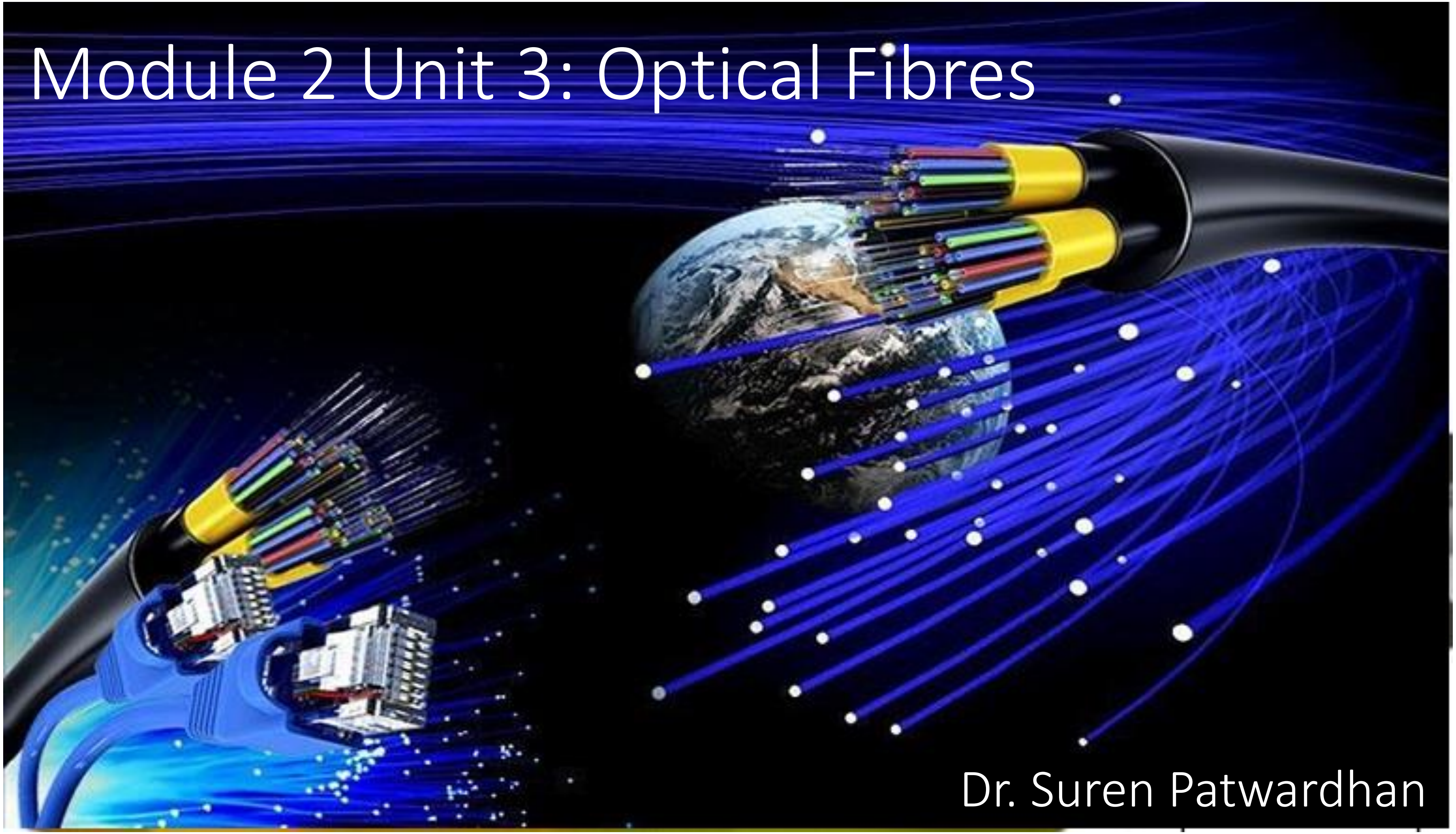
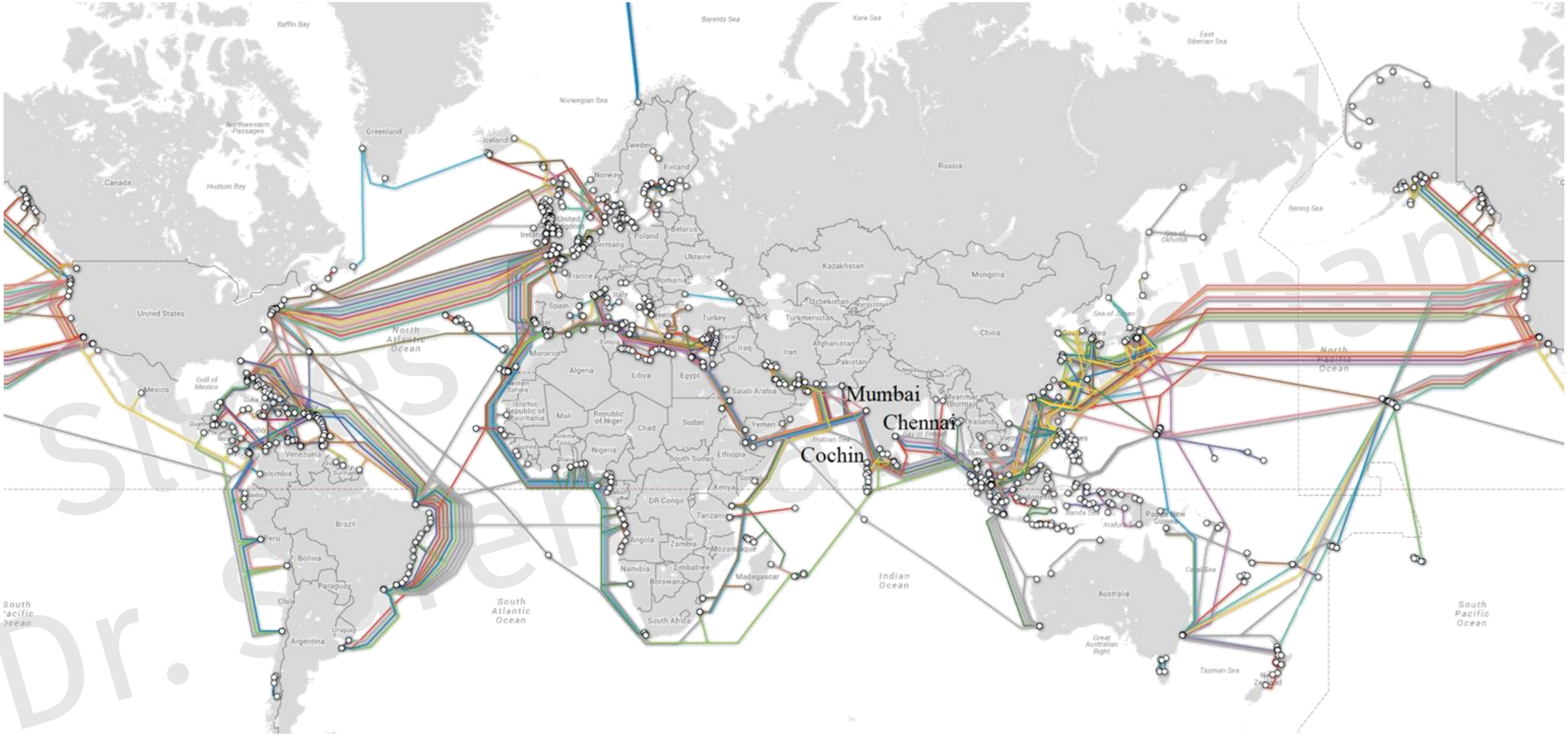
Module 2 Unit 3: Optical Fibres



