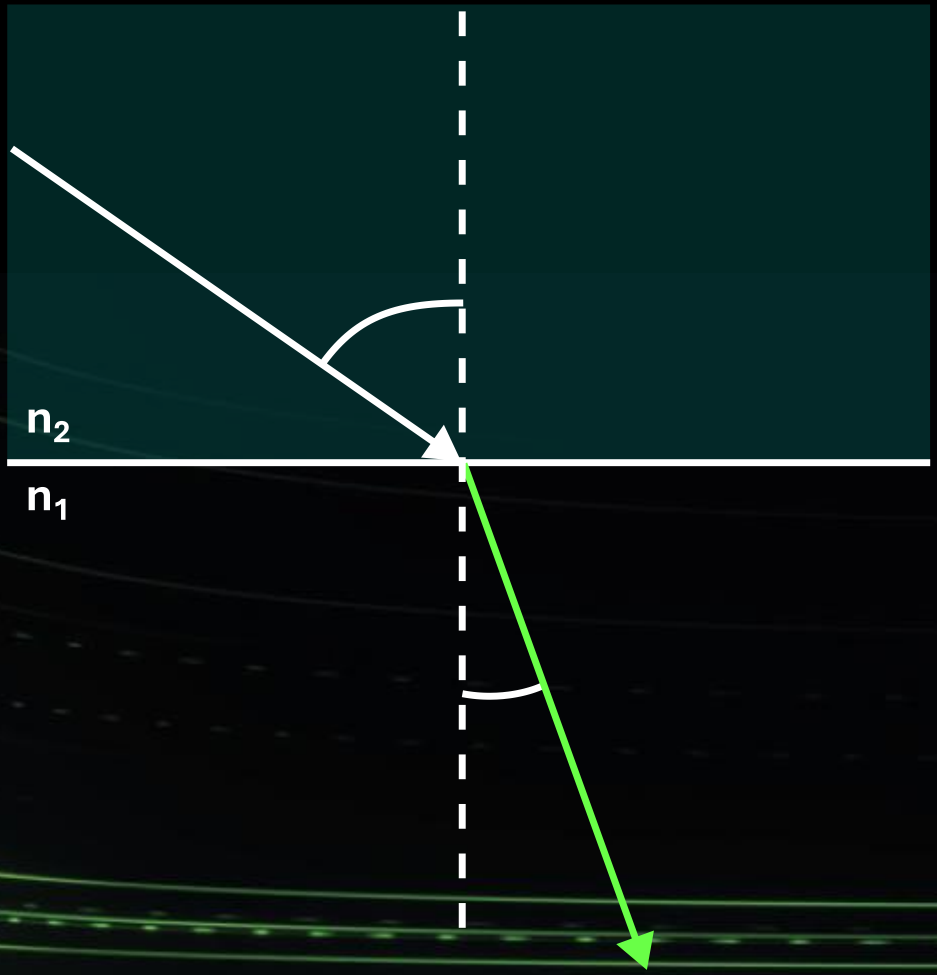
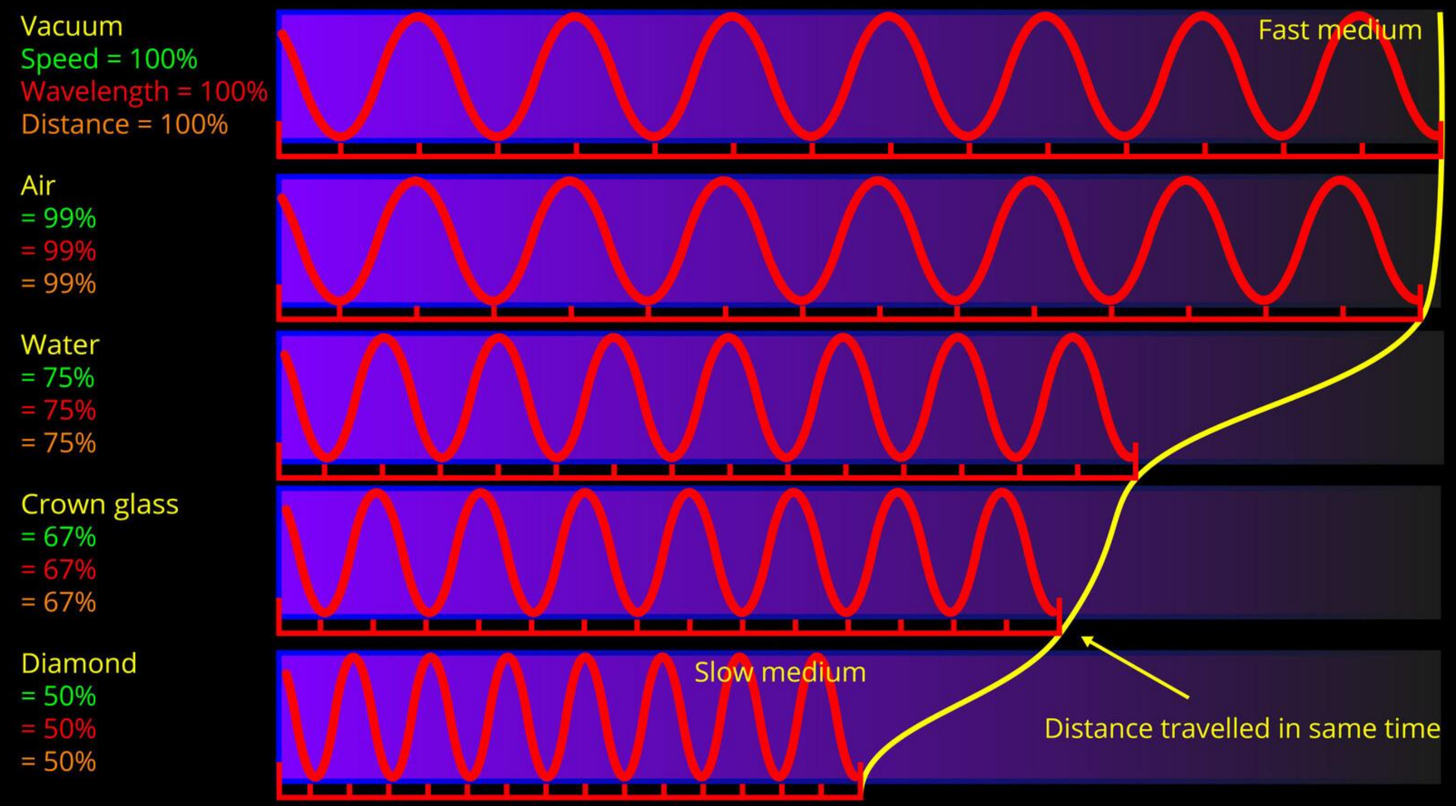
Light Changes Speed



