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CHAPTER 1

Introduction, schedule

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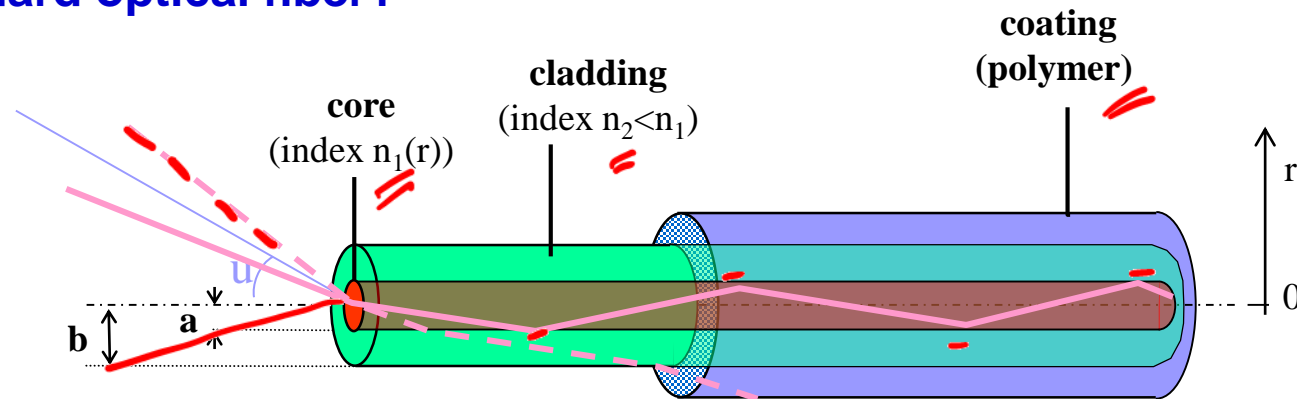


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What is a standard optical fiber?

2b = 125 μm



➤ guiding principle: total internal reflexion at the core-cladding interface

➤ Constituent materials: pure and doped silica (Al, Ge, P, B, F, rare earth), fluoride glass, chalcogenide, polymere, silica/polymere, ...

➤ Opto-géométrical parameters :

- core and cladding diameters
- index profile (step index, graded index, ...)

➤ Main characteristics:

- Numerical aperture
- Normalized spatial frequency

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

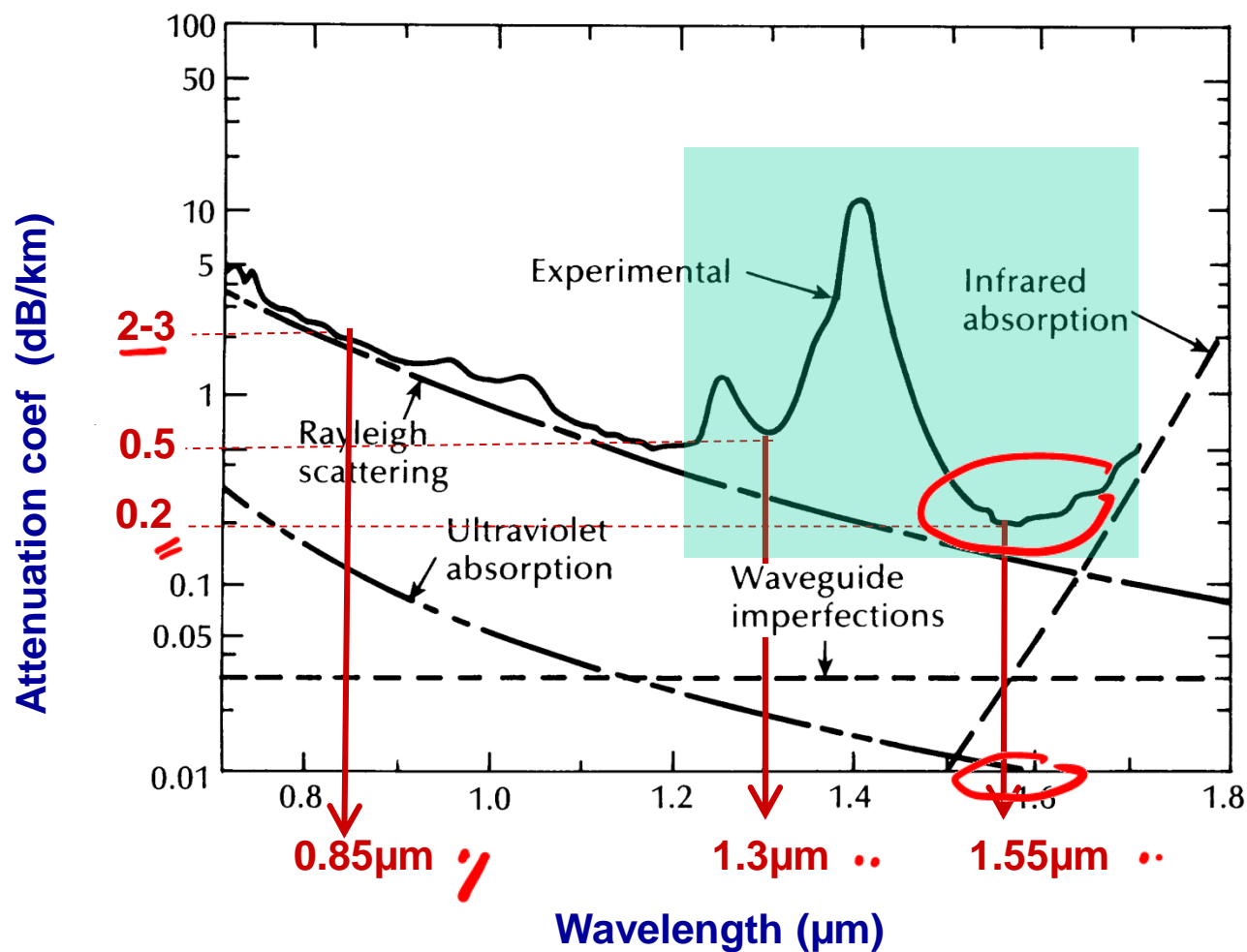
$$V = \frac{2\pi}{\lambda} \cdot a \cdot NA$$

