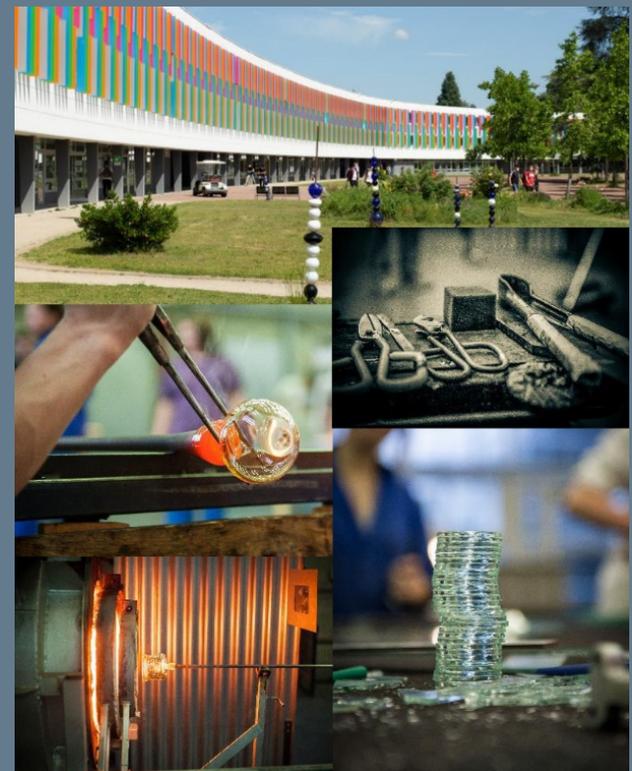


VERRES POUR L'OPTIQUE : SABLE ET LUMIÈRE POUR UNE PLAGE DE RÉVOLUTIONS

WILFRIED BLANC
INSTITUT DE PHYSIQUE DE NICE
UNIV. CÔTE D'AZUR, CNRS



ÉTYMOLOGIE

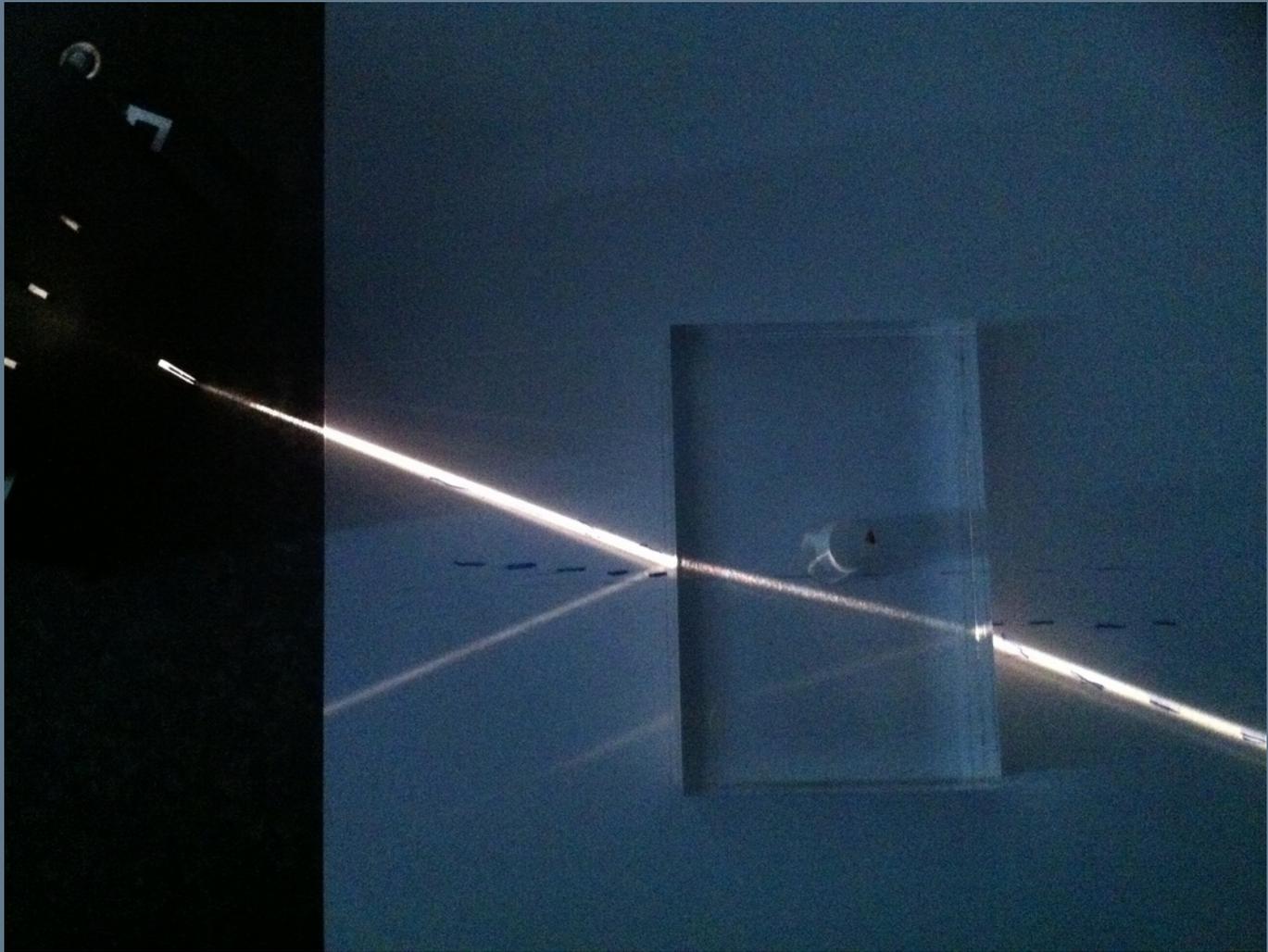
- Verre → *vitrum* (2000 ans), translucide, brillant
 - Glass → *glaesum*, ambre (couleur)
- Verre et optique sont intimement liés
1^{er} matériau transparent fabriqué par l'Humanité