WAVELENGTH & SPEED OF LIGHT



Vacuum
Speed = 100%
Wavelength = 100%
Distance = 100%

Air
= 99%
= 99%
= 99%

Water
= 75%
= 75%
= 75%

Crown glass
= 67%
= 67%
= 67%

Diamond
= 50%
= 50%
= 50%

Wavelength and speed change as light travels through different transparent media.
Frequency and so colour are unchanged.

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Light

Example: Transmission of light pulses in optical fibers

Energy of light expressed in photons

$E=hv$ $h = 6{,}626\times10^{-34}$ Js

For example, 1W of light at $\lambda = 1\,\mu$m:

$$E = hv = \frac{hc}{\lambda} = \frac{6{,}626\cdot10^{-34} * 3\cdot10^{8}}{10^{-6}} \cong 2\cdot10^{-19} J/photon$$

$$P = \frac{E}{t} = \frac{nº photons * Photon\ Energy}{t}; in\ a\ second:$$

$$\frac{nº photons}{s} = \frac{P}{E_{photon}} = \frac{1W}{2\cdot10^{-19}} = 5\cdot10^{18} photons/s$$

They seem alot, but generaly we use mW or µW and we transmit very fast.

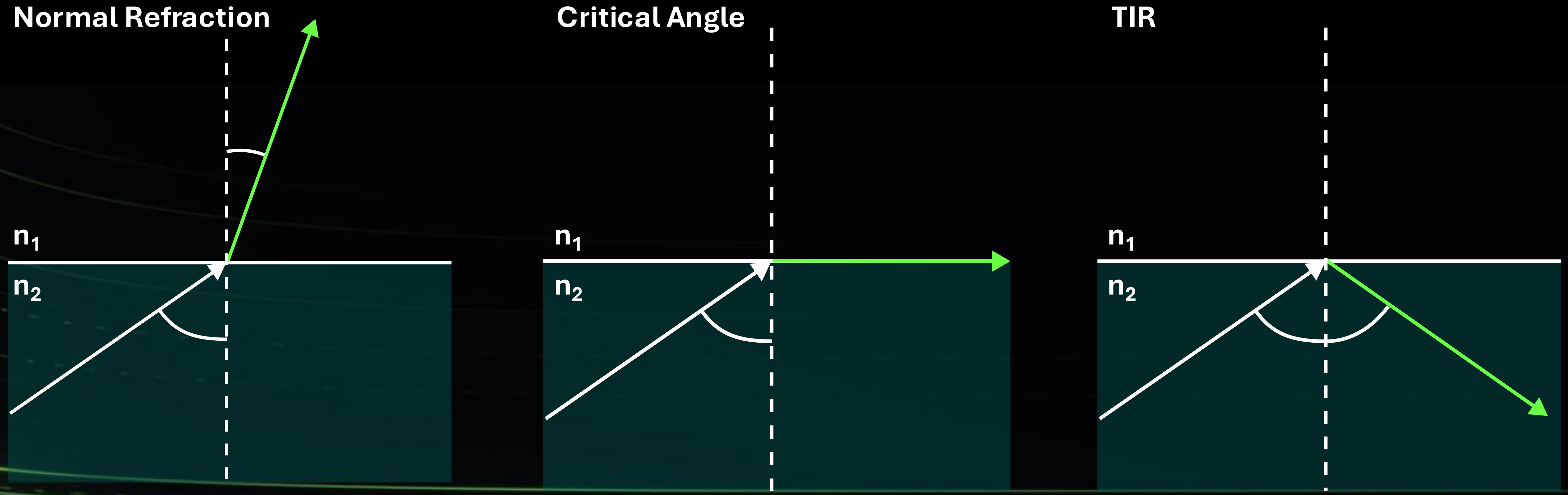
For example, a receptor which gets 1µW at a Tx of 10 Gbps:

1µW ≡ $5\cdot10^{12}$ photons to distribute between 10^{10} pulses ⇒ 500 photons/ pulse

The Surface Becomes a Mirror

TOTAL INTERNAL REFLECTION (TIR)

Beyond a specific critical angle, transmission ceases entirely.
100% of the light is reflected back into the denser medium.