*Silica
SiO₂*

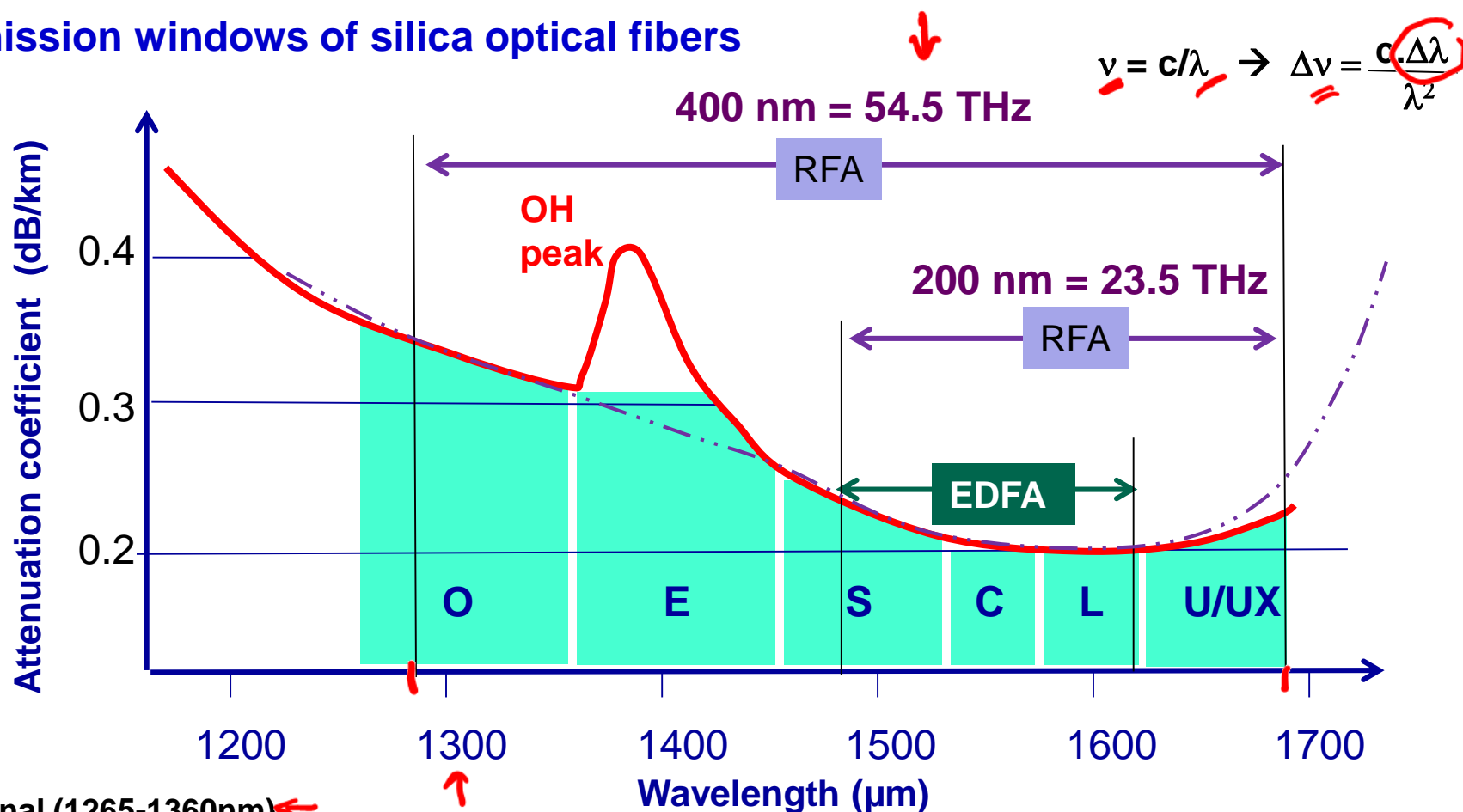
a = radius of the core



Transmission windows of silica optical fibers



Transmission windows of silica optical fibers



O : Original (1265-1360nm) ←

E : Extended (1360-1465 nm)

S : Short wavelengths (1465-1525 nm)

C : Conventional (1525 – 1565 nm)

L : Long wavelengths (1565 – 1625 nm)

U : Ultra-long wavelengths (1625 -1675 nm)

RFA : Raman Fiber Amplifier

EDFA : Erbium Doped Fiber Amplifier

Bit rate reachable in one fiber for optical communications (1)