Dr. Suren Patwardhan

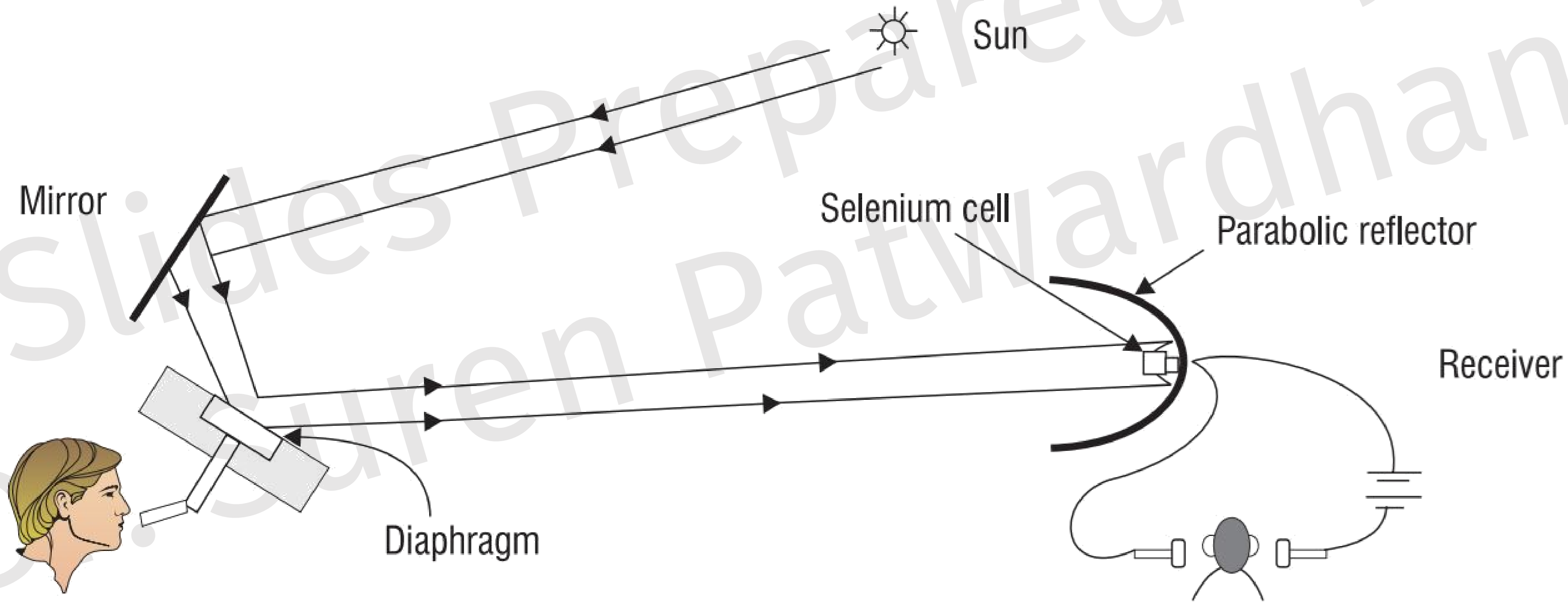
Contents

Global Fibre Optic Network

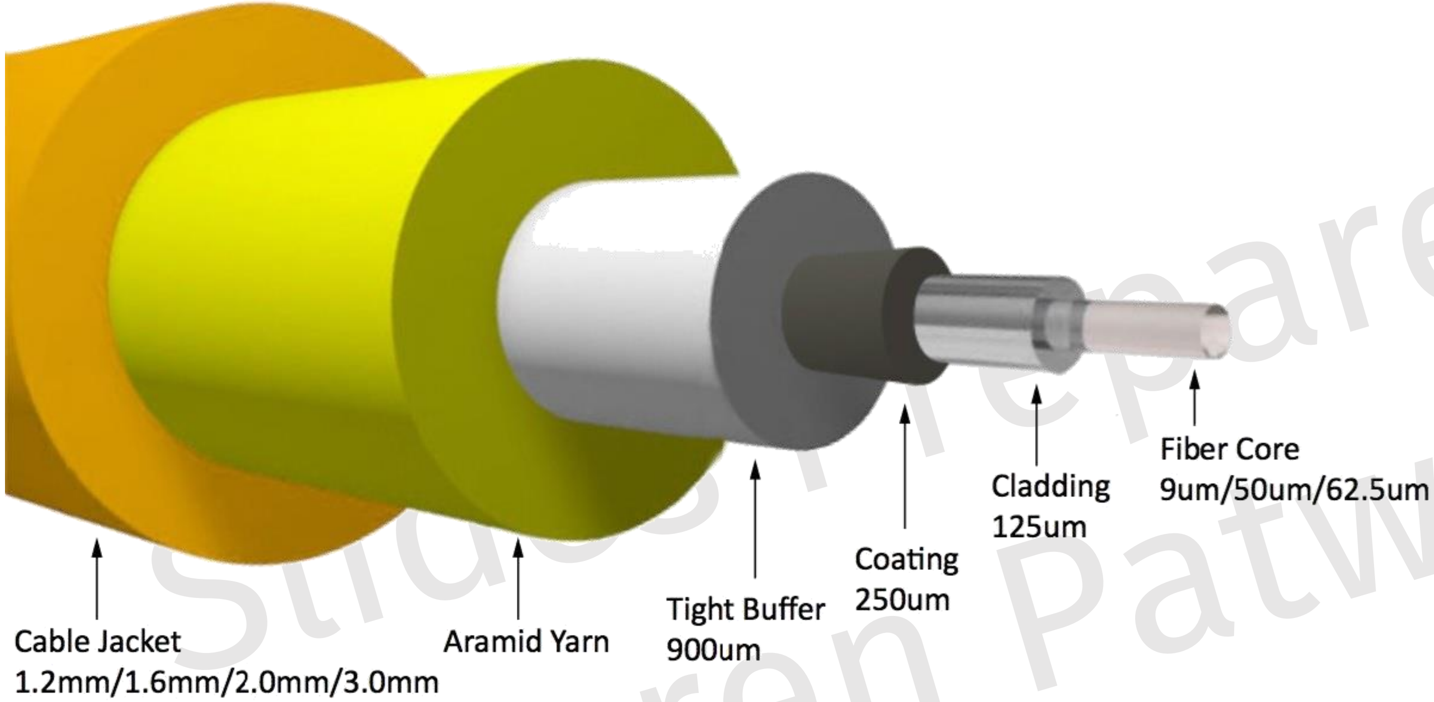


A Historic Note

- Alexander Graham Bell’s “Photo phone” in 1880
- Voice is fed over a beam of light – using light as a “carrier wave”