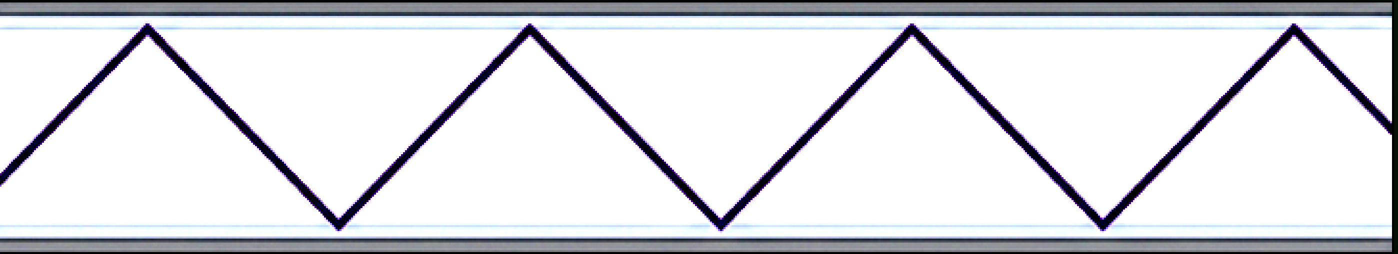


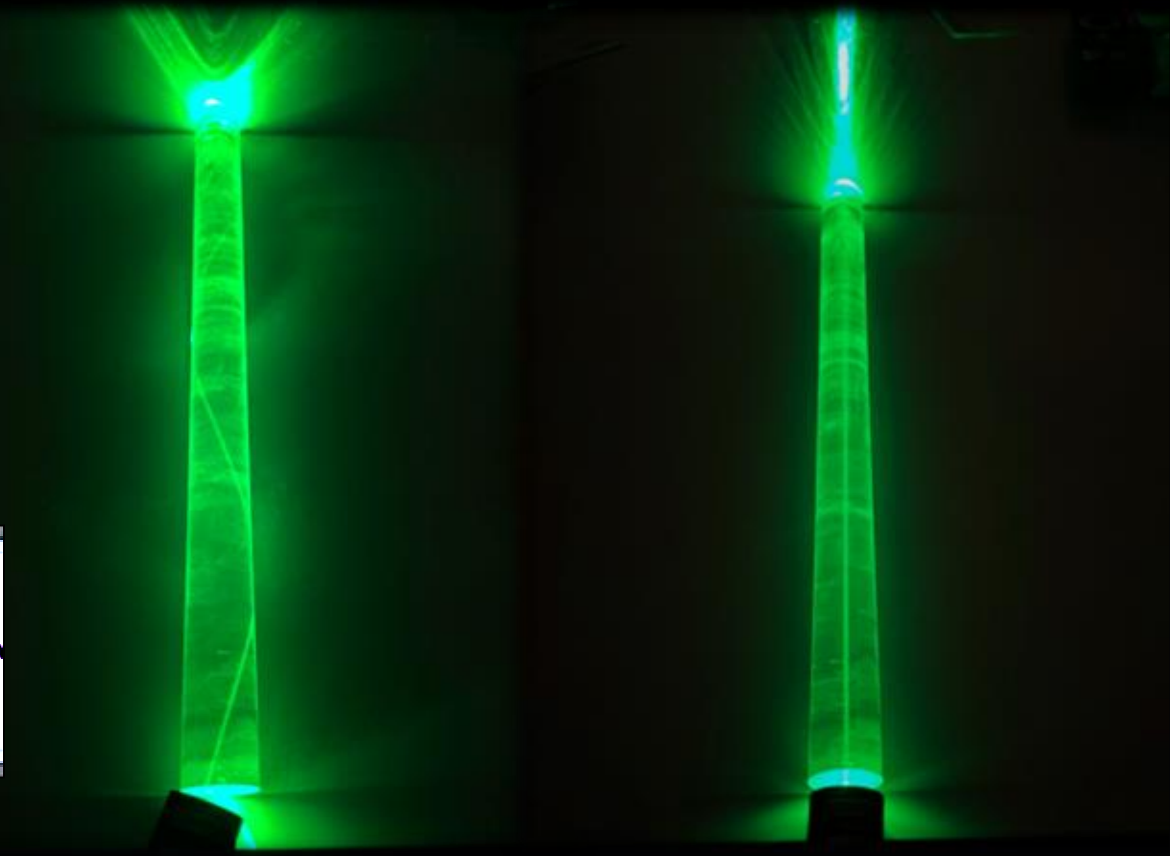
The Waveguide

GUIDING LIGHT

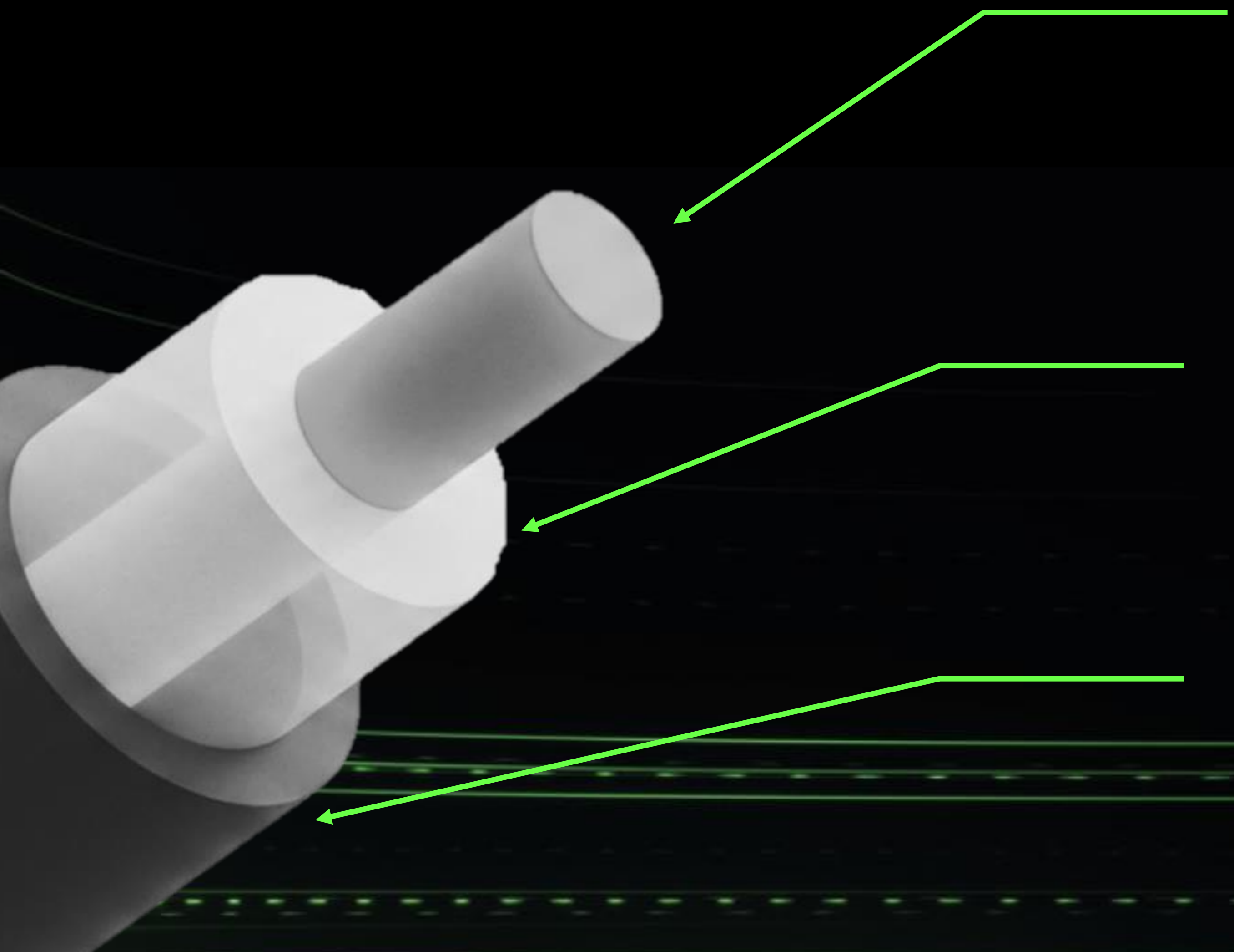
By trapping light between parallel faces (or inside a cilinder) using Total Internal Reflection, we can force light to travel along complex, non-linear paths.

