# CHAPTER 1
# Introduction, schedule

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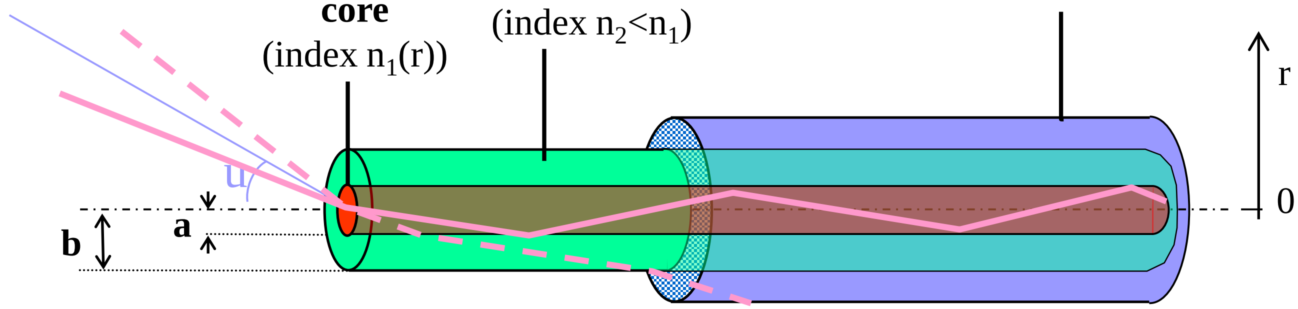
# What is a standard optical fiber?




➢ 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, ... )

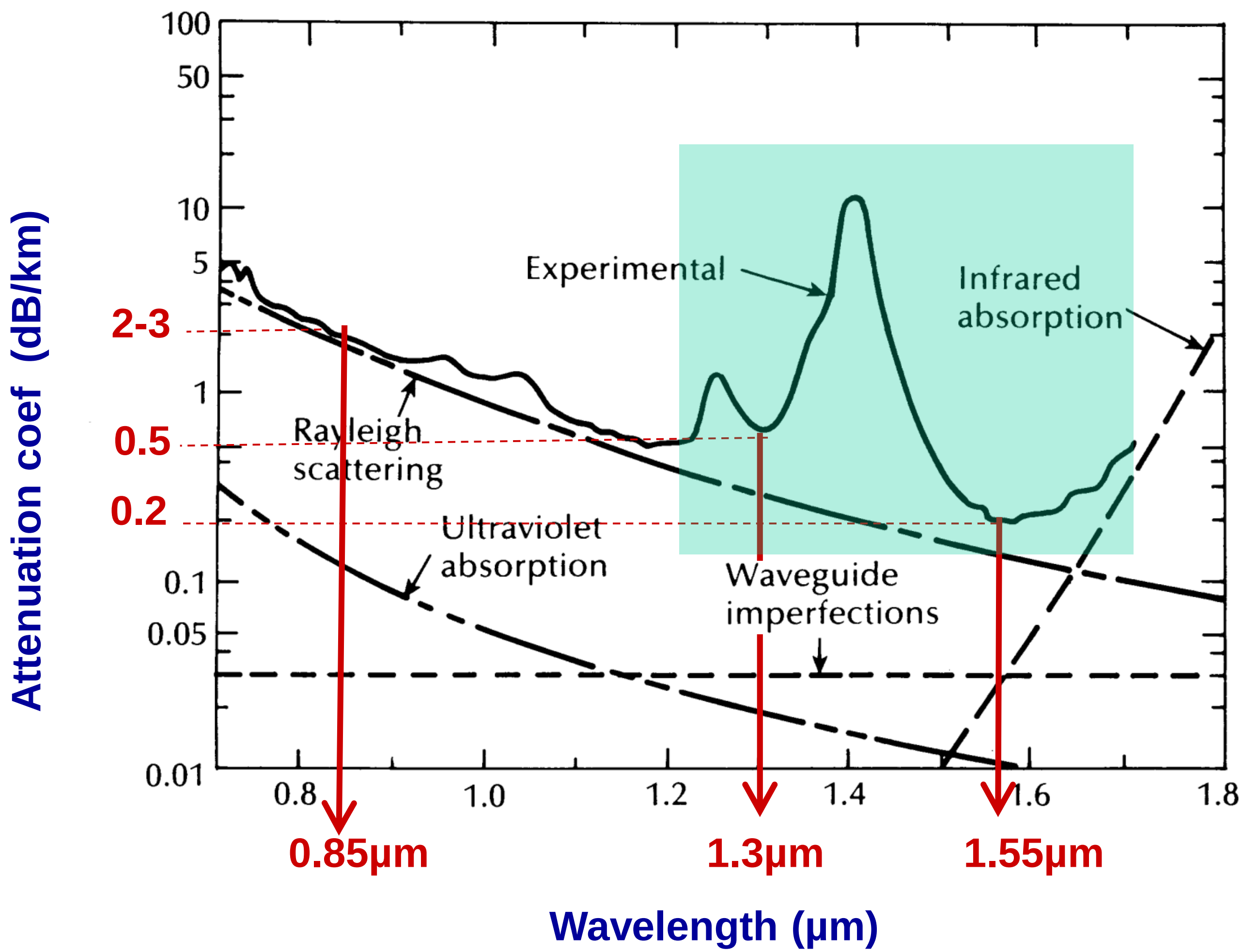
➢ Main characteristics:
- Numerical aperture