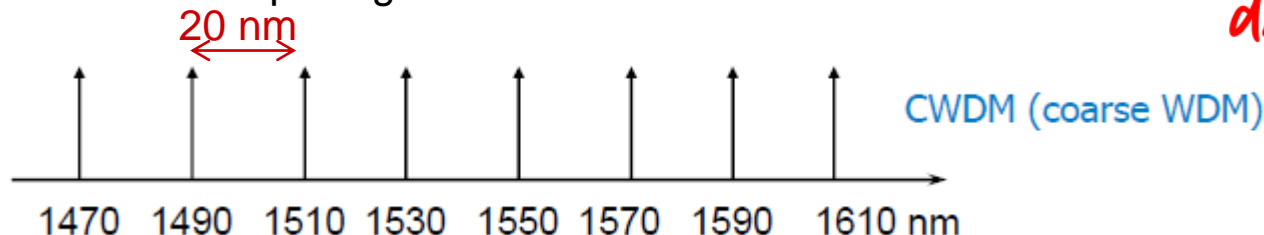
$$\lambda = c/\nu$$

* Carrier frequency @ $\lambda = 1.55 \mu\text{m}$: $\nu = 190 \text{ THz} \gg$ carrier frequency in microwave systems

* @ 10Gbits/s : pulse duration $\Delta t = 10^{-10} \text{ s} \rightarrow$ with $\Delta t \cdot \Delta \nu \sim 0.5$: $\Delta \nu = 5 \cdot 10^9 \text{ Hz}$
 $\rightarrow \Delta \lambda = \lambda^2 \cdot \Delta \nu / c = 0.04 \text{ nm}$ for one channel

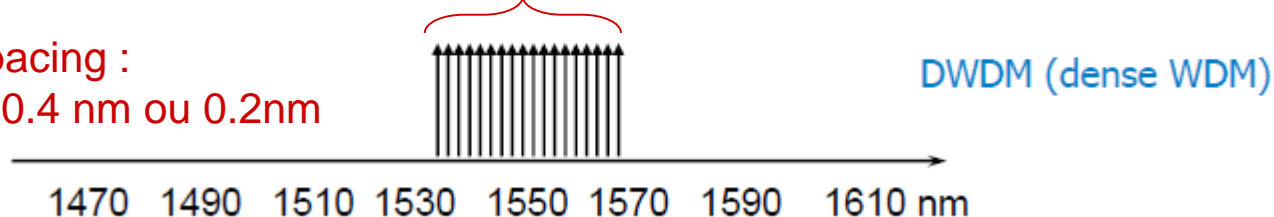
* Normalized channel spacing in ITU recommendations :