Requires the interior index to be strictly greater tan the exterior index ($n_{inside} > n_{outside}$)





Anatomy of an Optical Fiber



CORE
High refractive index.
(The channel that actively guides the light)

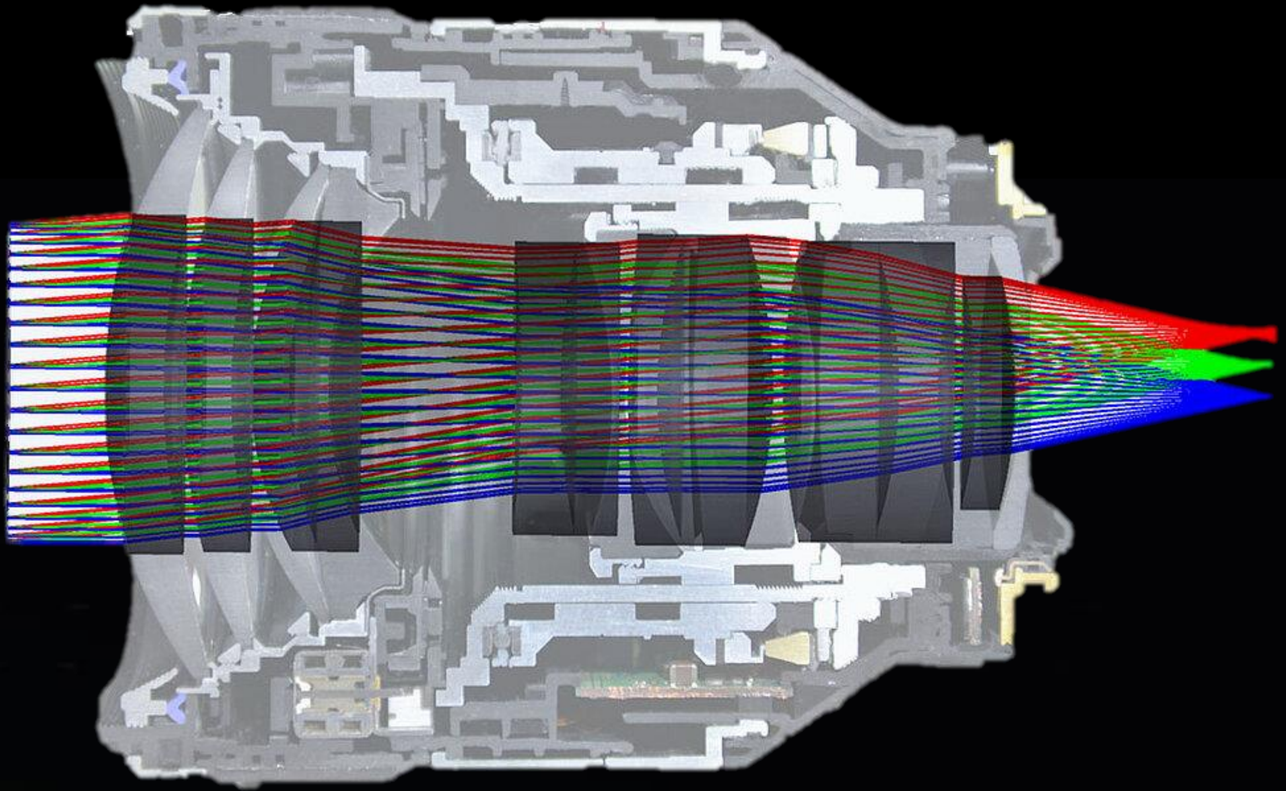
CLADDING
Lower refractive index.
(The barrier that forces Total Internal Reflection)