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

- Normalized spatial frequency

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

# Transmission windows of silica optical fibers

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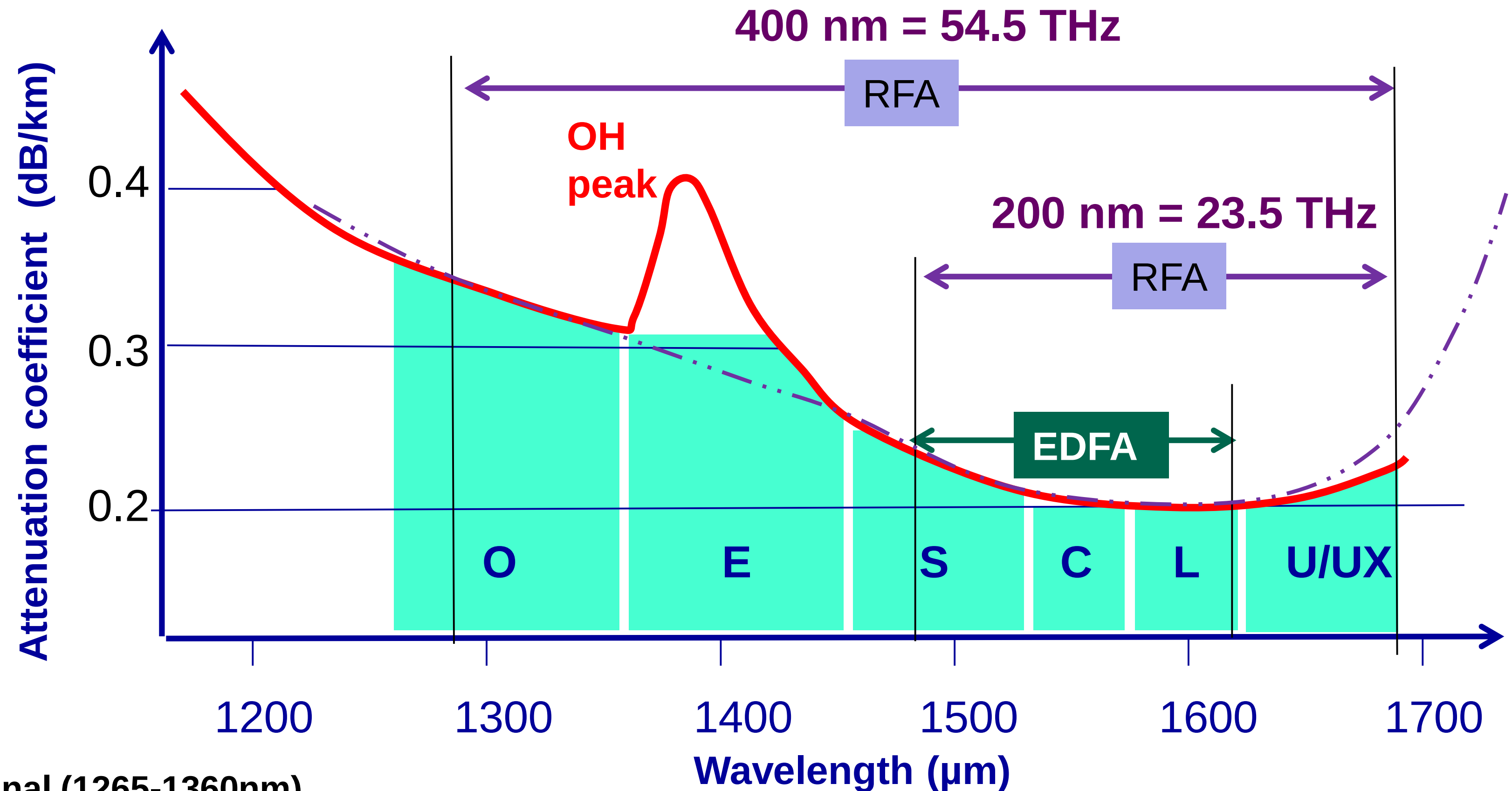
## Transmission windows of silica optical fibers