$$d\lambda = -\frac{c}{\nu^2} d\nu$$



or

usual spacing :
0.8 nm, 0.4 nm ou 0.2nm



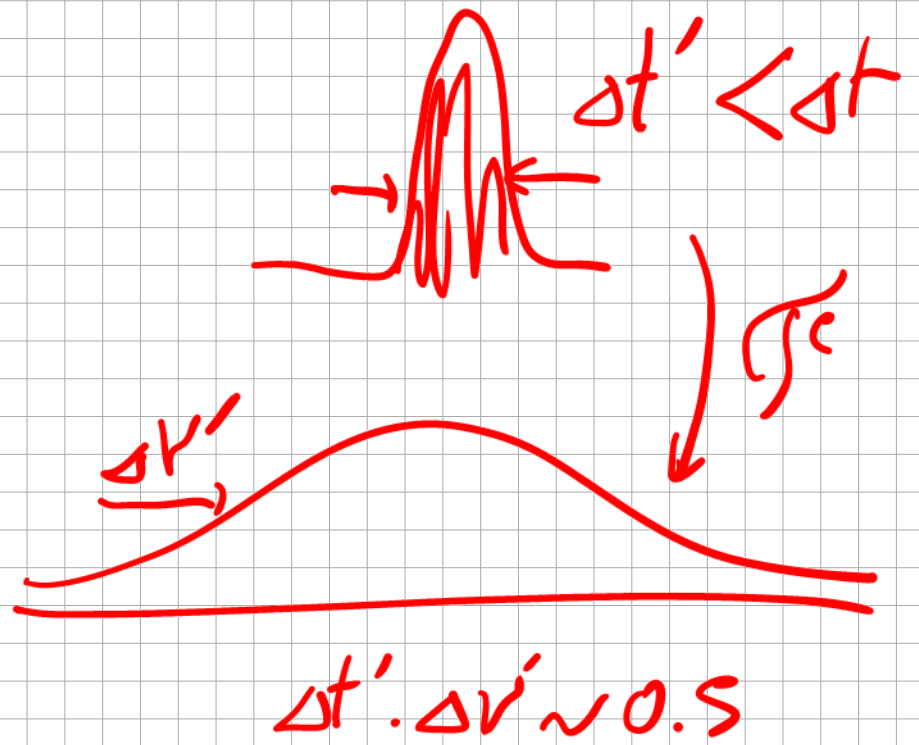
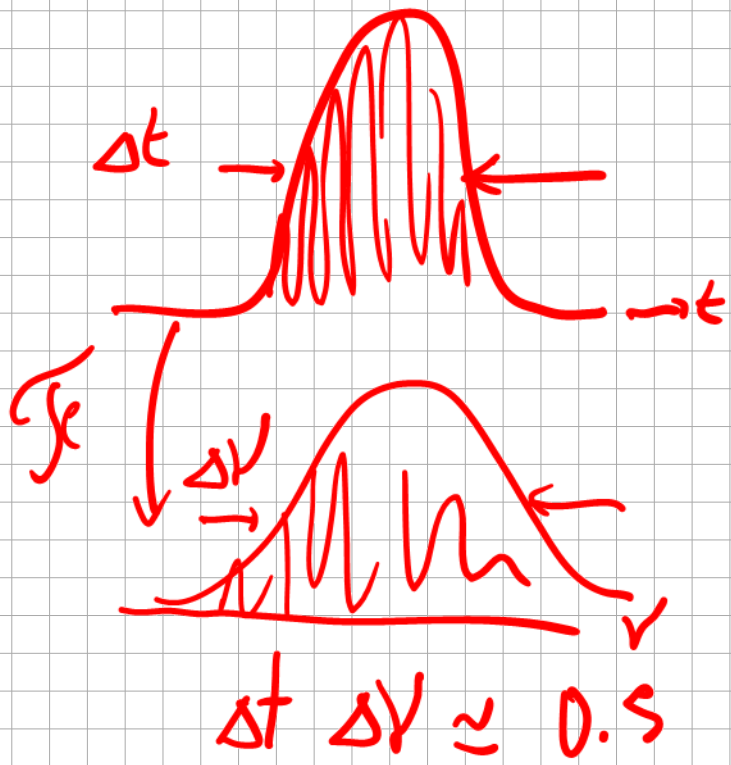
130nm



* With a channel spacing of 0.4nm, over the enlarged bandwidth $1480 \text{ nm} \leftarrow 1530 \text{ } 1560 \rightarrow 1610 \text{ nm}$