COATING
Protective outer layers guarding against physical damage

Free Space Optics

The phenomenon of guiding light is not exclusive to optical fibers. We can guide light using free-space optics to change its direction and focus.

Among optical devices, we find elements that guide light to capture high-quality images even from kilometers away.



Attenuation and Dispersion

Attenuation is a reduction in power that the signal experiences as it propagates through a medium. It is due to two factors: **diffuse reflection** (**scattering**) and **absorption**.

Dispersion is a temporal broadening of the signal as it propagates through the medium. It is not important when transmitting light itself, but it is important when transmitting **optical signals** (pulses). It is also caused by two factors

- **Intermodal** or **modal**: due to differences in path lengths between different modes.
  - It is measured in **ns/km**.

- **Intramodal** or **chromatic**: due to different propagation of different wavelengths within the same mode. It is measured in **ps/nm·km**:
  - **Waveguide** dispersion
  - **Material** dispersion

Total Attenuation

Total atenuation is the sum of all contributions.

Both scattering and absorption cause attenuation with distance according to the following equation:

$$P_{exit} = P_{entry}\exp(-\gamma L)\,;\gamma = \gamma_{scat} + \gamma_{abs}$$

$$P_{exit} = P_{entry}10\text{^}(-\left(\frac{\alpha_{dB}}{10}\right)L)$$

Losses are measured in dB/km and they are additive

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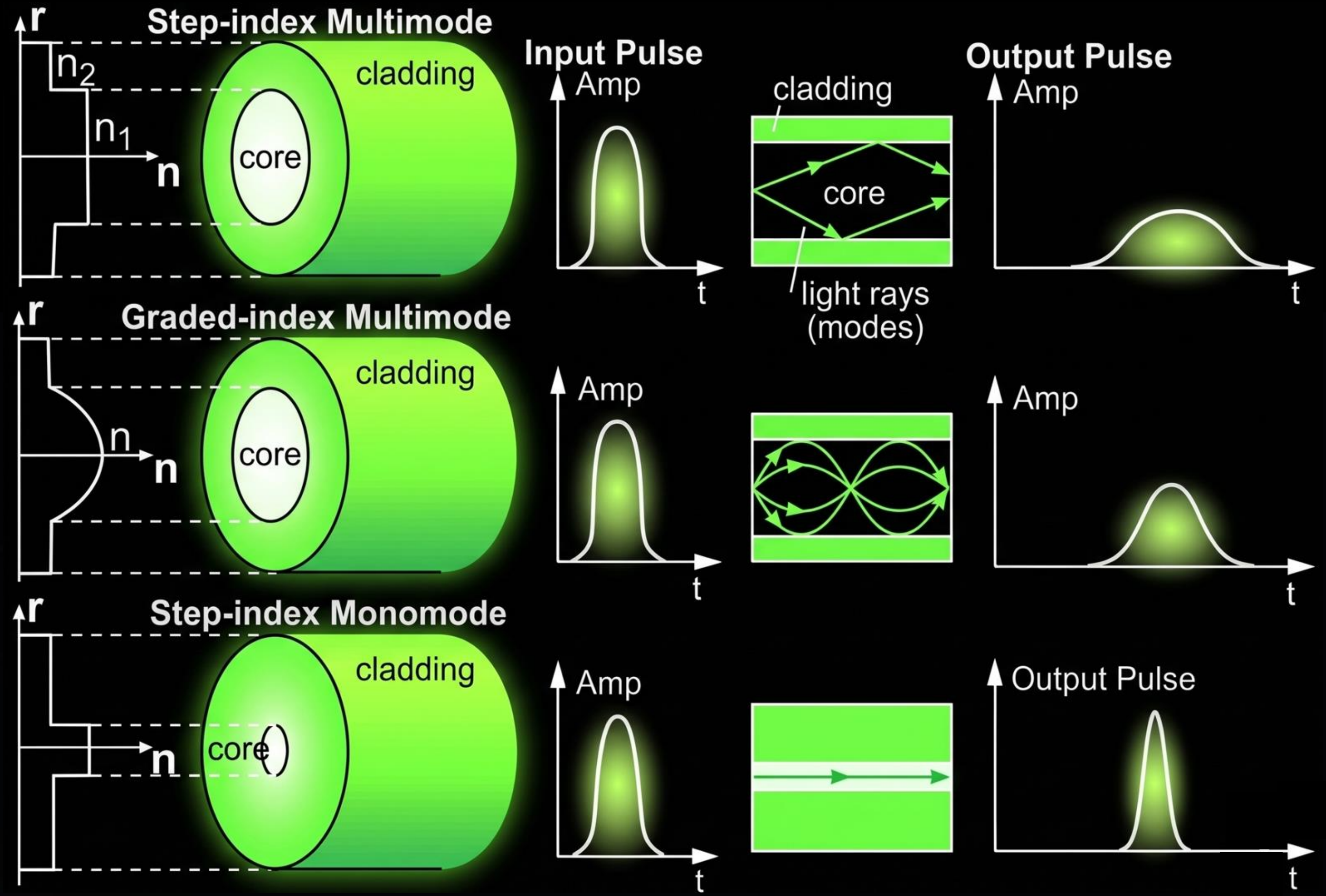
Intermodal Dispersion