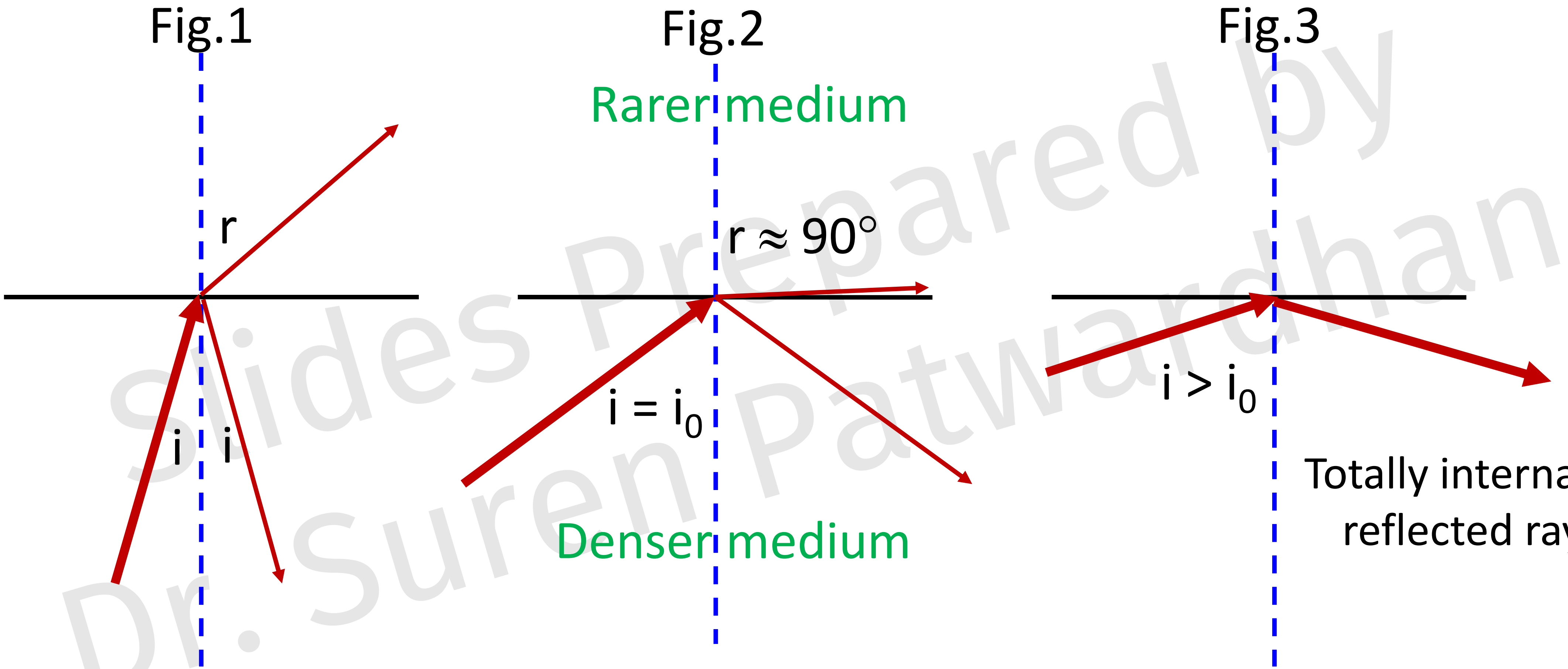


Structure of an Optical Fibre

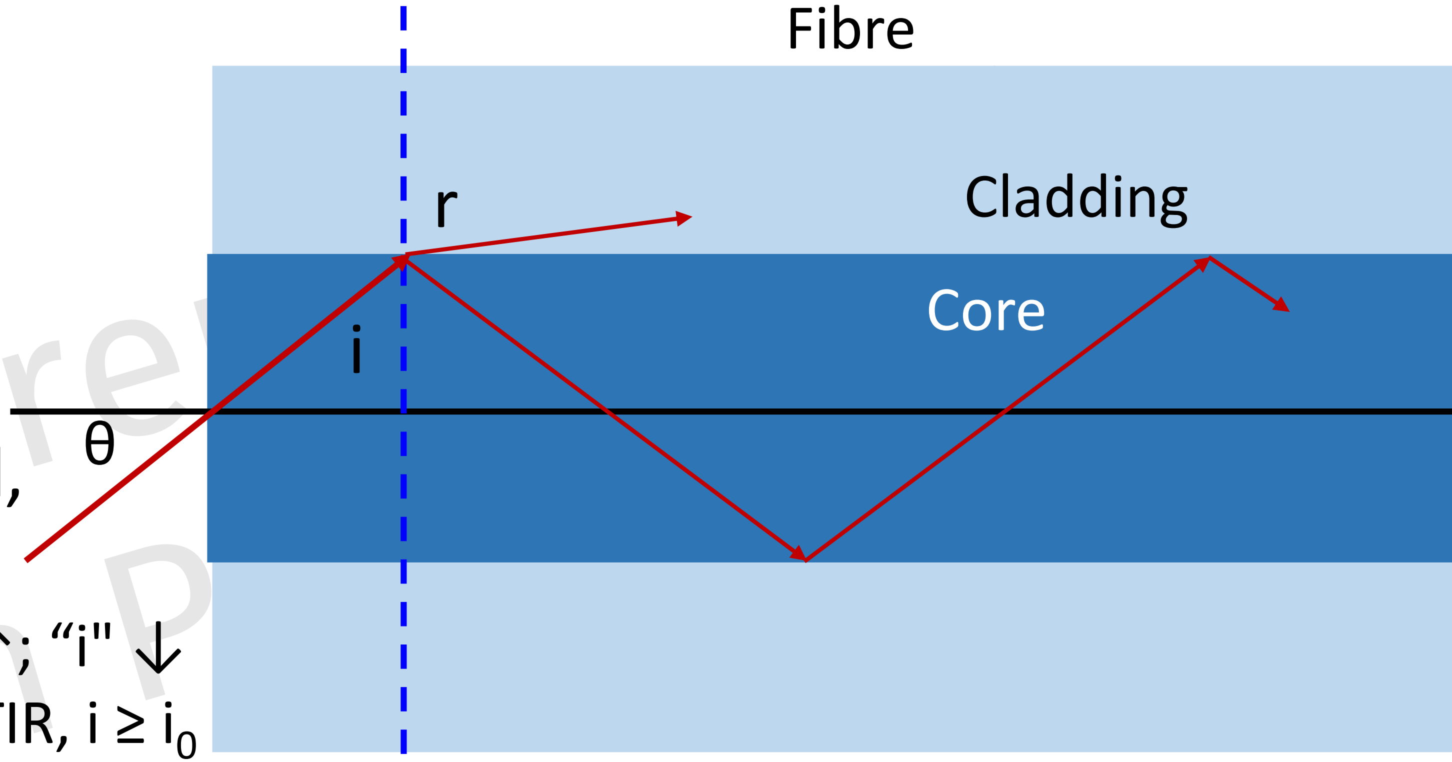


- Main two parts: core and cladding
- Core has slightly higher refractive index
- Light is fed into the core region

Principle of Working – Total Internal Reflection