\rightarrow Wavelength multiplexing of $130/0.4 = 325$ channels

\rightarrow @ 40Gbits/s per channel ($\Delta \lambda = 0.16 \text{ nm}$) : total bit rate = $325 \times 40 \cdot 10^9 = 13 \text{ Tbits/s}$

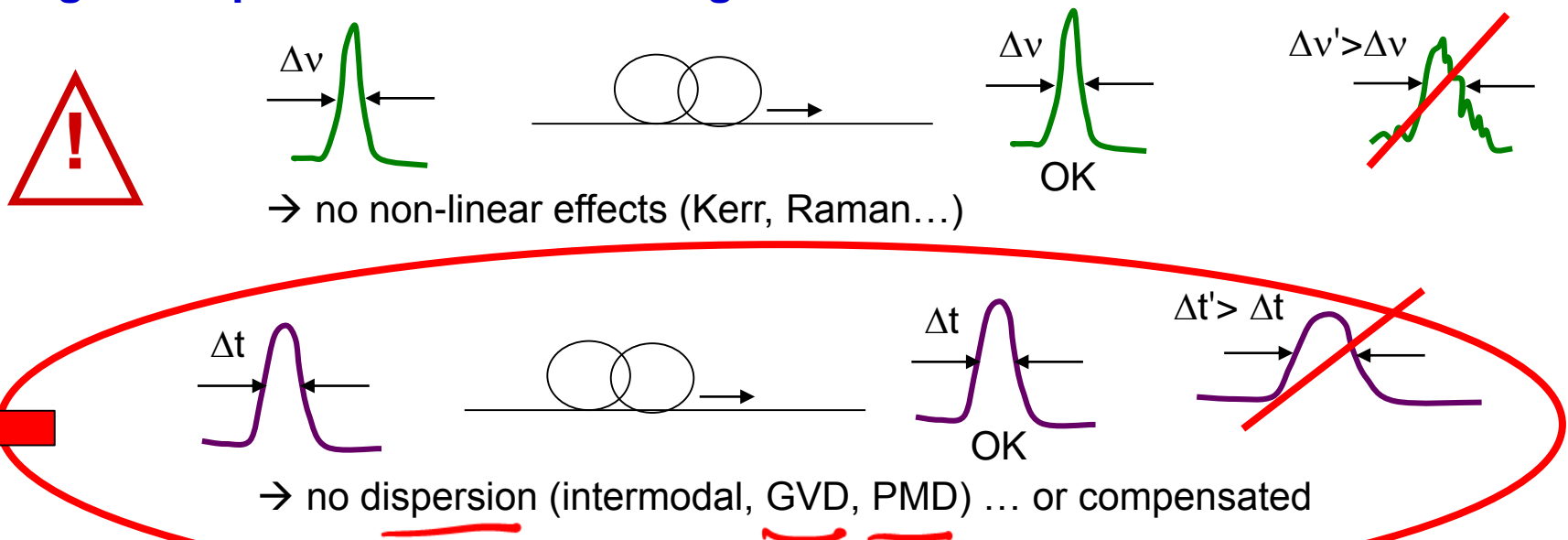


$$\Delta t \cdot \Delta E \approx 1$$

Bit rate reachable in one fiber for optical communications (2)

- highest bit rate in 2018 by Faster Cable (11 6000 km between Japan and USA) : 6 pairs of fibers with 10Tbits/s in each, reached with 100 multiplexed lasers modulated at 100Gbits/s in the C band (1530-1565 nm)
- In the lab (Nokia-Alcatel, 10/2016) : 65Tbits/s over 6600 km (= 10^7 HDTV channels !)
(with a novel modulation technique called "Probabilistic Constellation Shaping (PCS)")

Among the required conditions for high bit rate transmission:



Detailed knowledge of the modes and their propagation properties is necessary

content and objectives of this part of the lecture dedicated to linear propagation of light in optical fibers

→ chapter 2 : few reminders on what are transverse modes of waveguides, effective index, cutoff, dispersion curves,... based on the simple case of a slab waveguide

→ chapter 3 : calculation of LP modes of cylindrical waveguides (case of step index fibers) ; propagation properties of modes in multimode fibres, group velocity dispersion, modal population and modal effects ; single mode regime : fundamental gaussian mode, polarisation effects in single mode fibers

→ chapter 4 : dispersion in optical fibers (intermodal dispersion in multimode regime, chromatic dispersion in single mode regime); methods for compensating/cancelling the chromatic dispersion

end of the introduction chapter