When the fiber is multimode, intermodal dispersion occurs because each mode propagates at a different speed. This can largely be avoided by using graded-index fibers (GI fibers).

Currently, step-index multimode fibers are only used over very short distances, while graded-index fibers are used over medium distances (such as local area networks, LANs, in buildings).

To avoid intermodal dispersion, the simplest solution is to use single-mode fibers.



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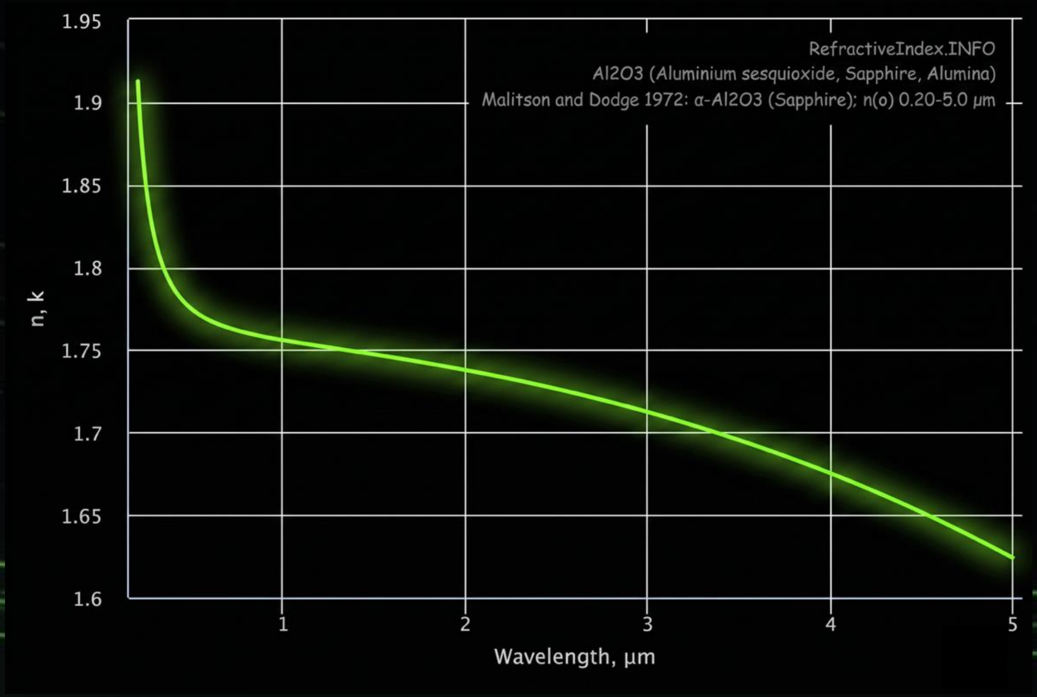
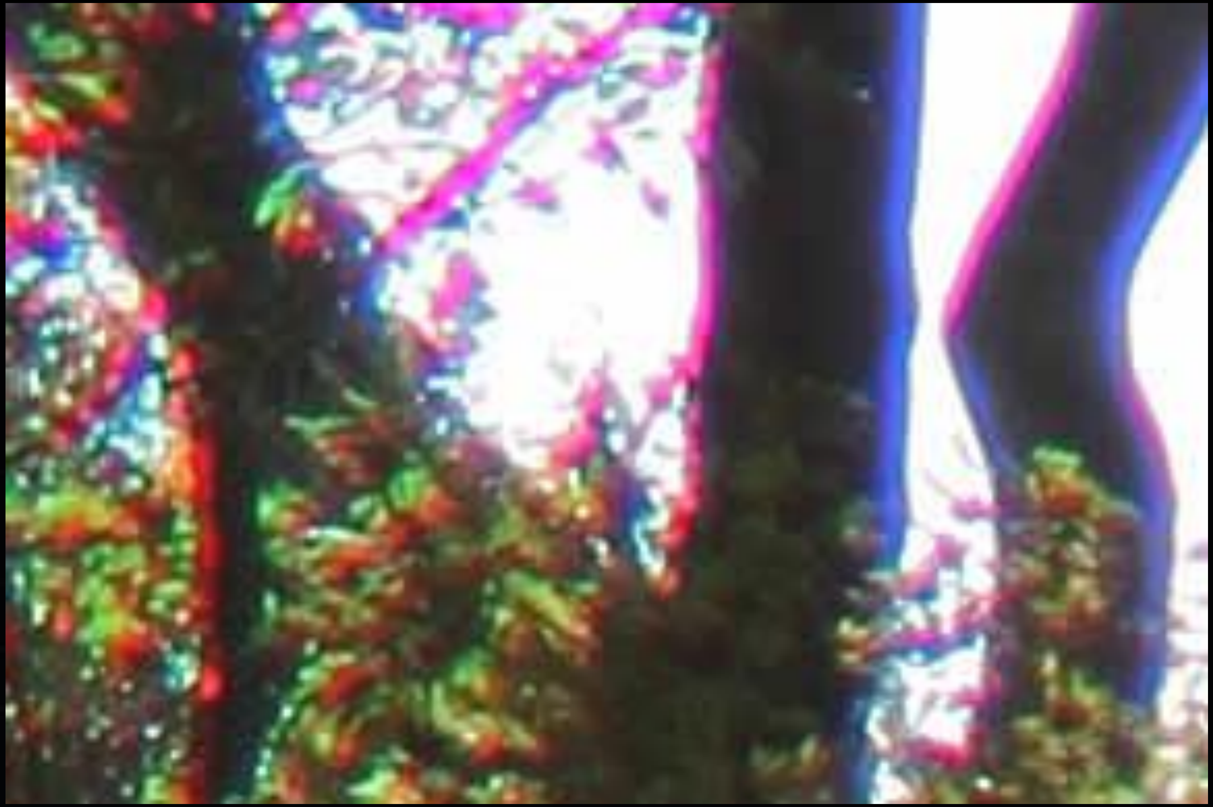
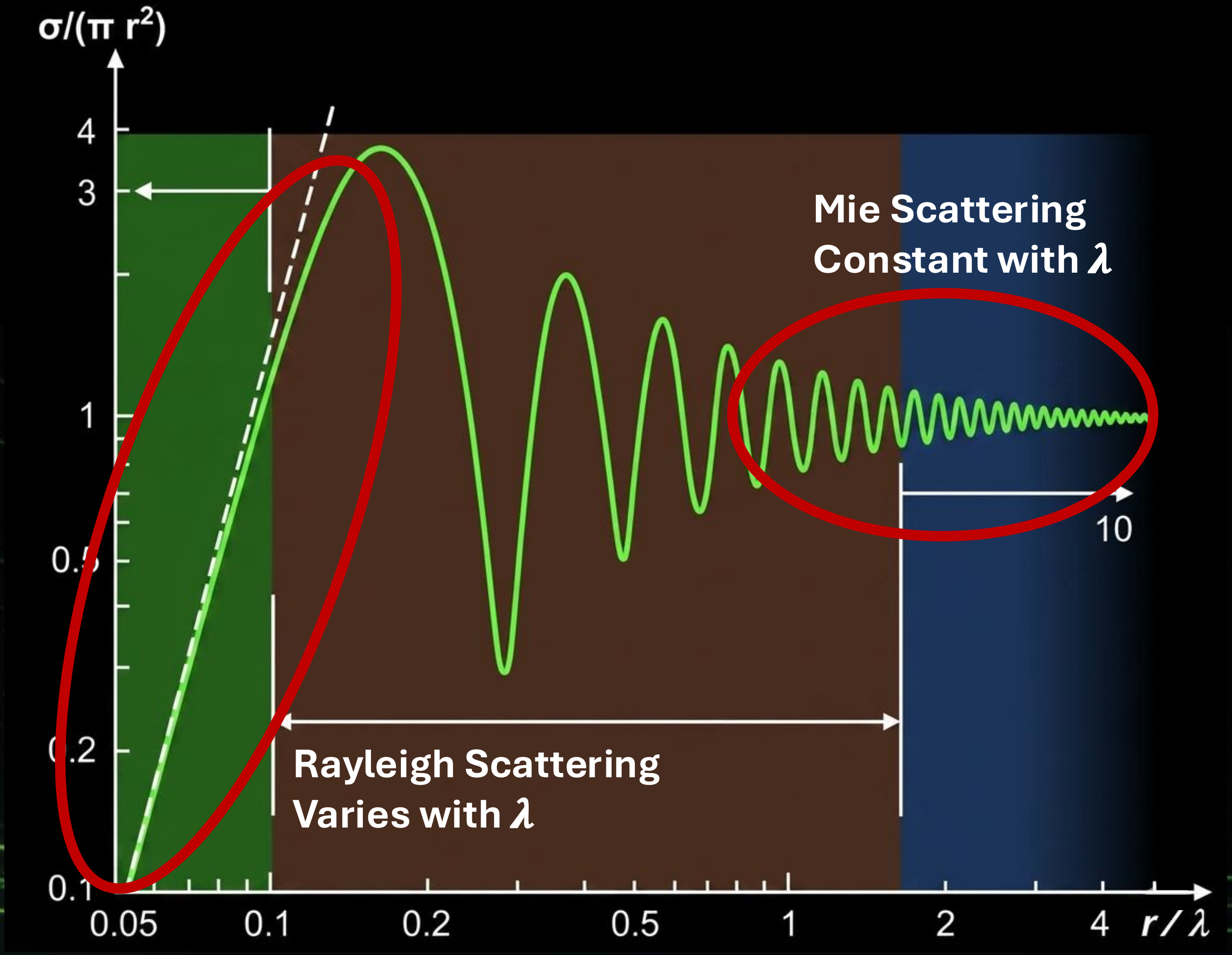
Intramodal Dispersion

Even if the fibers guide only a single mode, dispersion still exists: the so-called intramodal or chromatic dispersion, caused by the fact that the refractive index of the material varies with λ (wavelength).