$\nu = c/\lambda \rightarrow \Delta\nu = \dfrac{c.\Delta\lambda}{\lambda^2}$




O : Original (1265-1360nm)
E : Extended (1360-1465 nm)
S : Short wavelengths (1465-1525 nm)
C : Conventional (1525 – 1565 nm)
L : Long wavelegths (1565 – 1625 nm)
U : Ultra-long wavelengths (1625 -1675 nm)

RFA : Raman Fiber Amplifier
EDFA : Erbium Doped Fiber Amplifier

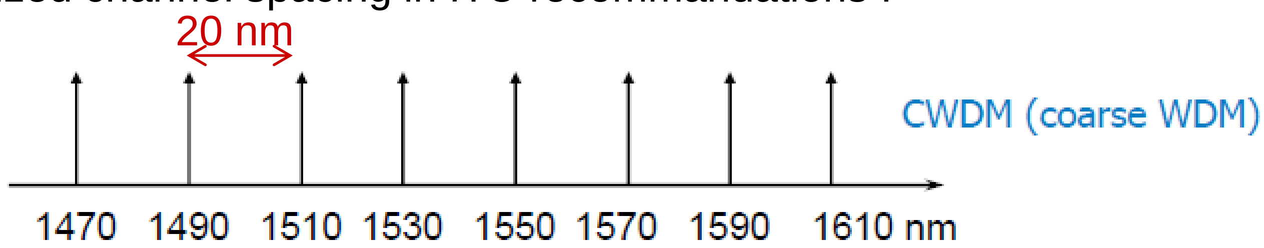
## Bit rate reachable in one fiber for optical communications

*** Carrier frequency @ $\lambda$=1.55µm : $\nu$ = 190 THz >> carrier frequency in microwave systems**

* @ 10Gbits/s : pulse duration $\Delta t = 10^{-10}$ s → with $\Delta t.\ \Delta\nu \sim 0.5$ : $\Delta\nu = 5\ 10^{9}$ Hz

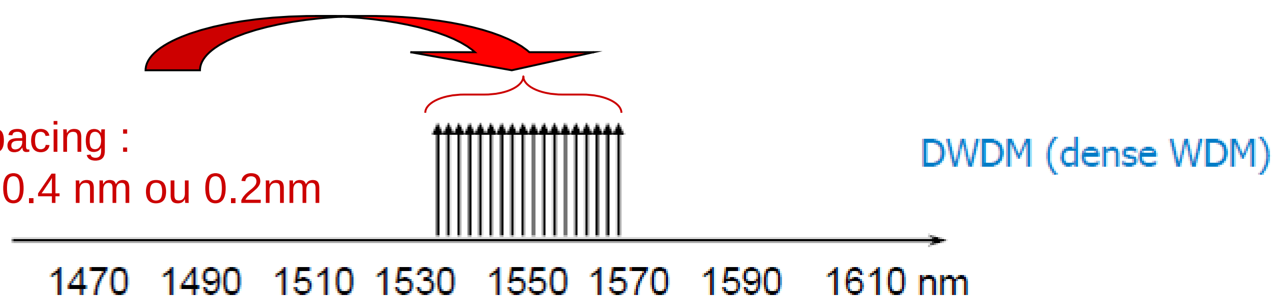
→ $\Delta\lambda = \lambda^2.\ \Delta\nu/c$ = 0.04nm for one channel