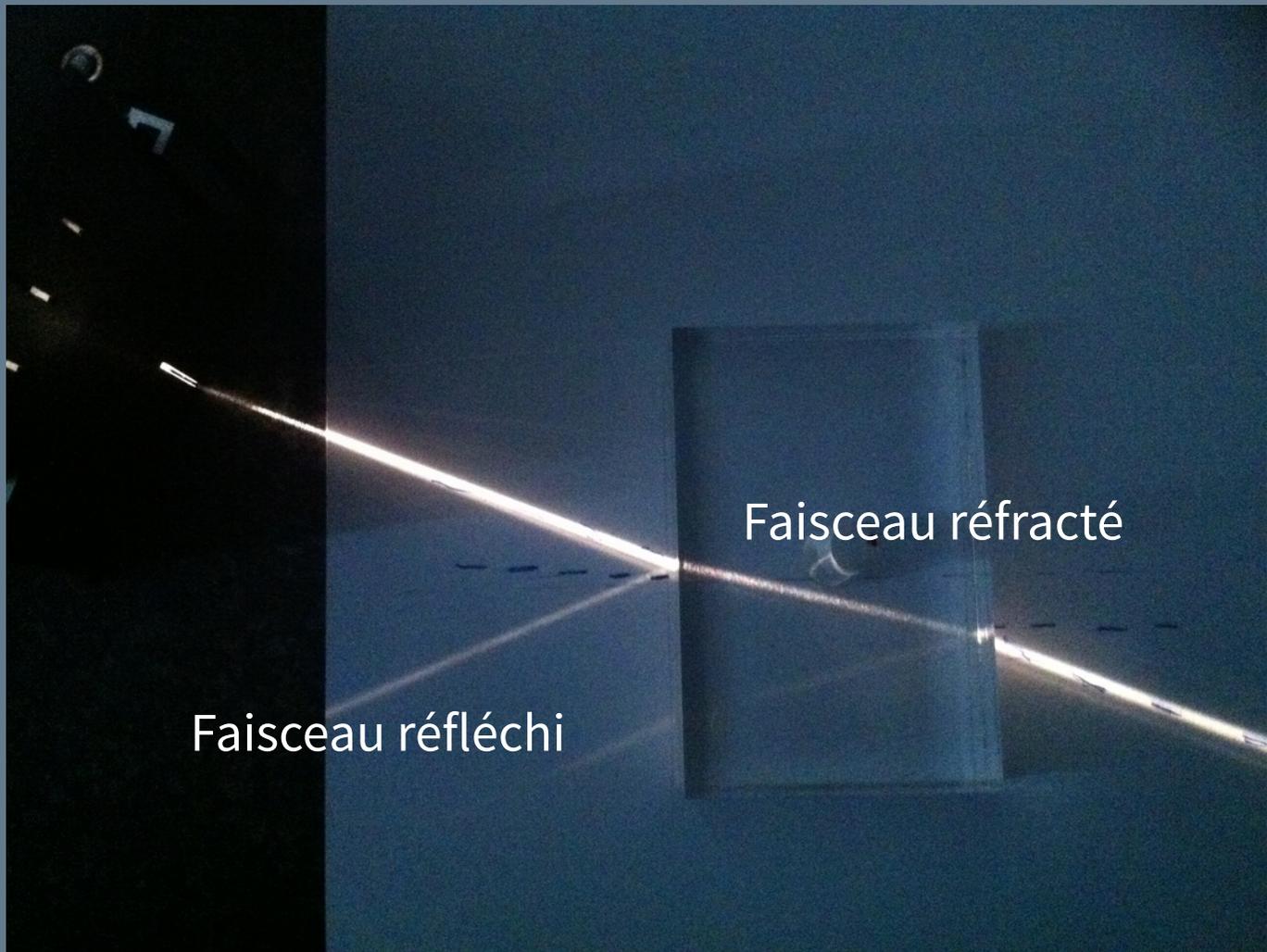


ambre

obsidienne

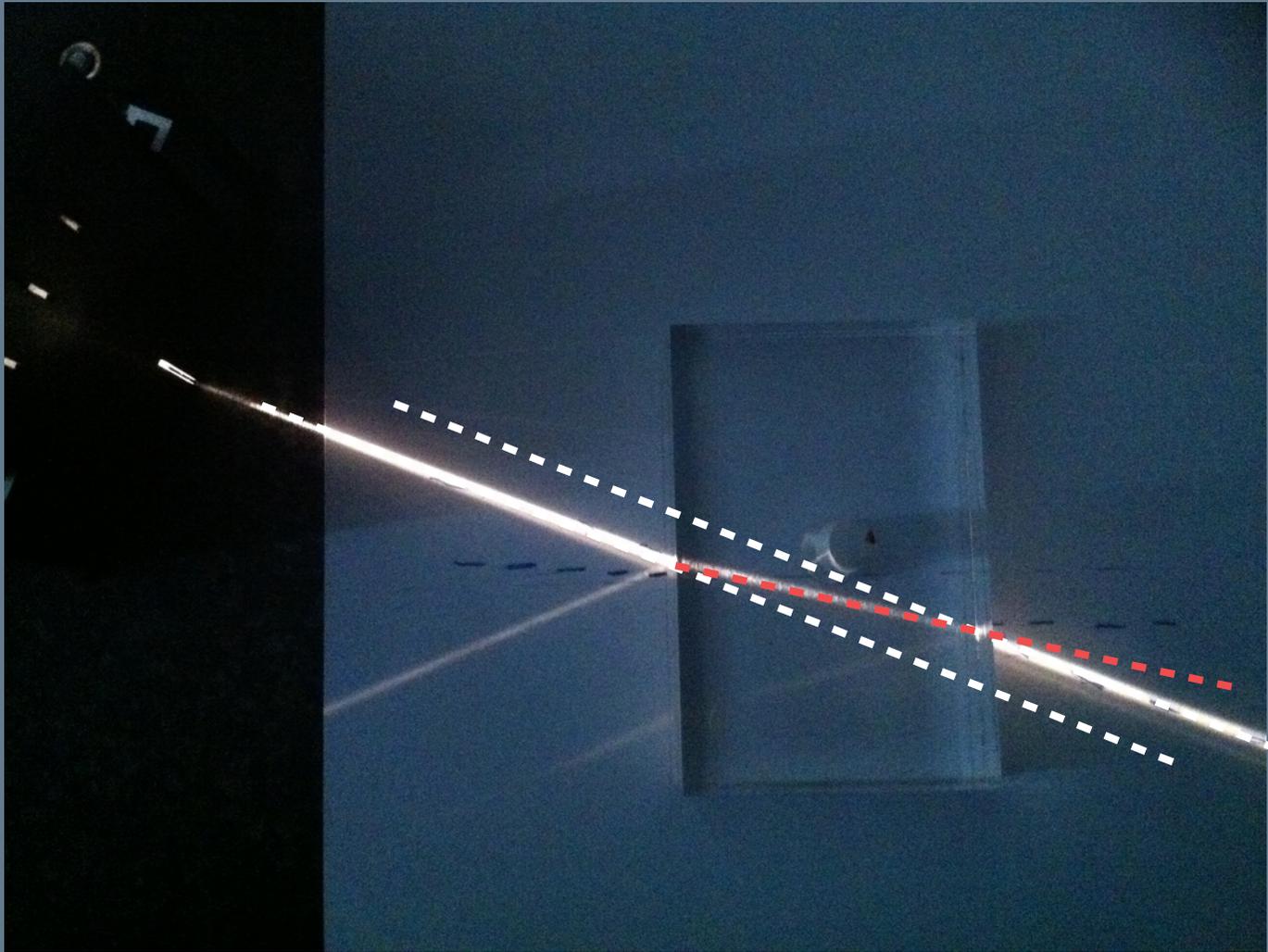
-
- Les propriétés optiques du verre

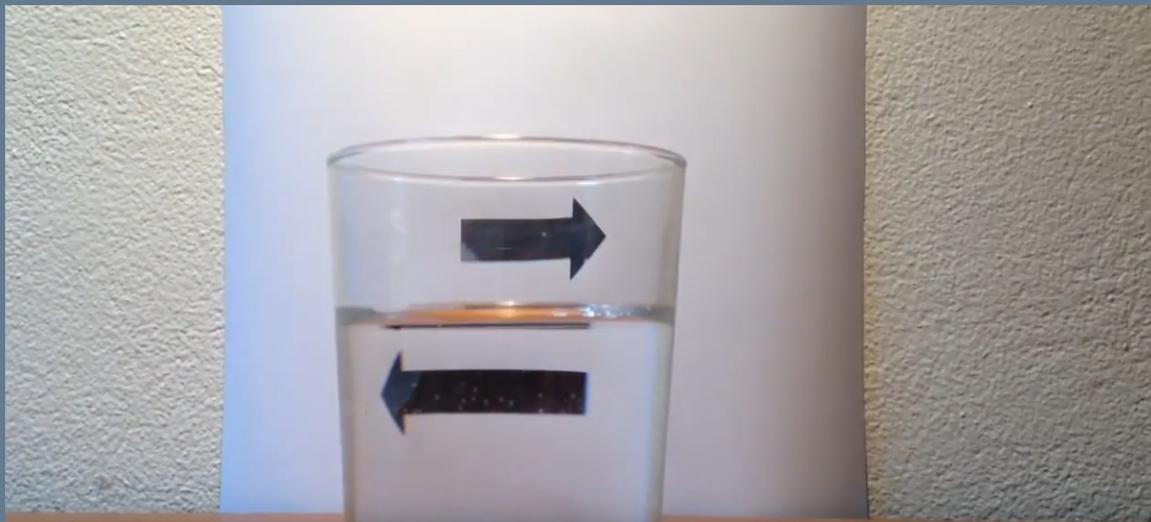
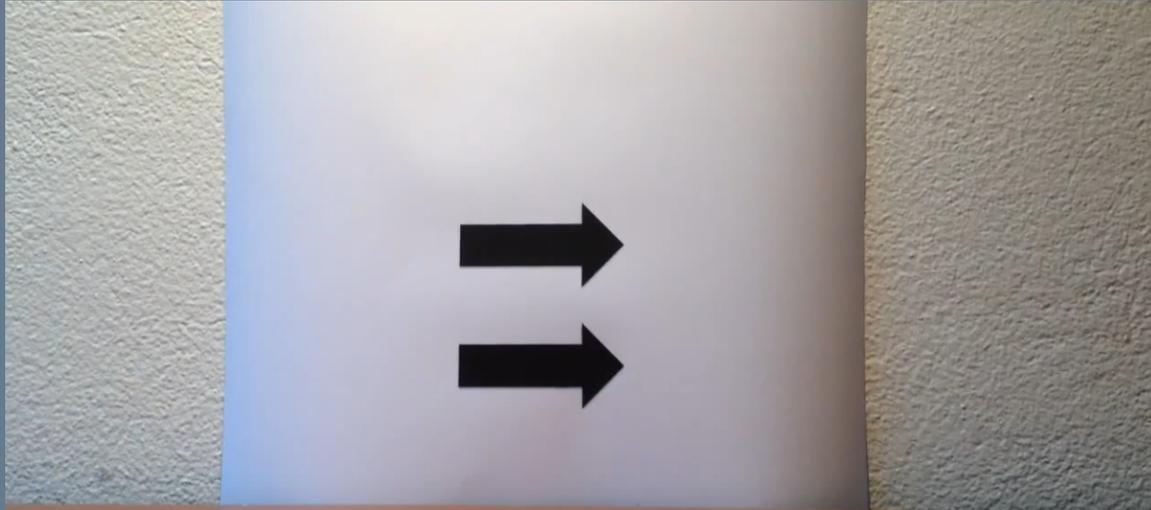




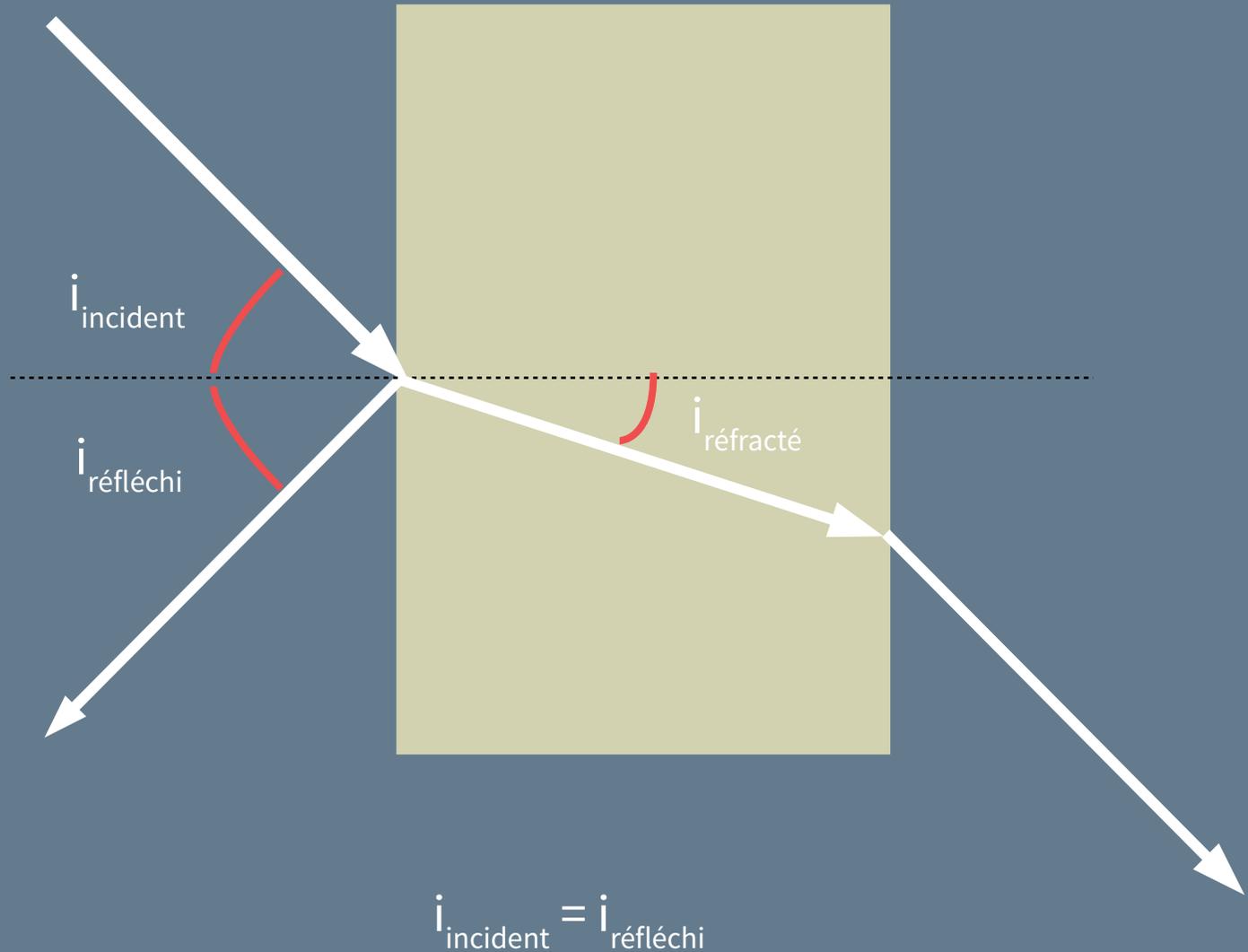
Faisceau réfléchi

Faisceau réfracté





RÉFRACTION



~ 1625 : Formule de Snell-Descartes : $n_{\text{air}} \times \sin i_{\text{incident}} = n_{\text{verre}} \times \sin i_{\text{réfracté}}$

L'INDICE DE RÉFRACTION

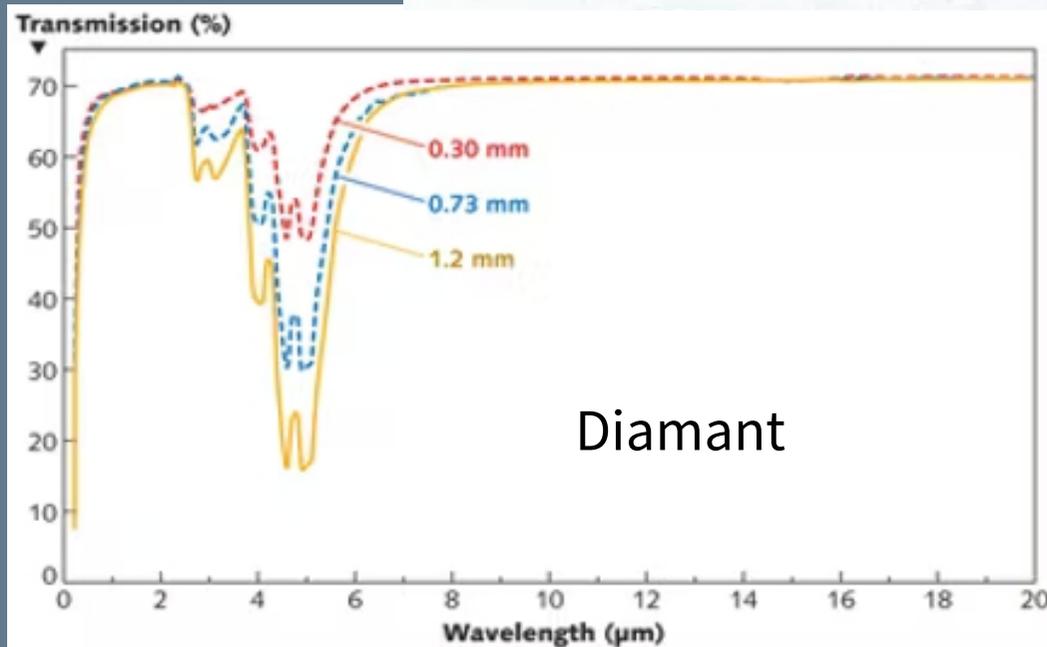
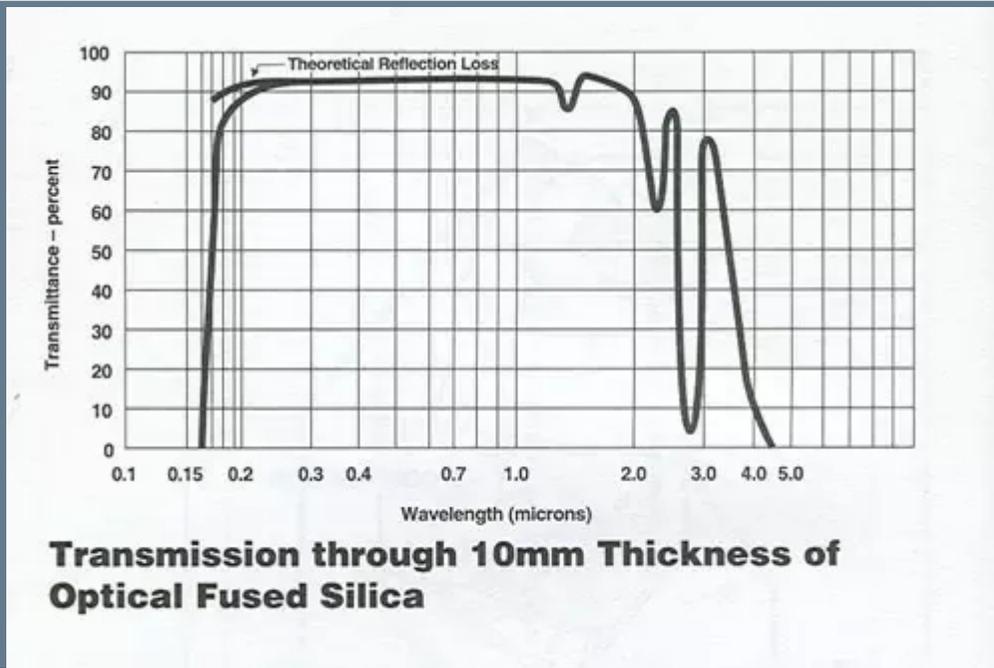
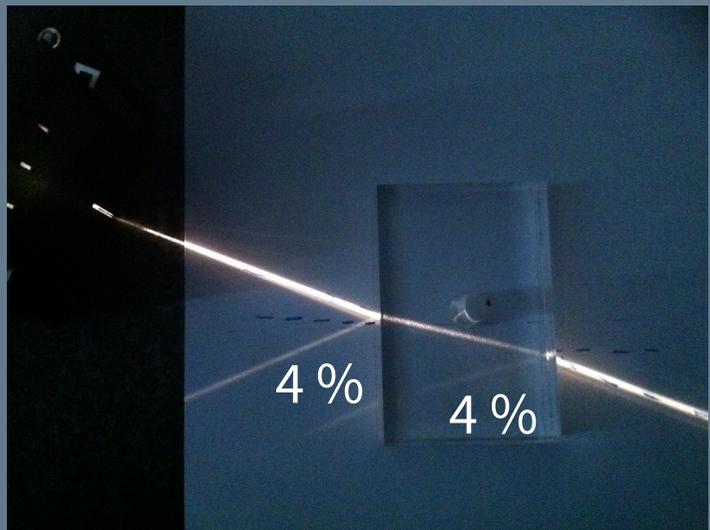
$$n = \frac{c}{v}$$