Total Internal Reflection and Acceptance Angle



Rarer medium

Denser medium

condition for TIR: $\theta \leq \theta_C$

When TIR condition is satisfied,

$i = i_0$ and $r = 90°$

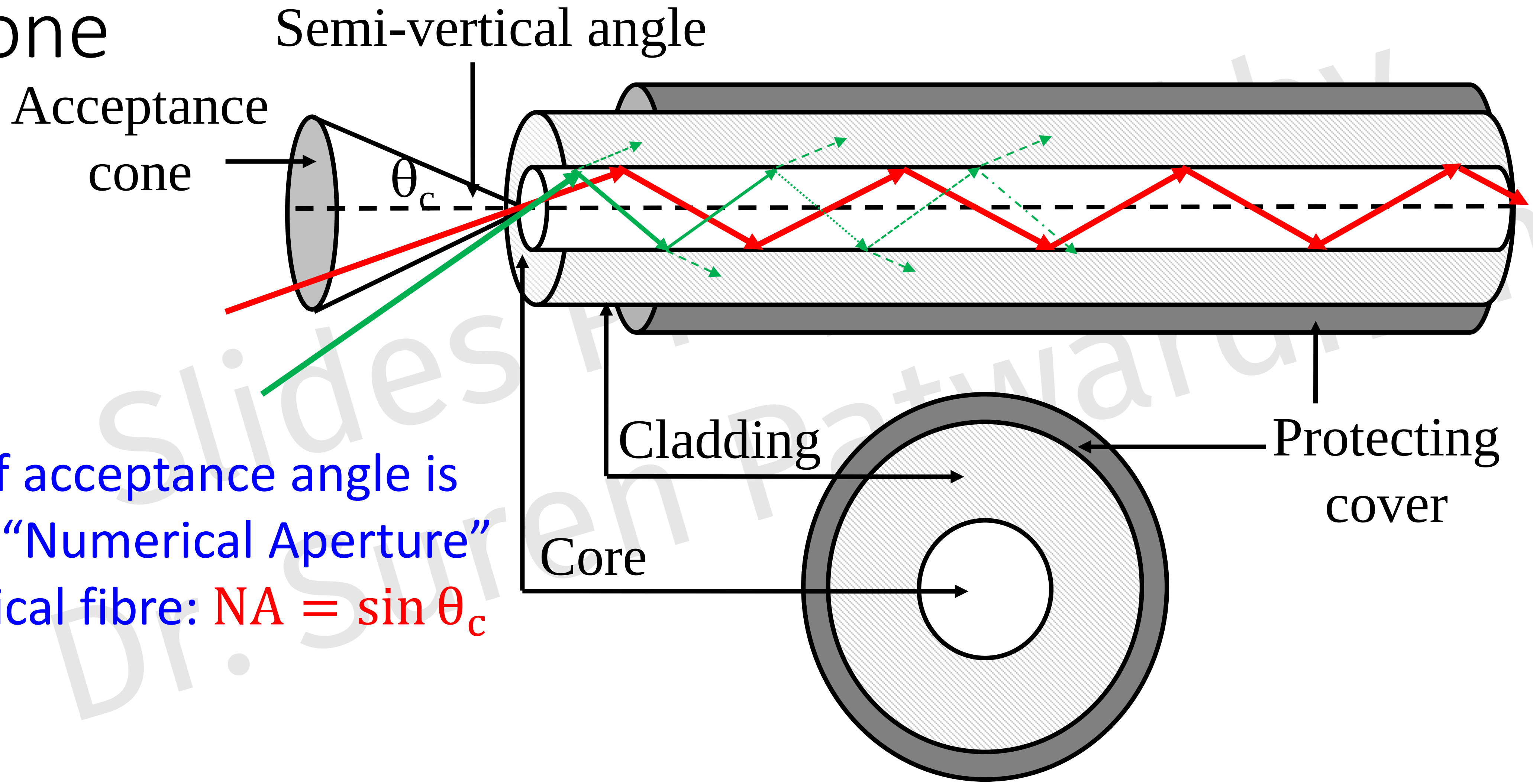
As "θ" ↑; "i" ↓

But for TIR, $i \geq i_0$

$\Rightarrow \theta$ should have some "ceiling" value.