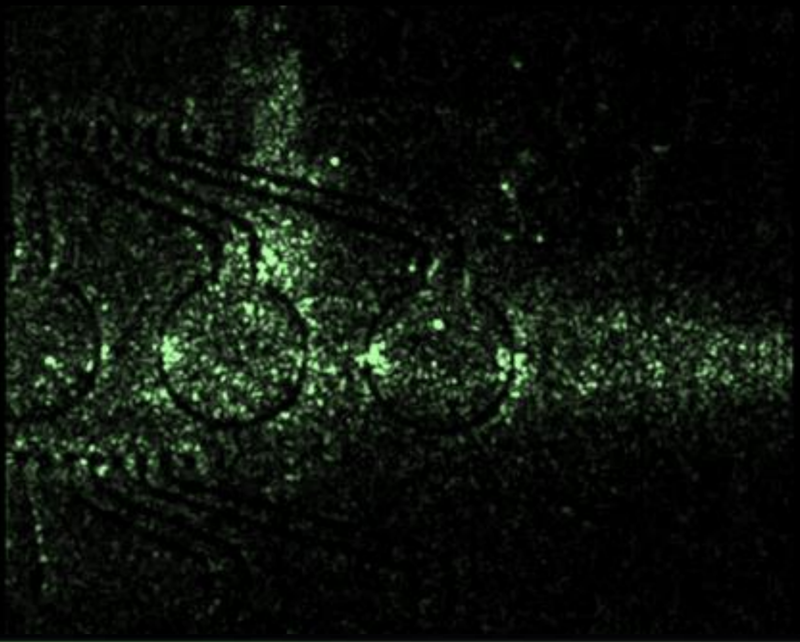




Scattering


Mie Scattering
Constant with λ

Rayleigh Scattering
Varies with λ



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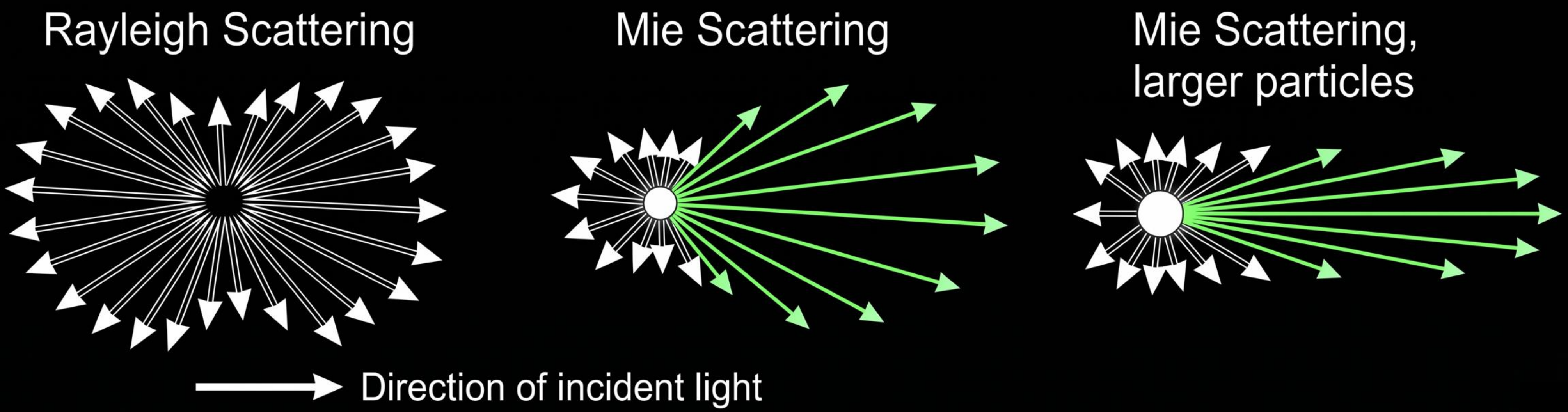
Types of Scattering



RAYLEIGH SCATTERING

- Highly dependent on wavelength (λ)
- Shorter wavelengths (blues) scatter exponentially more than longer ones (reds)

MIE SCATTERING

- Independent on wavelength (λ)
- Scatters all colors of the spectrum equally

Real-World Applications

TELECOM:

Powering the global fiber-optic internet infrastructure.

MEDICINE:

Enabling non-invasive laser surgery and high-resolution optical imaging.

SENSORS:

Driving environmental monitoring, chemical detection, and autonomous LiDAR.

LASERS:

Revolutionizing heavy manufacturing, nanolithography, and precision cutting.

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THE FUTURE IS PHOTONIC

The 20th century was defined by the manipulation of the electron.
The 21st century is being defined by the manipulation of the photon.

Faster transmission, cleaner energy, and limitless bandwidth

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