Vitesse de la lumière dans le vide

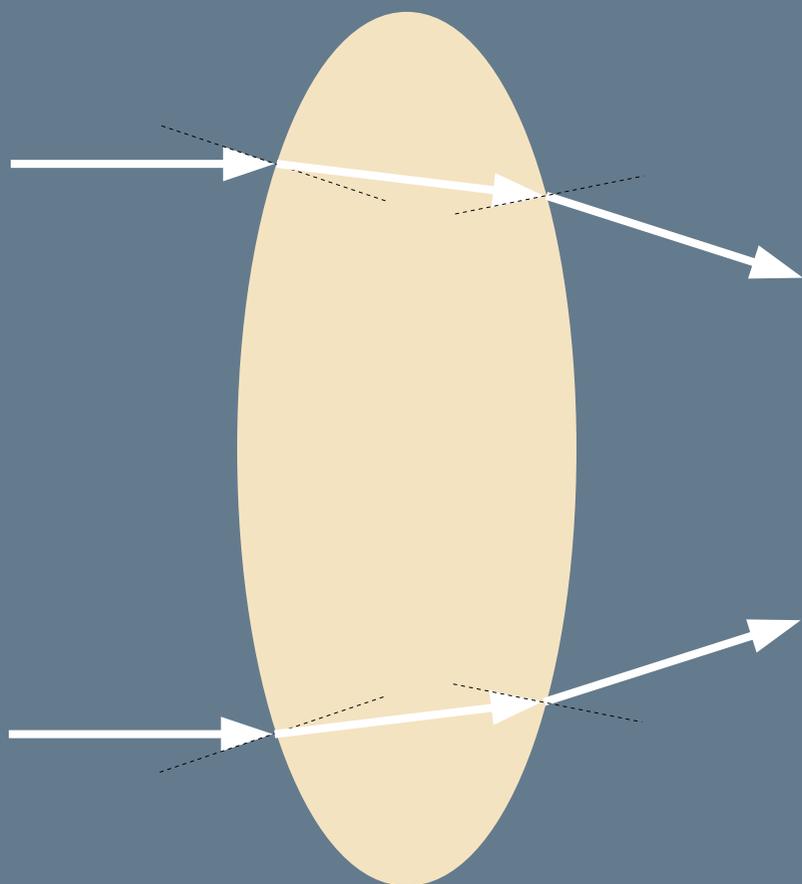
Vitesse de la lumière dans le matériau

	verre	eau	diamant
n	1,5	1,3	2,4
v (km/s)	200 000	230 800	125 000
R (%)	4	2	17

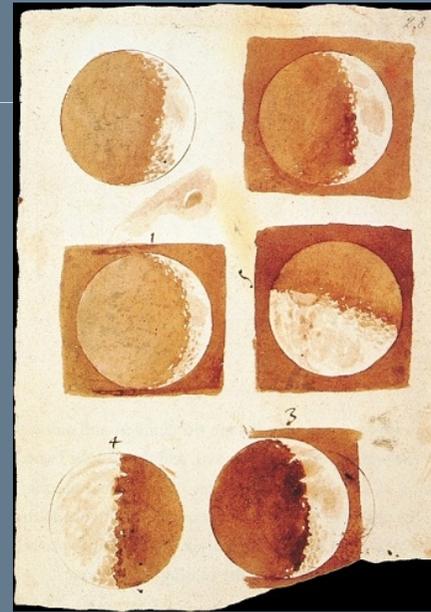
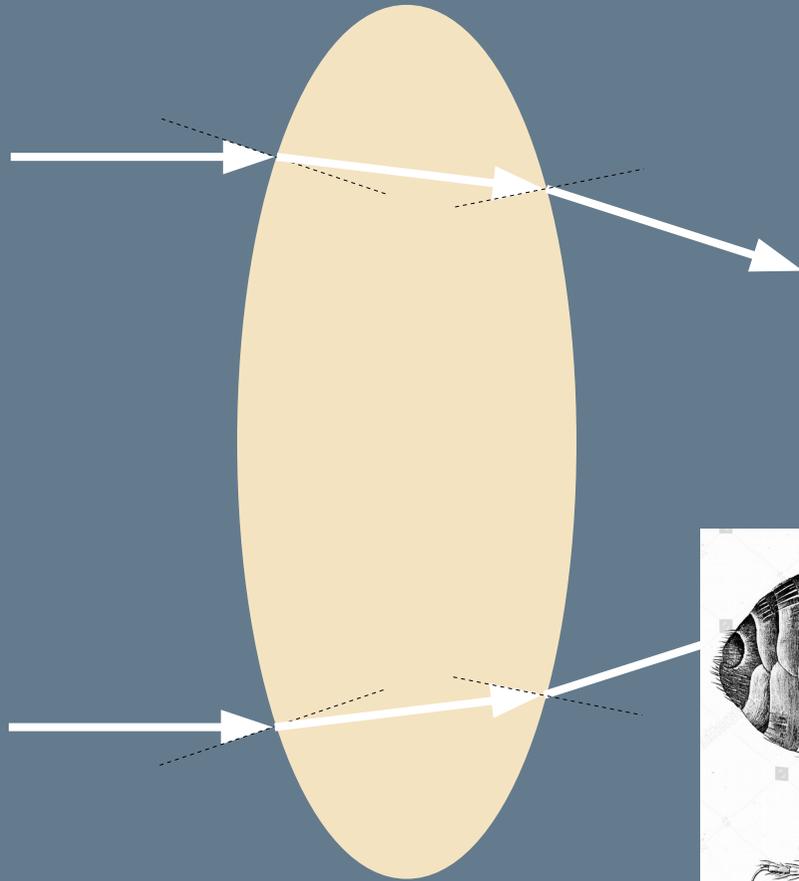
TRANSMISSION