* Normalized channel spacing in ITU recommandations :




**or**

usual spacing :
0.8 nm, 0.4 nm ou 0.2nm




130nm

* With a channel spacing of 0.4nm, over the enlarged bandwidth 1480nm ← *1530 1560* → 1610 nm

→ Wavelength multipexing of 130/0.4 = 325 channels

→ @ 40Gbits/s per channel ($\Delta\lambda$ = 0,16nm) : total bit rate = 325 x 40 $10^{9}$ = 13 Tbits/s

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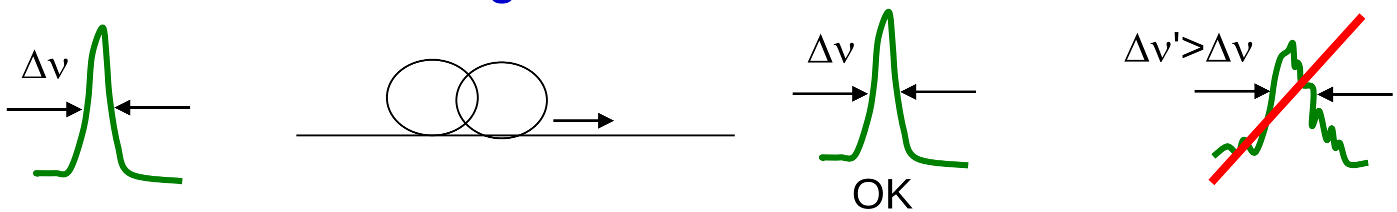
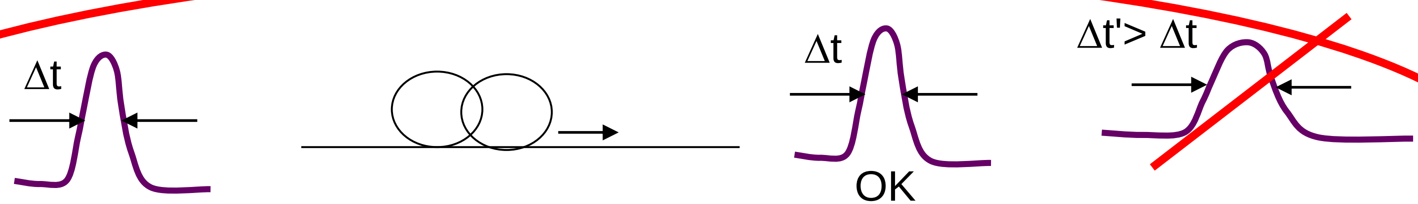
# Bit rates already reached for optical communications

- In the lab (Nokia-Alcatel, in 2016) : 65Tbits/s over 6600 km ( $=10^7$ HDTV channels ! )
  *(with a novel modulation technique called « Probabilistic Constellation Shaping (PCS ) » )*
- in the lab (NICT-Japan in 2021) : more than 1Pbit/s over 50 km !
  *(with a multicore (4 cores) fiber + DWDM (801 chanels) + Space div mux + advanced modulation :*
- installed (Faster Cable in 2018): highest bit rate of 6x 10Tbits/s over 11 6000 km between Japan and USA):
  *(with 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))*

# Among the required conditions for high bit rate transmission:




→ no non-linear effects (Kerr, Raman…)




→ no dispersion (intermodal, GVD, PMD) … or compensated

**Detailed knowledge of the modes and their propagation properties is necessary**

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## 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***