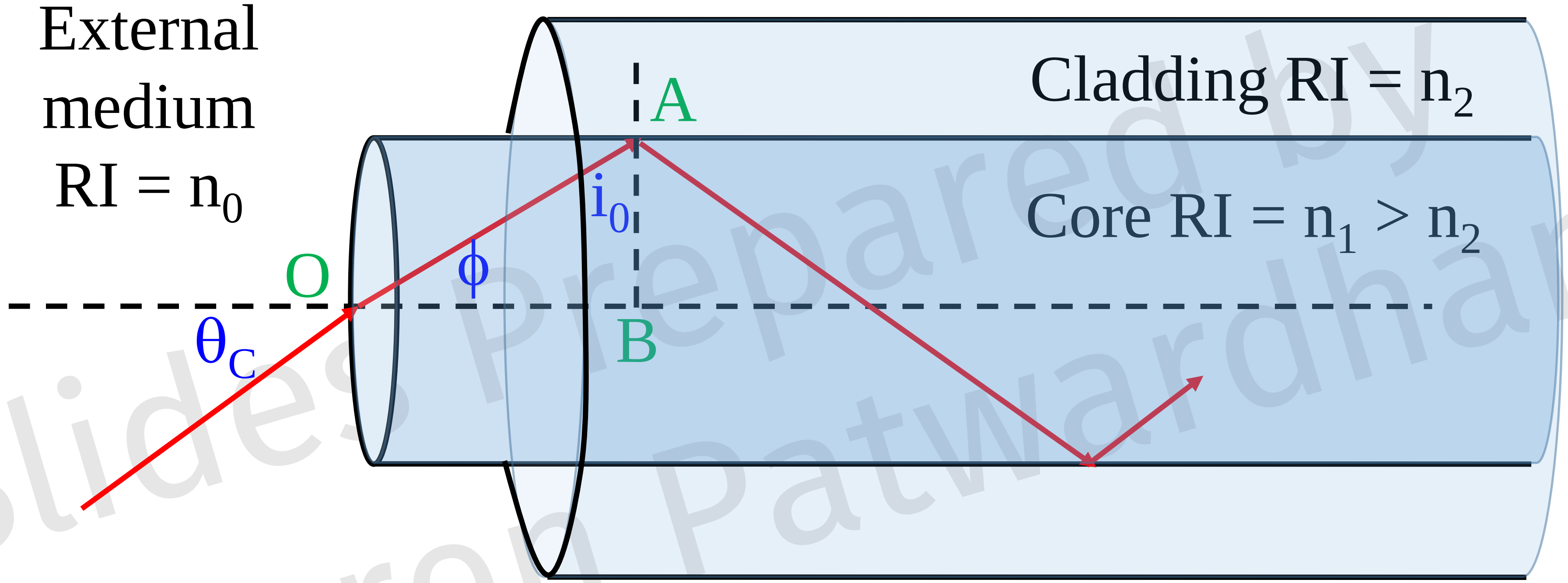
This value is called "acceptance angle"

Optical Fibre – Cross Sections and Acceptance Cone



Sine of acceptance angle is called "Numerical Aperture" of optical fibre: $\mathrm{NA} = \sin\theta_c$