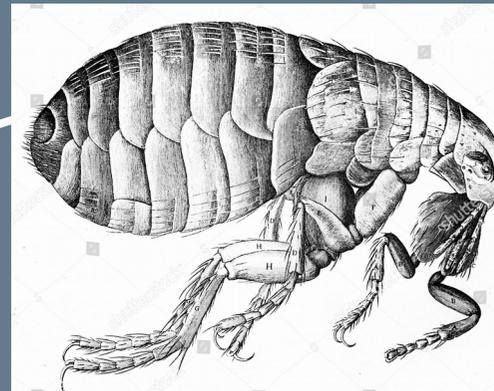
LENTILLES



LENTILLES

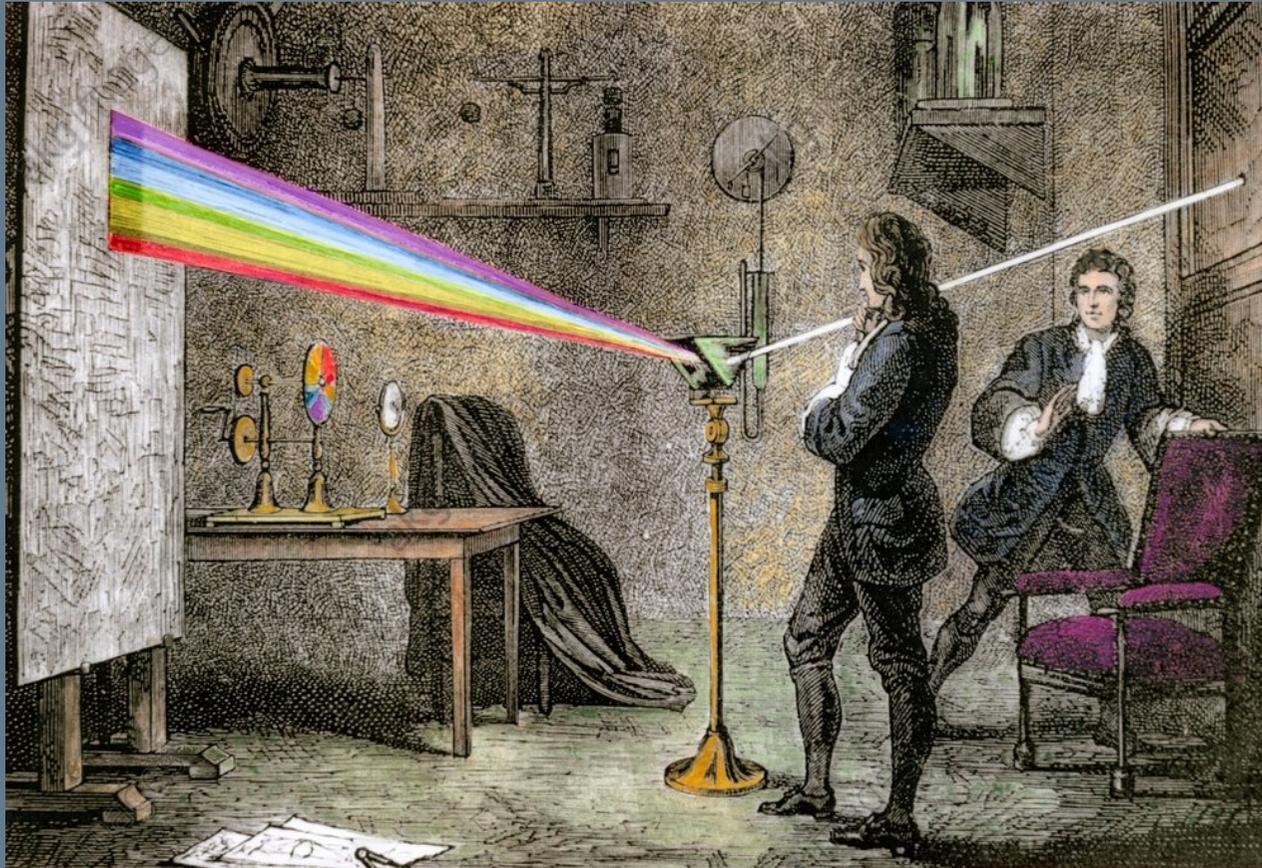


1609 - Galilée



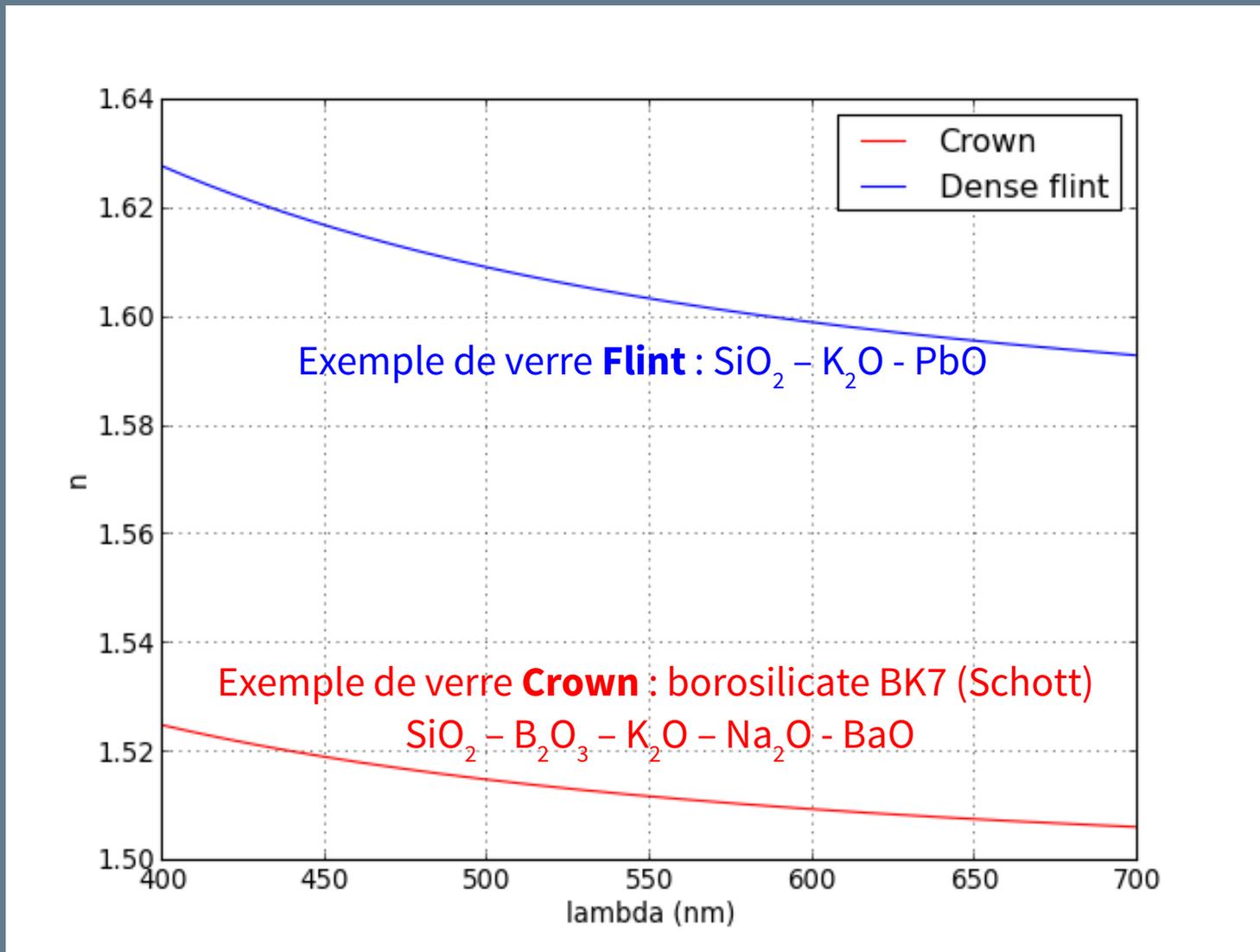
1665 - Micrographia, Robert Hooke

DISPERSION CHROMATIQUE

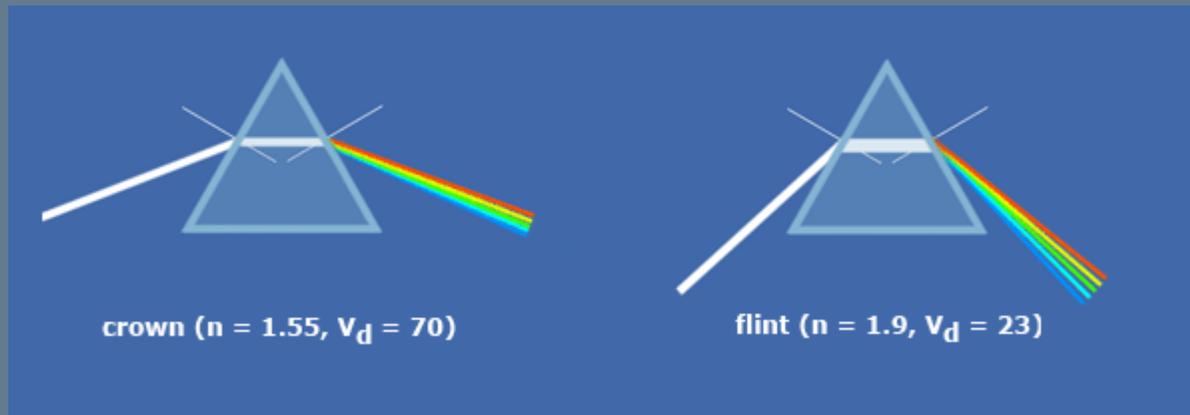
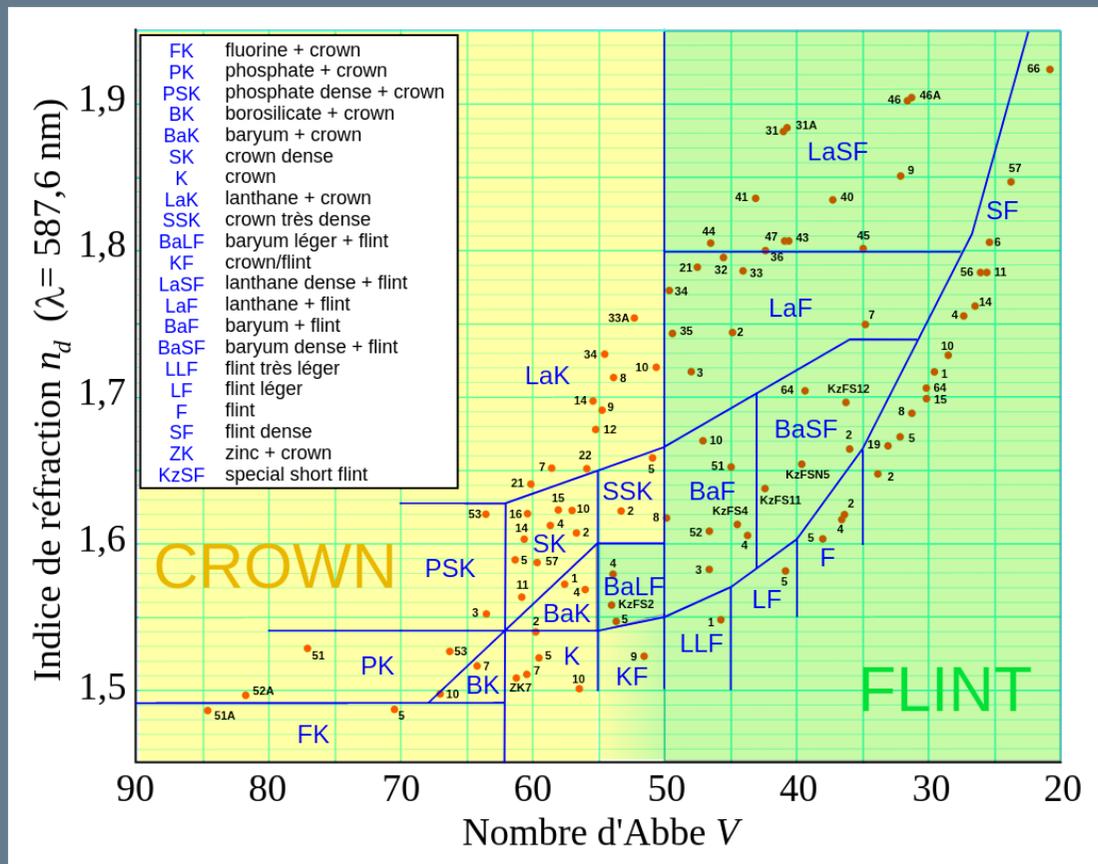


Expériences de Newton en 1666 (24 ans),
confiné à Woolsthorpe à cause de la Grande Peste

DISPERSION CHROMATIQUE

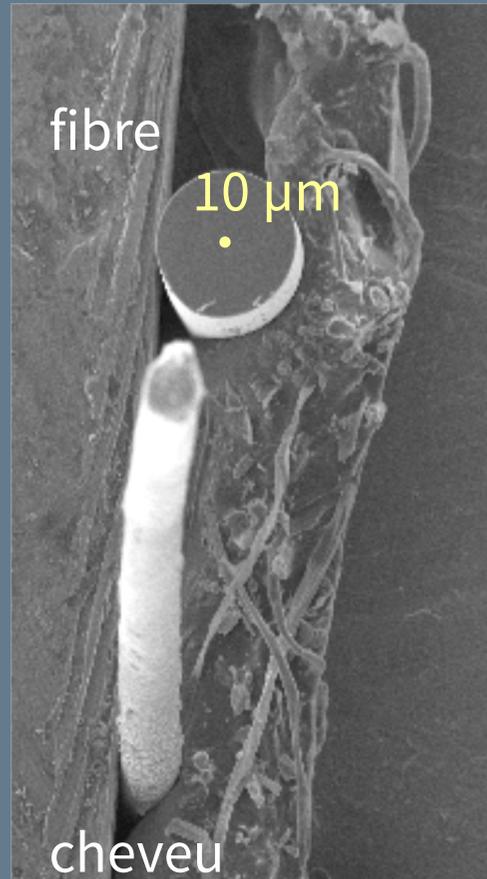


DISPERSION CHROMATIQUE



-
- Les fibres optiques

LA FIBRE OPTIQUE, UN CHEVEU DE LUMIÈRE



1 mm = 1000 μm

PLAN DE LA CONFÉRENCE

- Les origines
- L'apport de la fibre pour internet et les télécommunications
- D'autres applications

LES ORIGINES

L'ORIGINE DU GUIDAGE DE LA LUMIÈRE



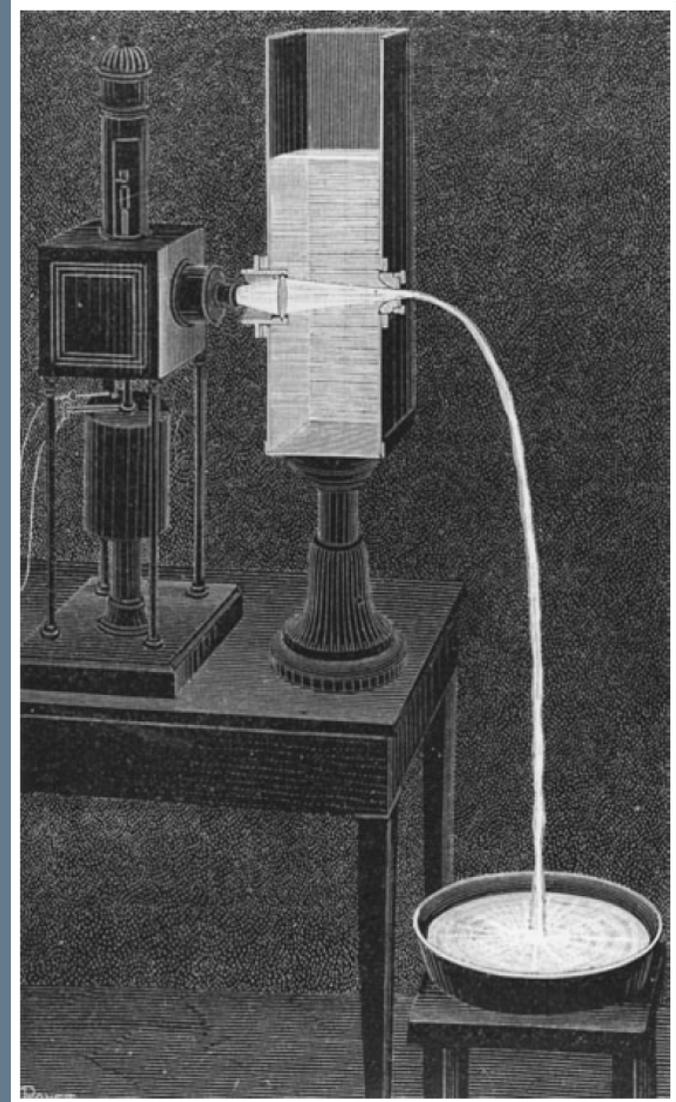
Félix Savart - 1833



JEAN-DANIEL COLLADON (1802-1893)

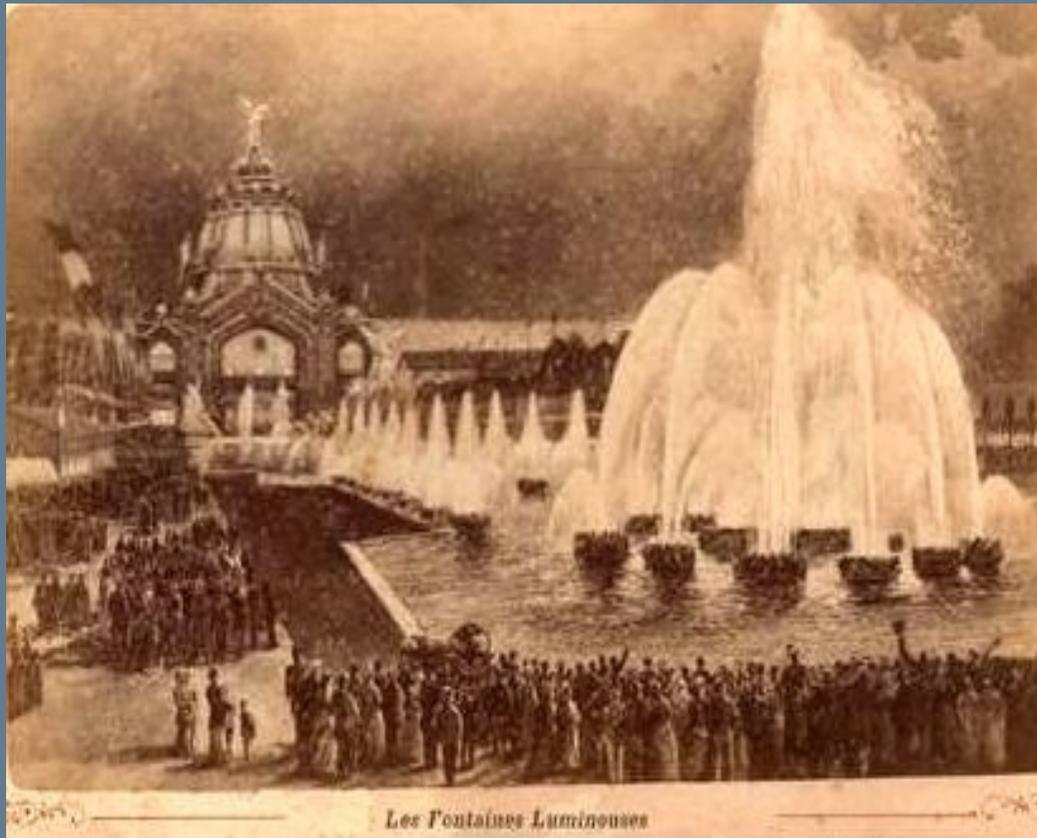
1841 : La fontaine lumineuse

« Une des plus belles et des plus curieuses expériences que l'on puisse faire dans un cours d'optique. »



*« Sur les réflexions d'un rayon de lumière à l'intérieur d'une veine liquide parabolique »,
Comptes rendus hebdomadaires des séances de l'Académie des sciences, 15 (Oct. 24), 800-802, (1842).*

LES FONTAINES LUMINEUSES



Exposition Universelle
Paris 1889

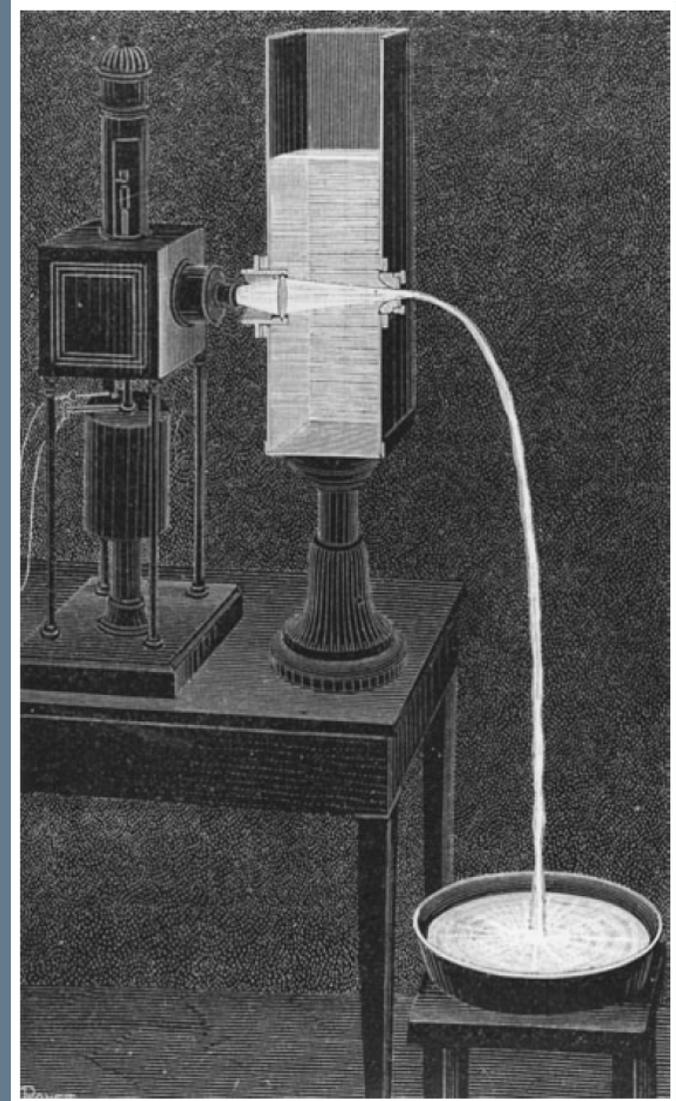
~1860 : invention de l'ampoule électrique

JEAN-DANIEL COLLADON (1802-1893)

1841 : La fontaine lumineuse

« Une des plus belles et des plus curieuses expériences que l'on puisse faire dans un cours d'optique. »

1842 : article dans CRAS



*« Sur les réflexions d'un rayon de lumière à l'intérieur d'une veine liquide parabolique »,
Comptes rendus hebdomadaires des séances de l'Académie des sciences, 15 (Oct. 24), 800-802, (1842).*

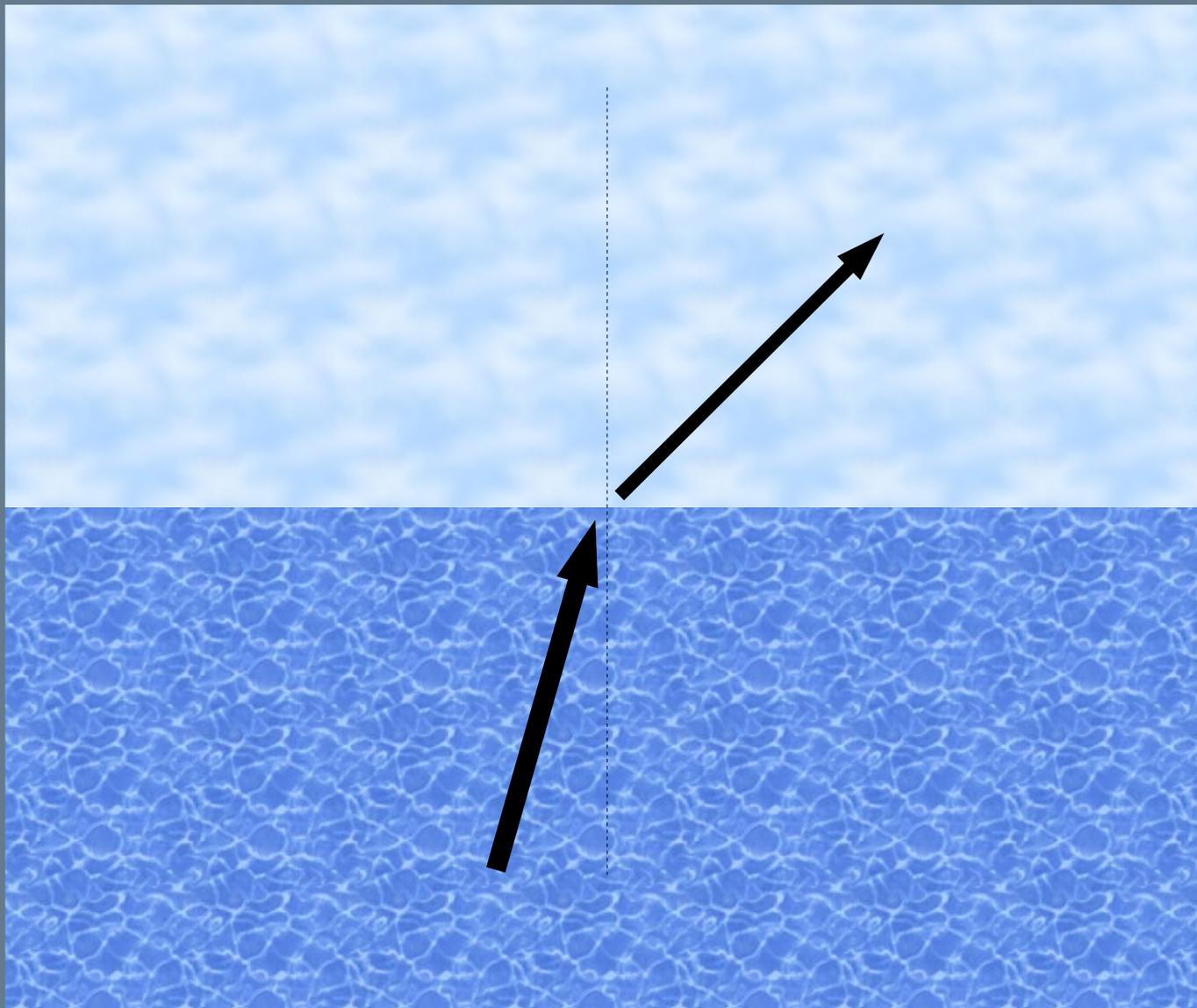
JACQUES BABINET (1794 - 1872)



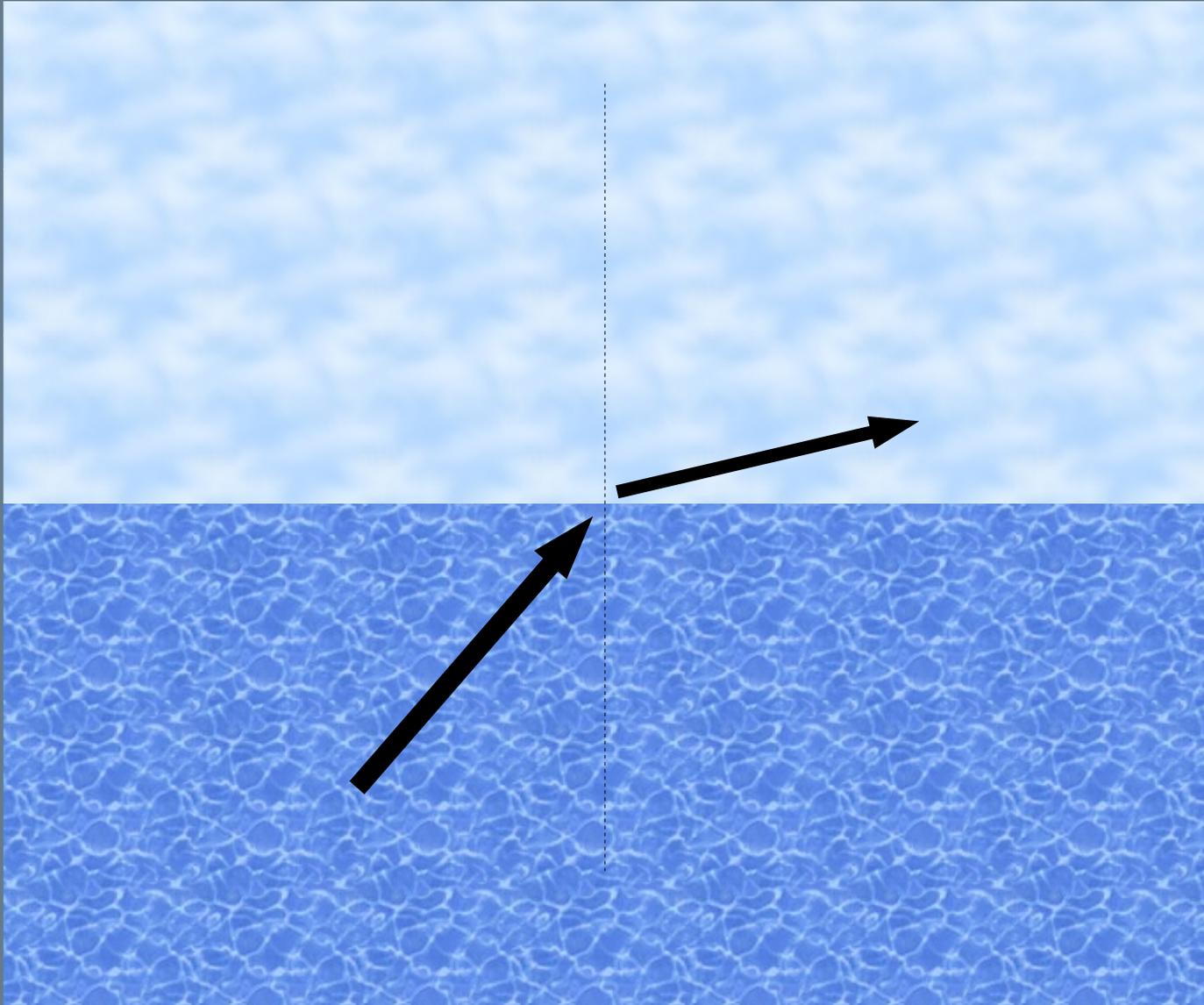
- Observation du guidage dans des barreaux de verre courbés « *de manière quelconque* »
- Propose de l'utiliser pour éclairer l'intérieur de la bouche ou des préparations de microscope

« Note sur la transmission de la lumière par des canaux sinueux »,
Comptes Rendus hebdomadaires des séances de l'Académie des sciences 15 (Oct. 24), s. 802, (1842).