Numerical Aperture of an Optical Fibre



$$NA = \sin\theta_c = \sqrt{n_1^2 - n_2^2}$$

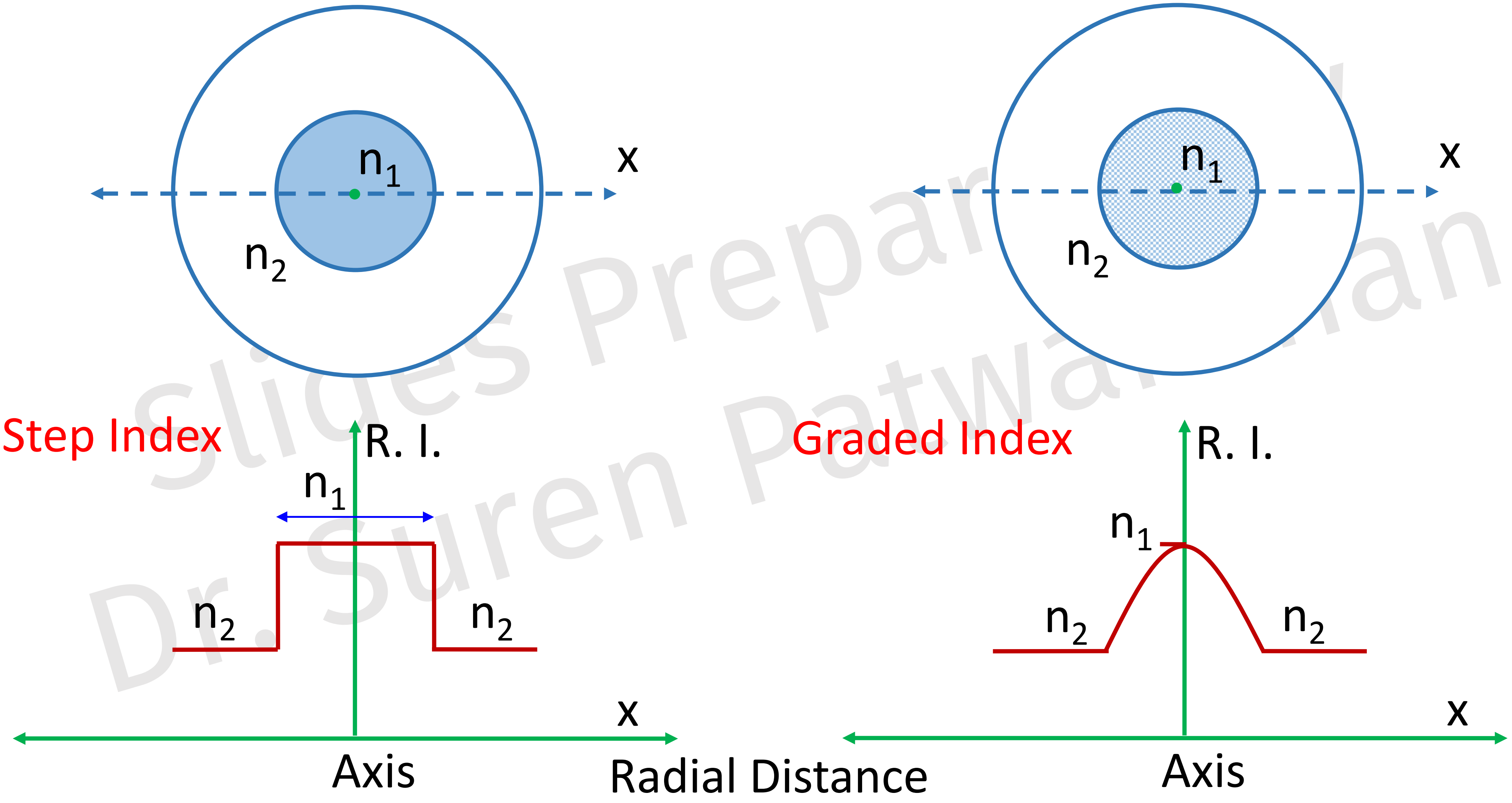
$$NA \approx n_1\sqrt{2\Delta}$$

Types of Fibres

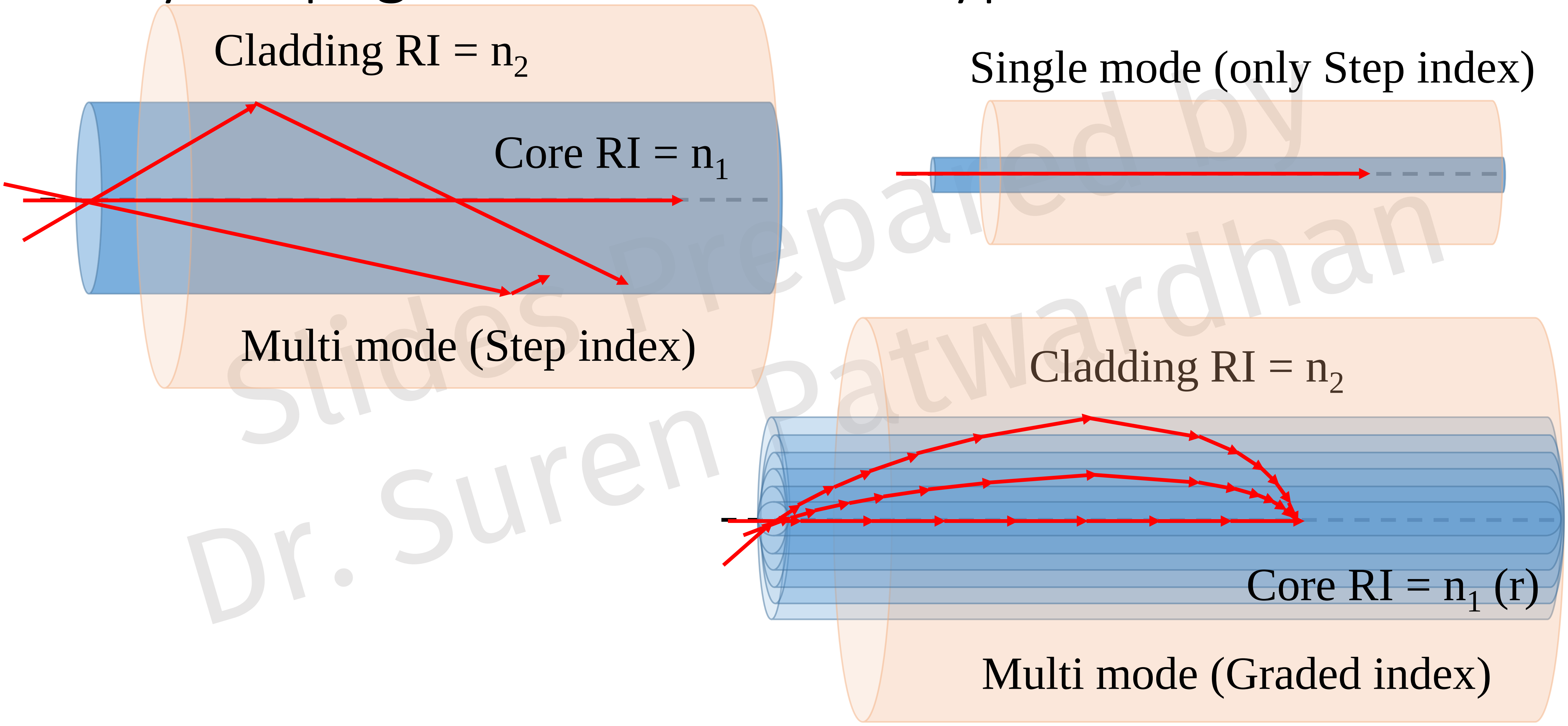
Based on →

- **Material**
  - All-glass
  - All-plastic
  - PCS
- **Refractive index profile**
  - Step index
  - Graded index
- **Modes of Propagation**
  - Single mode
  - Multi mode

Refractive Index Profile

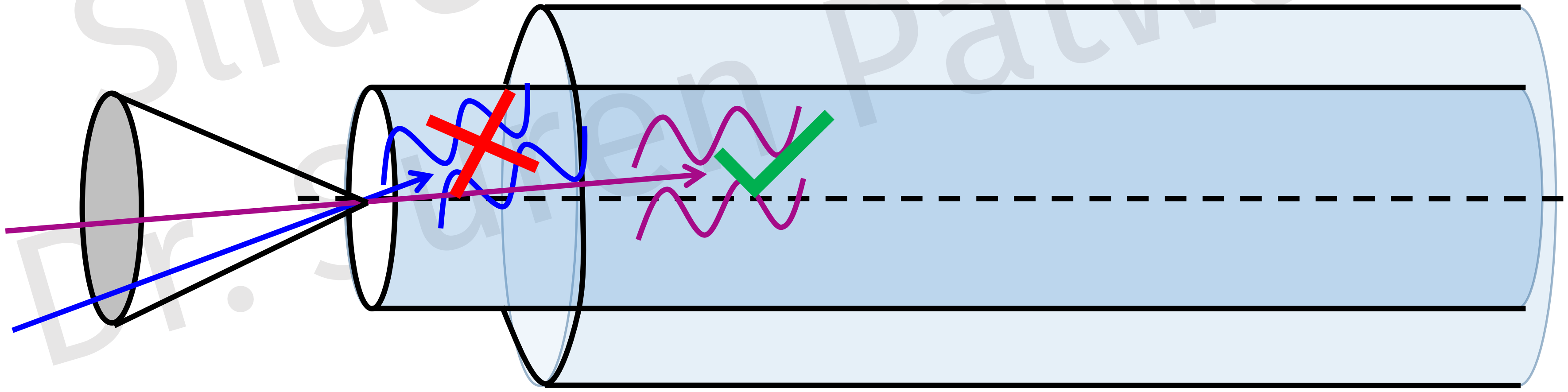


Ray Propagation in Different Types of Fibres



Mode of Propagation - Concept

- Defined as “allowed” directions for light entering optical fibre
- Fibre does not guide all light even though it is launched within acceptance cone
- Due to restricted space, light undergoes diffraction
- Light waves are in phase only along certain paths
- These paths are the “allowed” directions and called “modes of propagation”