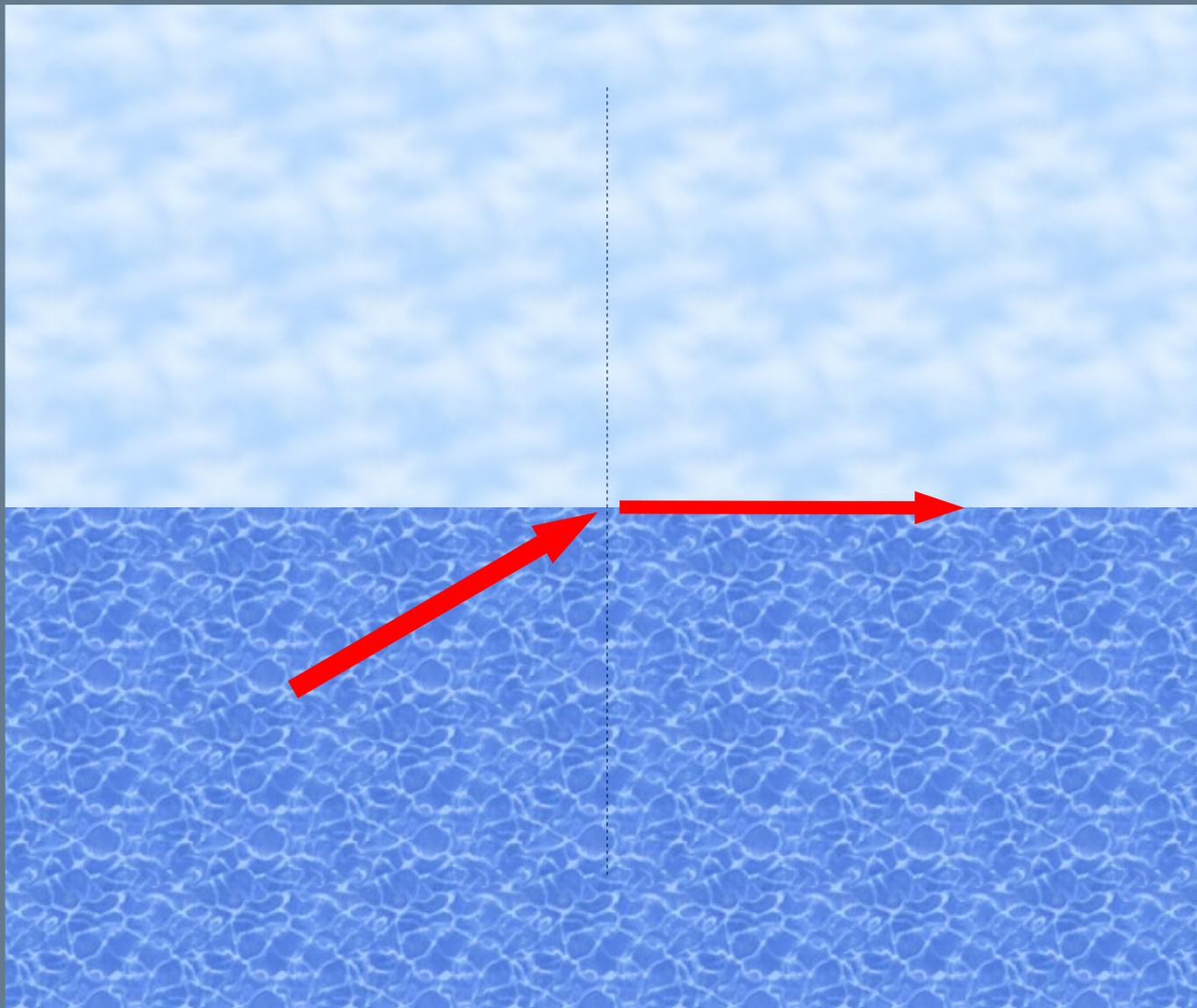
RÉFRACTION



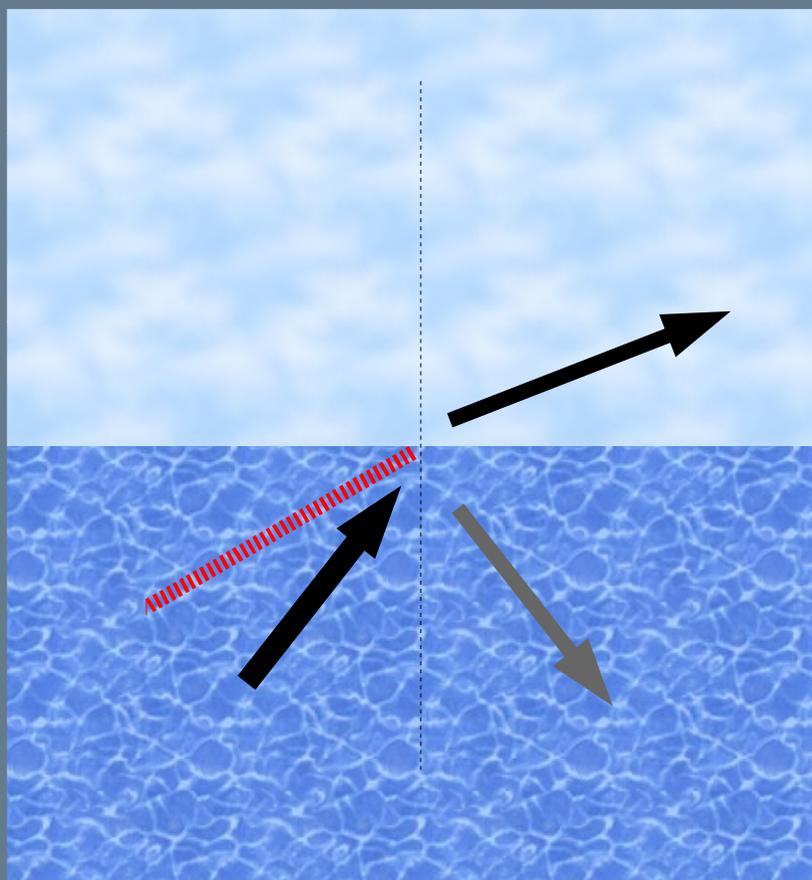
RÉFRACTION



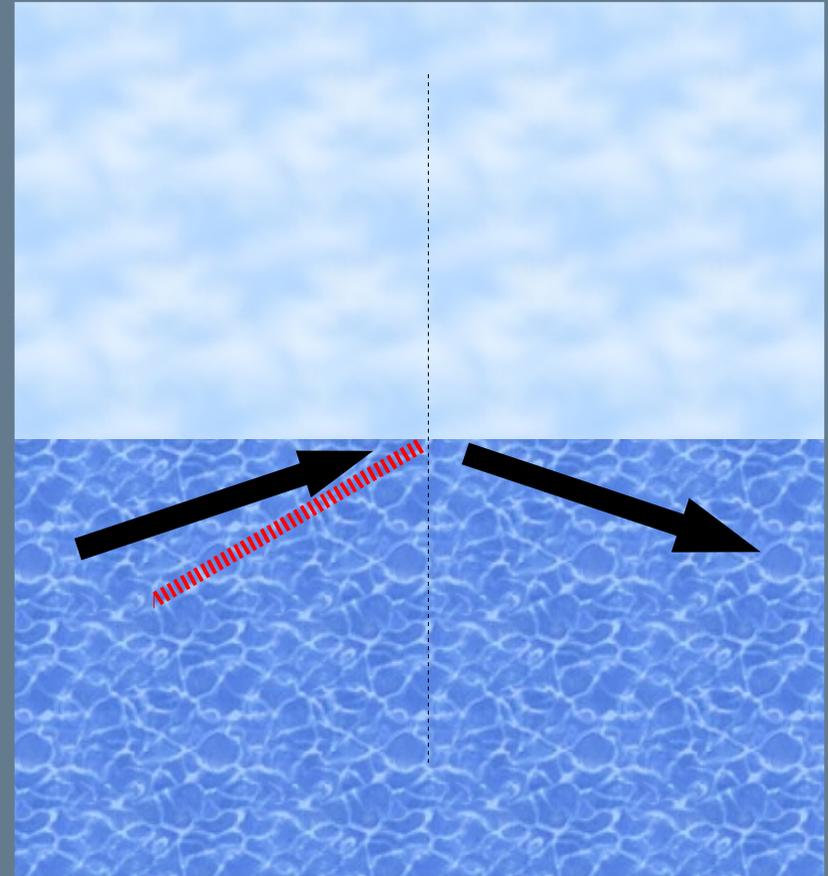
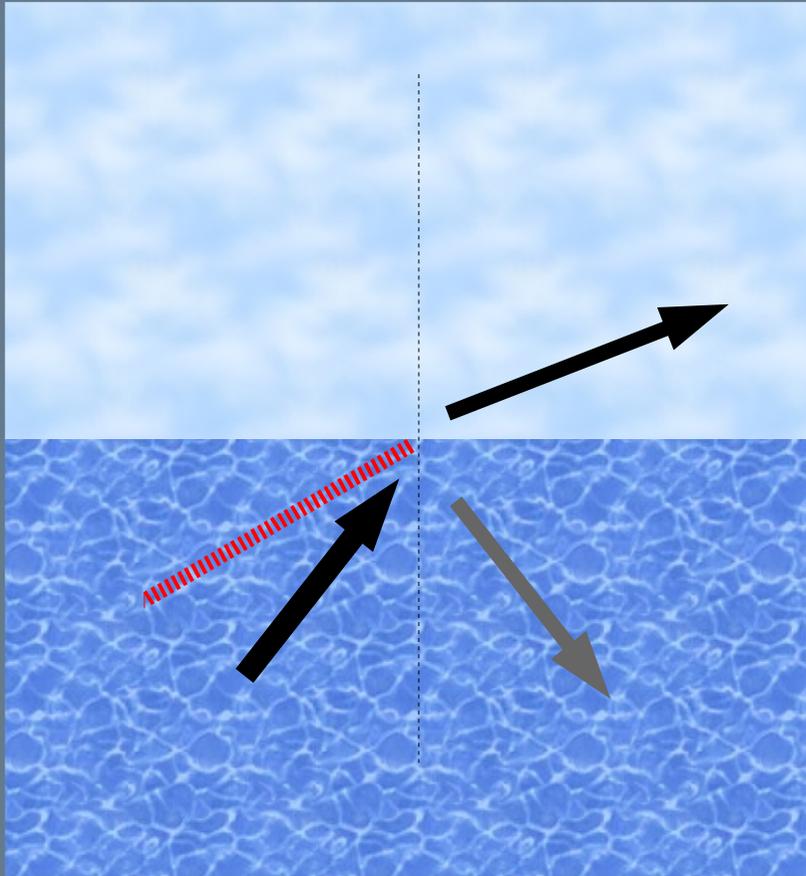
RÉFRACTION



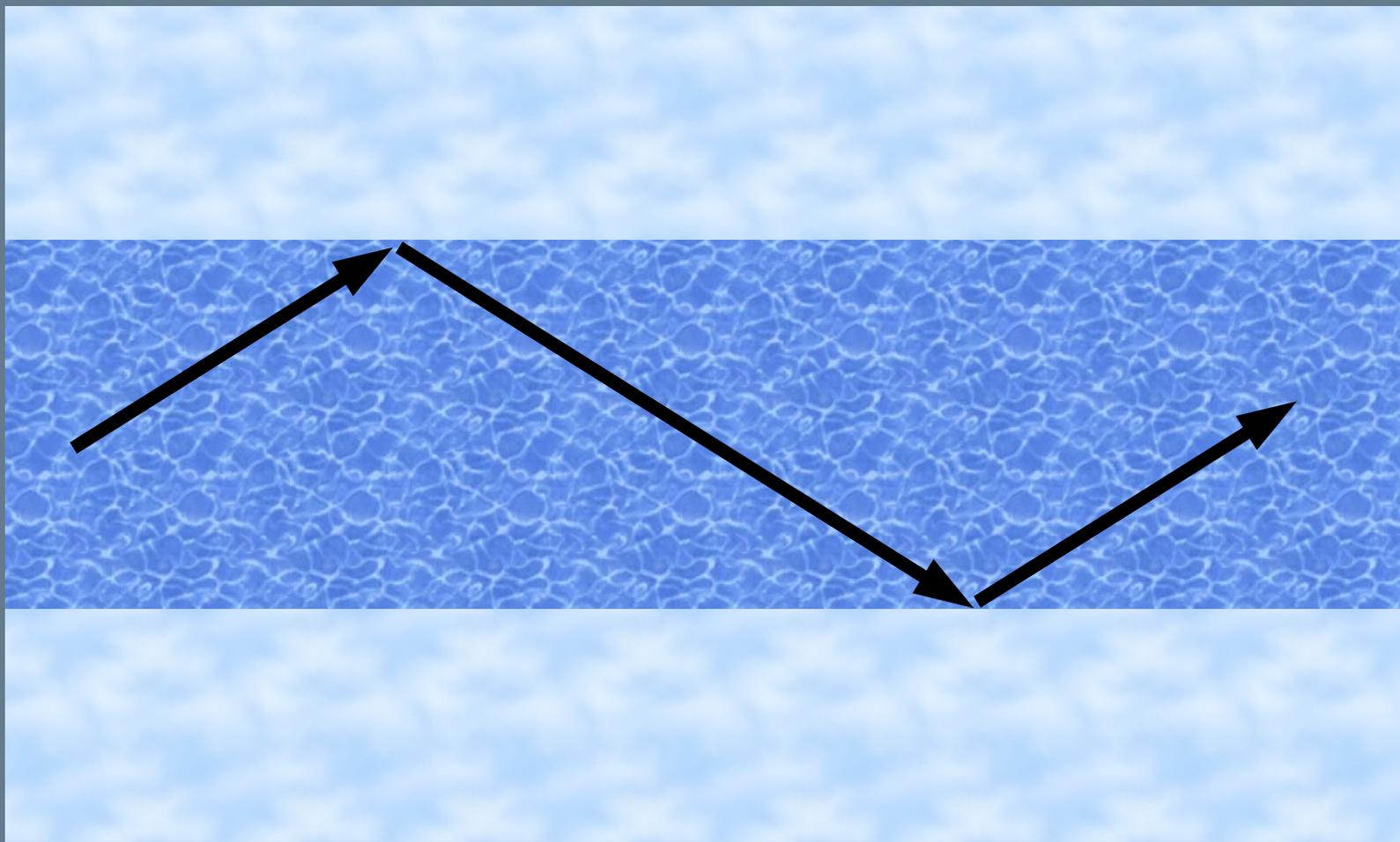
RÉFRACTION



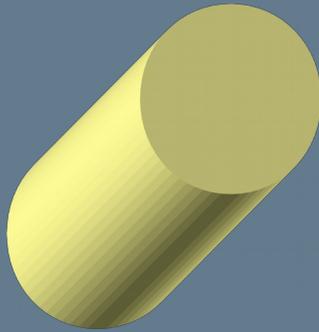
RÉFLEXION TOTALE INTERNE



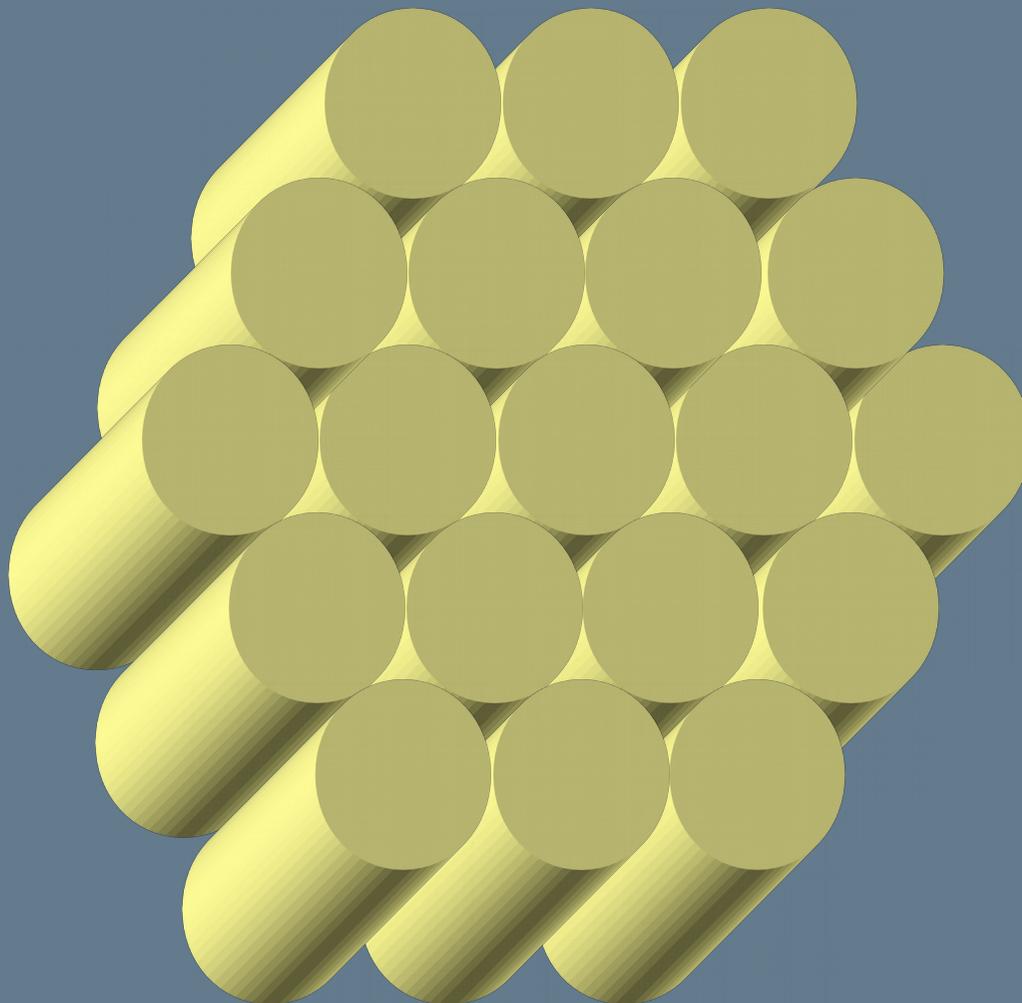
GUIDAGE DE LA LUMIÈRE



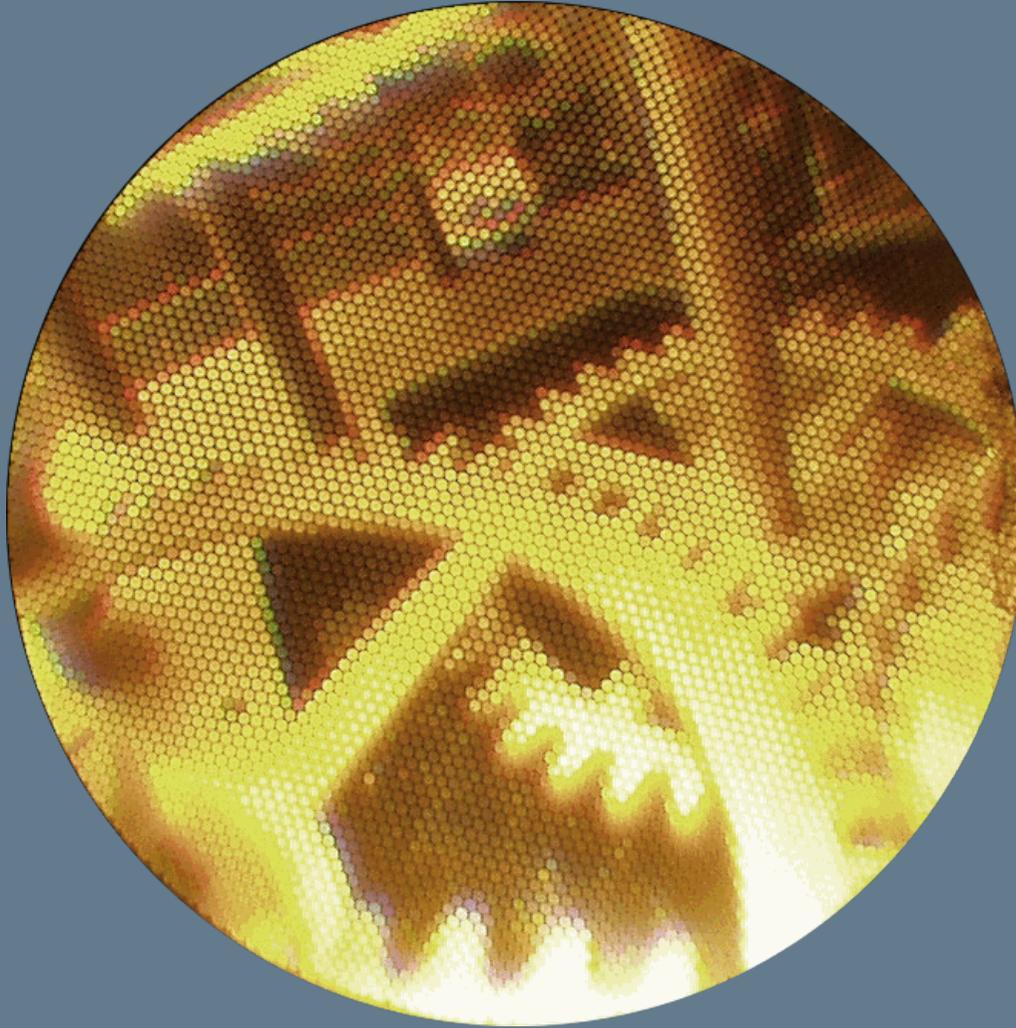
UNE FIBRE : 1 POINT LUMINEUX



PLUSIEURS FIBRES : UNE IMAGE



L'IMAGE PIXELISÉE



1895 : Principe du « pixel » par H.C. Saint-René

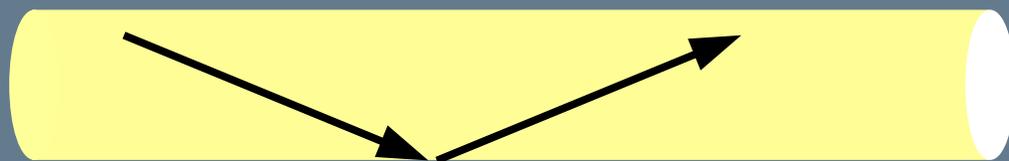
« Sur une solution du problème de la vision à distance », Pli cacheté, 8 juillet 1895

FIBROSCOPE

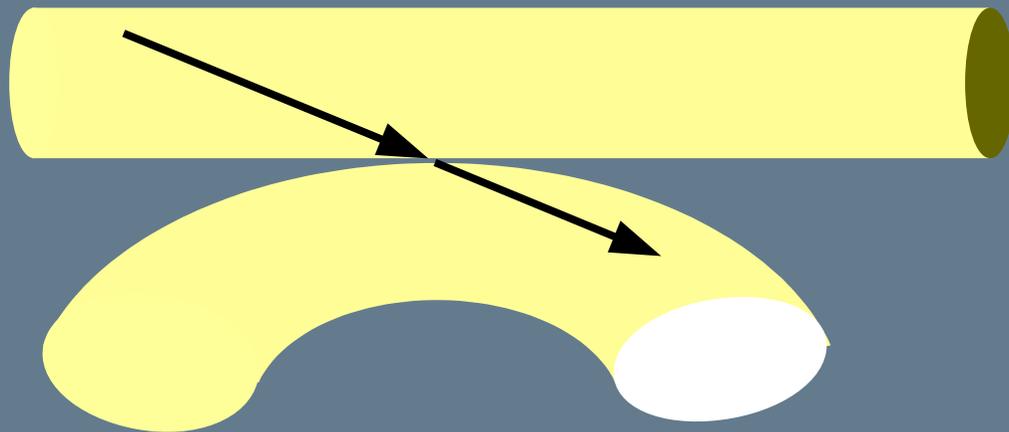


- 1926 : Brevet avec des tubes par J.L. Baird
- 1927 : Brevet avec des fibres pleines par C.W. Hansell
- 1930 : Prototype par H. Lamm

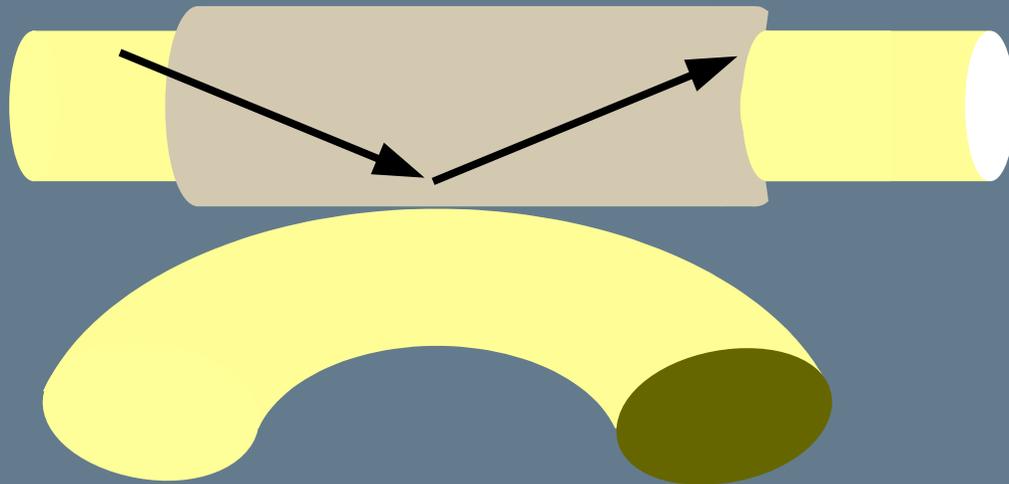
1 FIBRE, ÇA VA...



2 FIBRES...



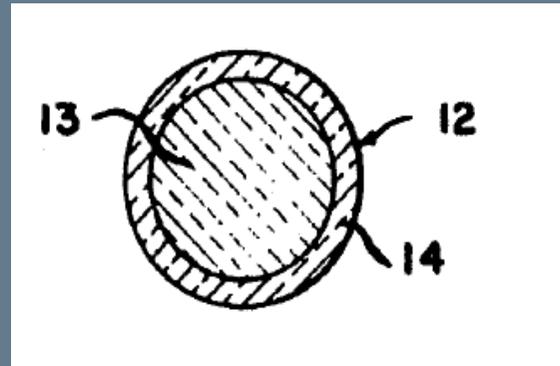
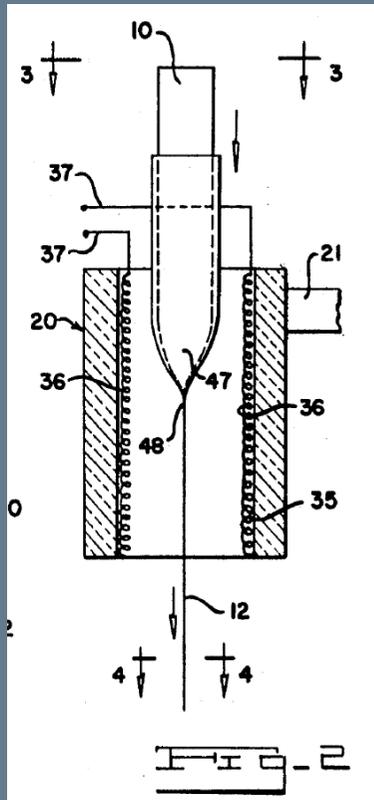
FIBRE GAINÉE



- « A New Method of transporting Optical Images without Aberrations », A. C. S. Van Heel, Nature 173 (1954) 39
- « A Flexible **Fibrescope**, using Static Scanning », H. H. Hopkins & N. S. Kapany, Nature 173 (1954) 39

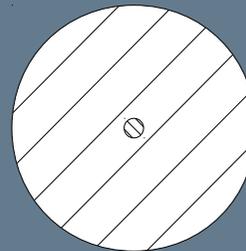
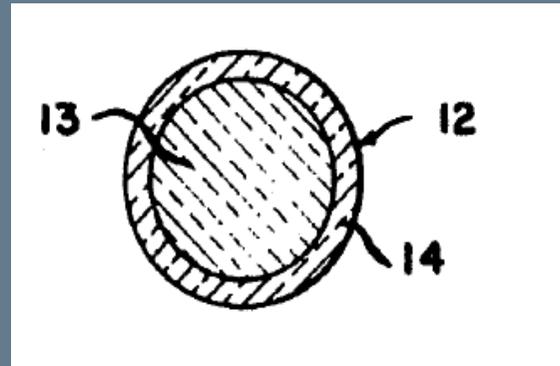
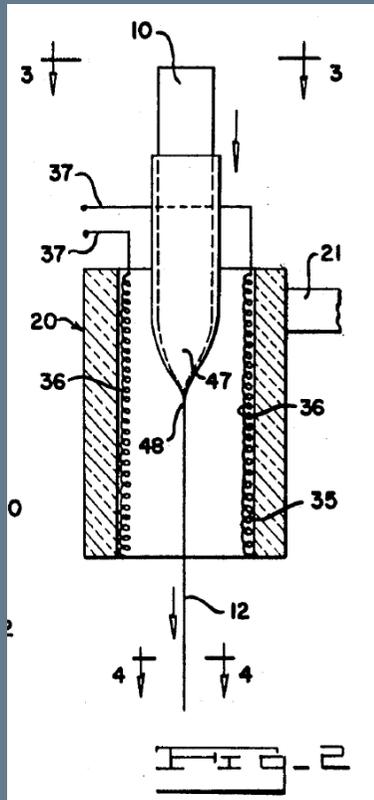
FIBRES GAINÉES

- 1955 : stage de licence de L.E. Curtiss avec B. Hirschowitz & C. W. Peters
- 1957 (accepté en 1971!) : « Glass fiber optical devices », L.E. Curtiss
- 1957 : test sur un patient par B. Hirschowitz



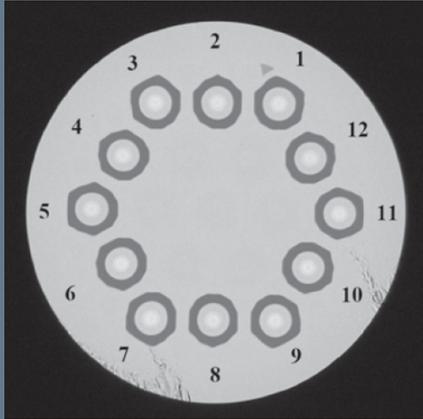
FIBRES GAINÉES

- 1955 : stage de licence de L.E. Curtiss avec B. Hirschowitz & C. W. Peters
- 1957 (accepté en 1971!) : « Glass fiber optical devices », L.E. Curtiss
- 1957 : test sur un patient par B. Hirschowitz

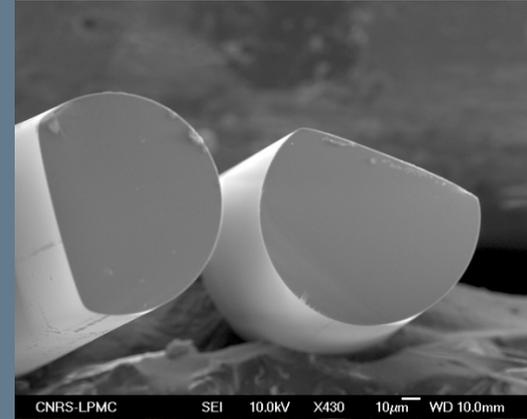


Fibre *télécoms*

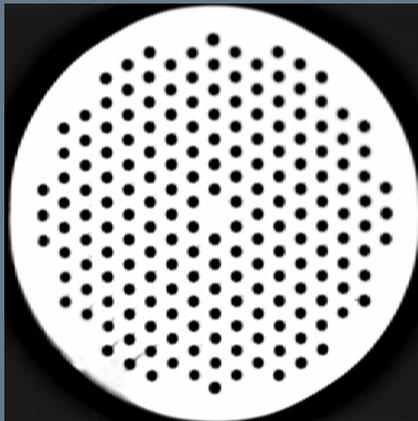
AU-DELÀ DU MODÈLE STANDARD...



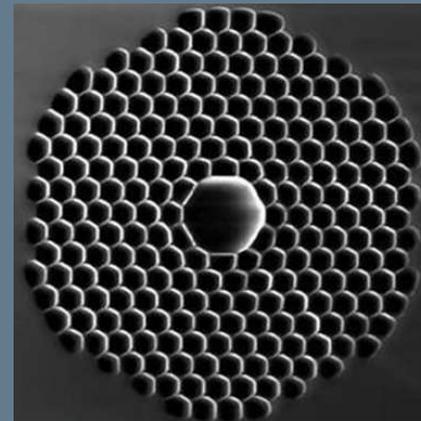
Fibre à plusieurs cœurs



Fibres en D



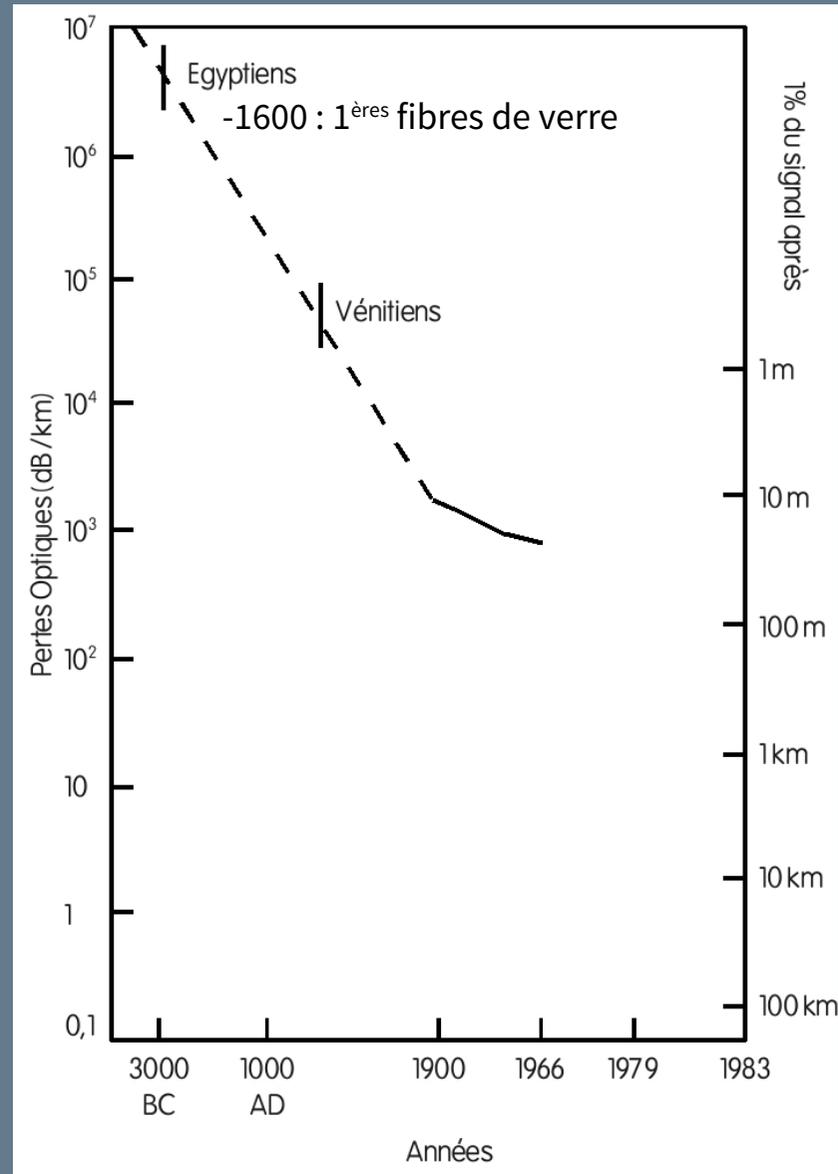
Fibre micro-structurée



Fibre avec un cœur « vide »

L'APPORT DE LA FIBRE POUR INTERNET ET LES TÉLÉCOMMUNICATIONS

TRANSPARENCE DU VERRE



« Introduction to fiber optics », A. Ghatak & K. Thyagarajan, Cambridge Univ. press, , 2004

Dielectric-fibre surface waveguides for optical frequencies

K. C. Kao, B.Sc.(Eng.), Ph.D., A.M.I.E.E., and G. A. Hockham, B.Sc.(Eng.), Graduate I.E.E.

Supplies
PROC. IEE, Vol. 113, No. 7, JULY 1966

information capacity. Physical-realisation aspects are also discussed. Experimental investigations at both optical and microwave wavelengths are included.