V-number and Number of Modes

- An optical fibre is characterized by another important parameter called as the V-number or normalized frequency. It is given by,

$$V = \frac{2\pi a}{\lambda} \times NA$$

a: radius of core, λ: wavelength of light, NA: numerical aperture

- The maximum number of modes supported by the fibre is given by,

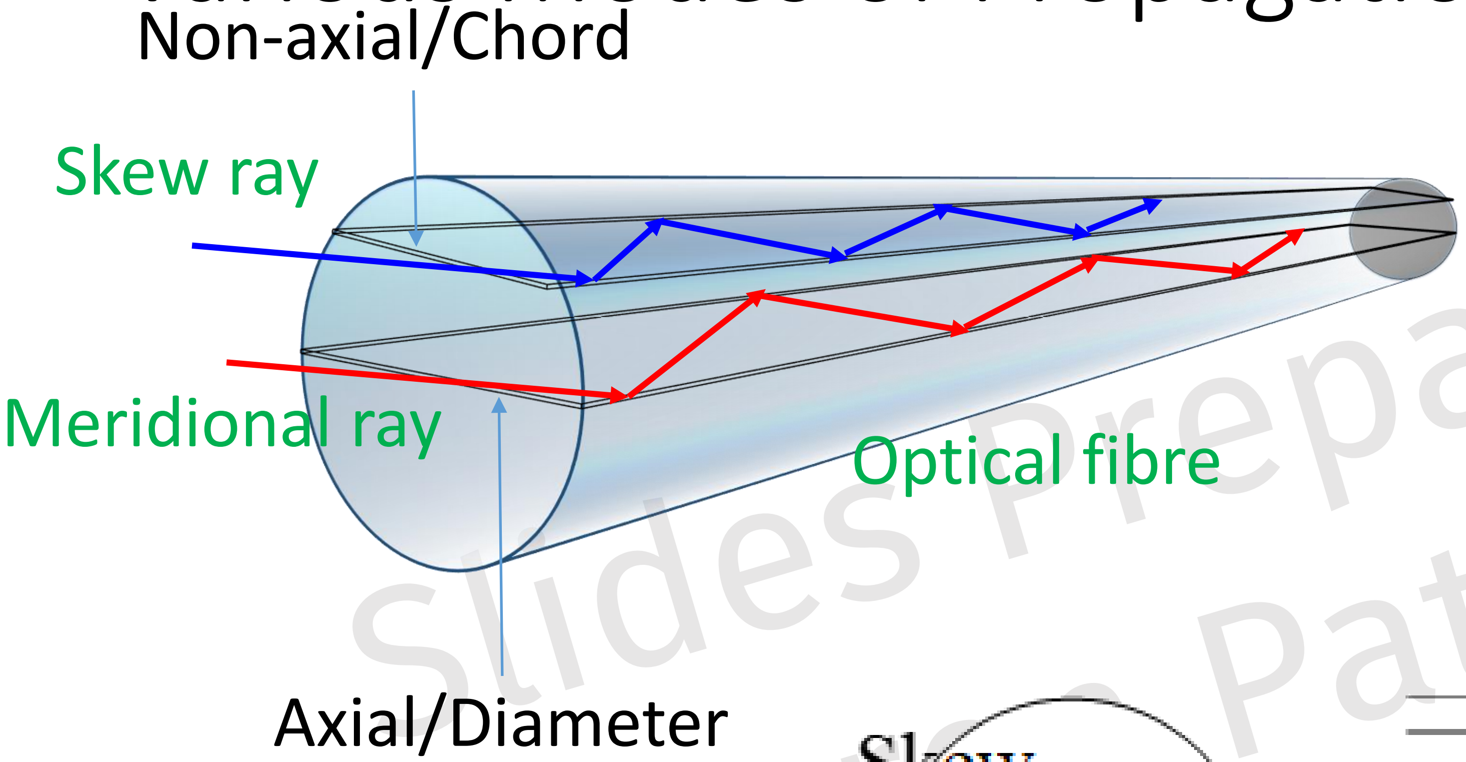
$$N_m = \frac{V^2}{2}; \qquad \text{SI}$$

$$= \frac{V^2}{4}; \qquad \text{GI}$$

- From electromagnetic theory, it is deduced that

$$V < 2.405; \qquad \text{SM}$$

Various Modes of Propagation



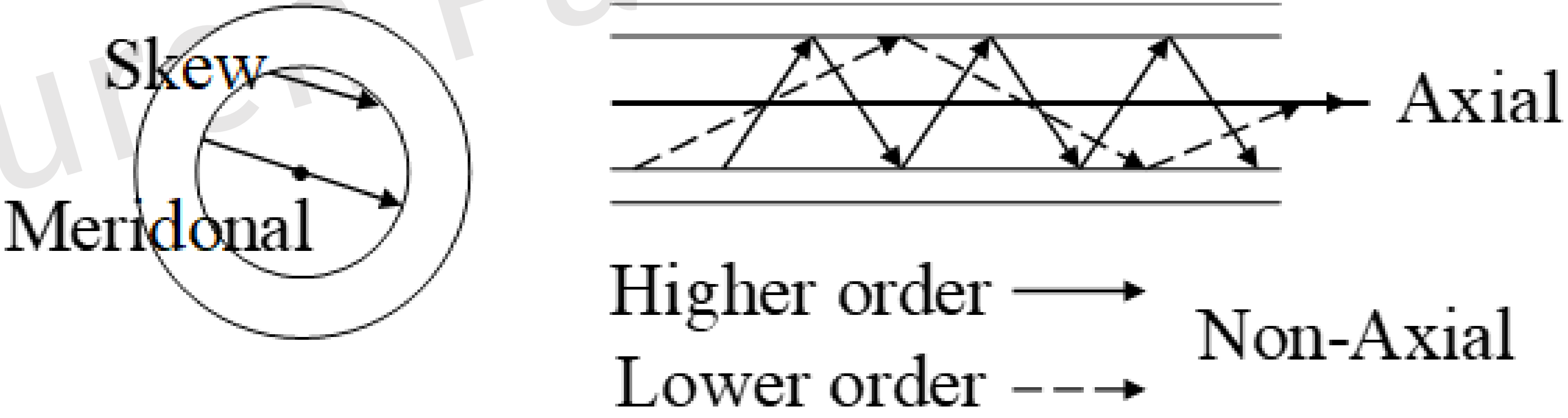
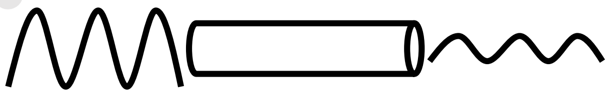


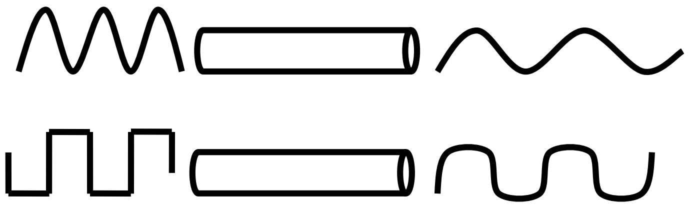
Figure of Merits for an Optical Fibres

Fibre Losses

- **Attenuation**
  - Loss of amplitude
  - Signal becomes weaker
  - Measured in dB/km
  - Typical: 0.2-0.3 dB/km



- **Dispersion**
  - Loss of synchronization
  - Signal is distorted
  - Measured in ps/km
  - Typical: 100 ps/km



Causes of Attenuation in Fibres

Absorption

- By fibre itself (intrinsic absorption)
- By impurities in fibre (Na, Fe, OH^-, Cr)

Scattering

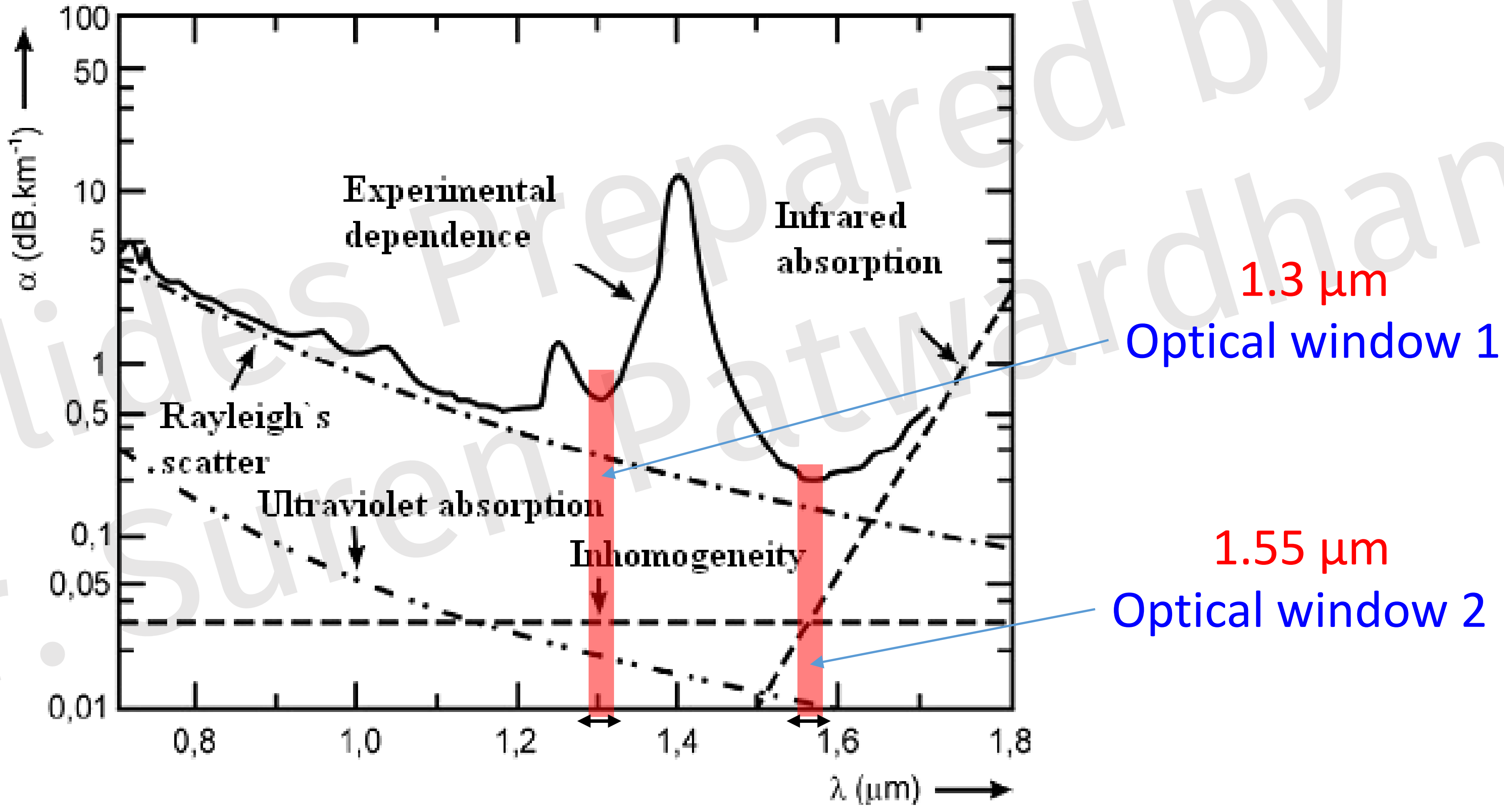
- Due to non-uniform density of glass (Rayleigh scattering)

Geometric

- Bending of fibre into tighter loops
- Micro-kinks inside fibre

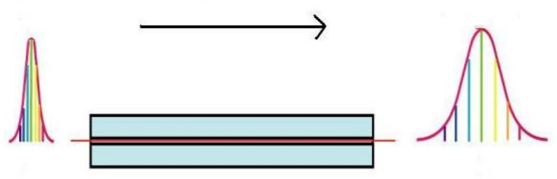
Attenuation coefficient: $\alpha = \frac{1}{L} 10 \log \left(\frac{P_{in}}{P_{out}} \right) m^{-1}$

“Communication” Wavelengths of the Internet



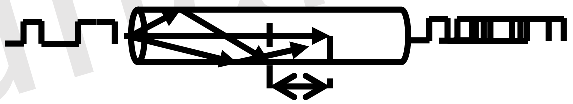
Causes of Dispersion in Fibres

Chromatic Dispersion



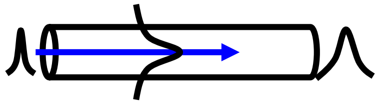
- When light has broad spectrum
- Can be eliminated using laser source

Intermodal Dispersion



- When time-synchronization between light waves is lost
- Can be eliminated using graded index fibre

Waveguide Dispersion



- When fibre diameter is extremely small (SM fibre)

Pulse Dispersion and Bit Rate

Intermodal dispersion for SI: $\tau_i = \frac{n_1 L}{c}\Delta$

Intermodal dispersion for GI: $= \frac{n_2 L}{2c}\Delta^2$

Total dispersion (intermodal + material): $\tau = \sqrt{\tau_i^2 + \tau_m^2}$

Bit Rate: $B \approx \frac{0.7}{\tau}$ usually expressed in “MBPS”

Fibre Optic Communication System