List of principal symbols

J_n = n th-order Bessel function of the first kind
 K_n = n th-order modified Bessel function of the second kind

boundary conditions imposed by the physical structure, the characteristic equations are as follows:
for HE_{nm} modes

7 Conclusions

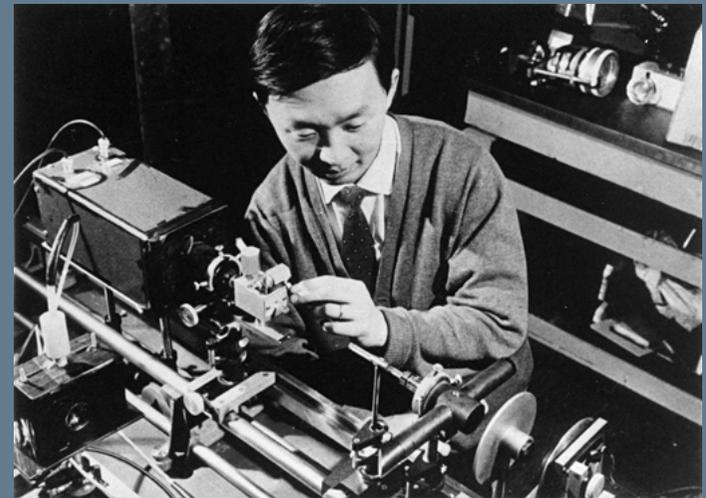
Theoretical and experimental studies indicate that a fibre of glassy material constructed in a cladded structure with a core diameter of about λ_0 and an overall diameter of about $100\lambda_0$ represents a possible practical optical waveguide with important potential as a new form of communication medium. The refractive index of the core needs to be about 1% higher than that of the cladding. This form of waveguide operates in a single HE_{11} , E_0 or H_0 mode and has an information capacity in excess of 1 Gc/s. It is completely flexible and calls for a mechanical tolerance of around 10%, which can be readily met in practice. Thus, compared with existing coaxial-cable and radio systems, this form of waveguide has a larger information capacity and possible advantages in basic material cost. The realisation of a successful fibre waveguide depends, at present, on the availability of suitable low-loss dielectric material. The crucial material problem appears to be one which is difficult but not impossible. Certainly, the required loss figure of around 20 dB/km is much higher than the lower limit of loss figure imposed by fundamental mechanisms.

Paper 5033 E, first received 24th November 1965 and in revised form 15th February 1966
Dr. Kao and Mr. Hockham are with Standard Telecommunication Laboratories Ltd., Harlow, Essex, England

PROC. IEE, Vol. 113, No. 7, JULY 1966

frequencies will now be studied in detail. Conclusions are drawn as to the feasibility and the expected performance of such a waveguide for long-distance-communication application.

1151



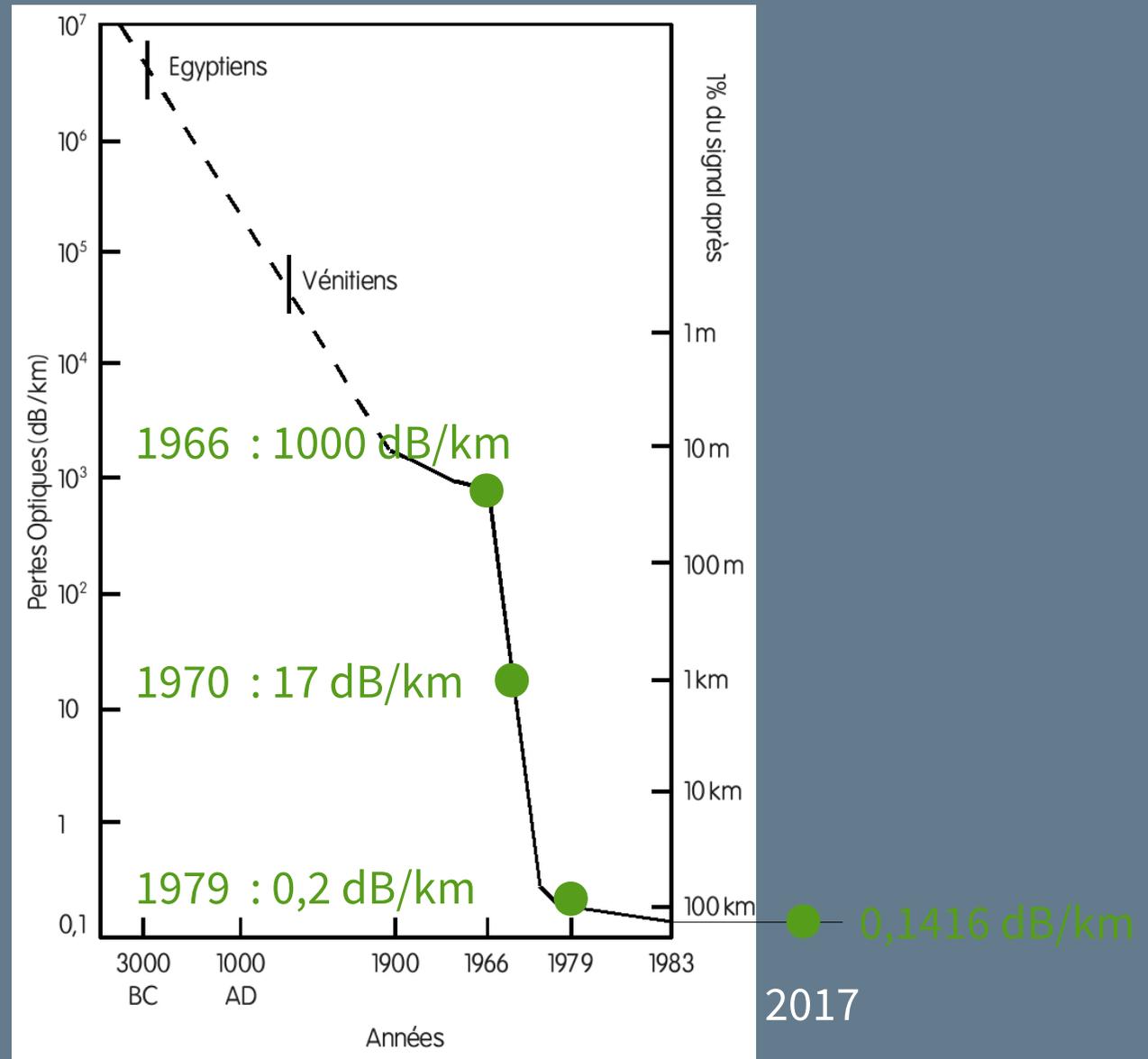
Prix Nobel de Physique en 2009

1970 : Première fibre optique à 17 dB/km



Donald B. Keck, Robert D. Maurer and Peter C. Schultz
Corning Glass Works - USA

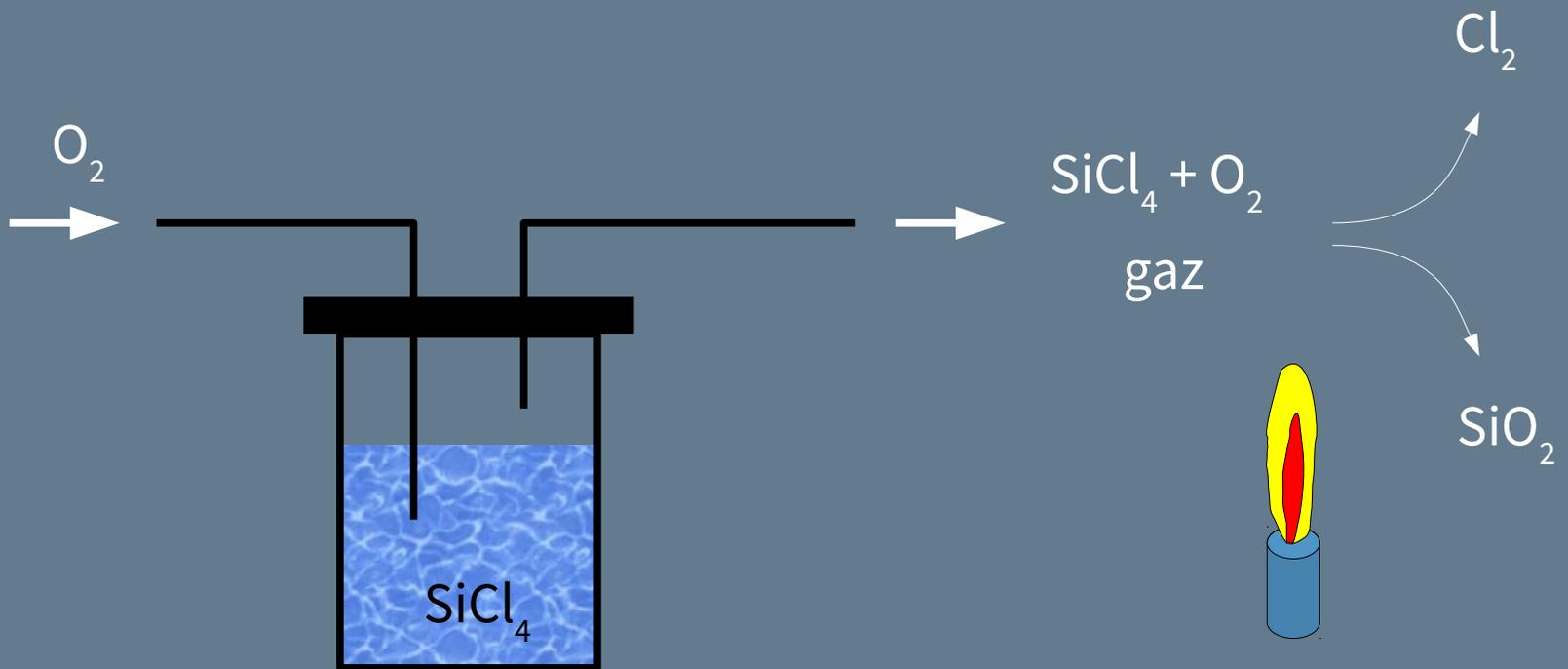
TRANSPARENCE



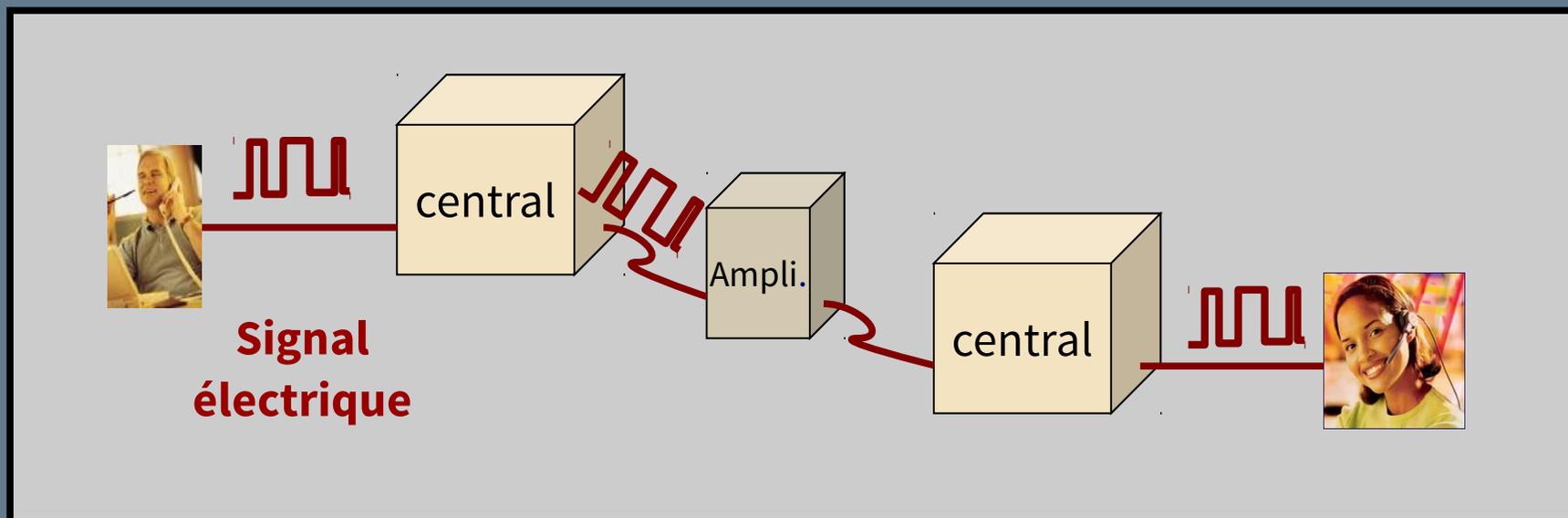
K. Nagayama et al., SEI Tech. Rev. 57(2004)3

SYNTHÈSE DE SILICE ULTRA-PURE

- 1934 (1942) : ~CVD, Corning, J.F. Hyde (US patent 2,272,342)

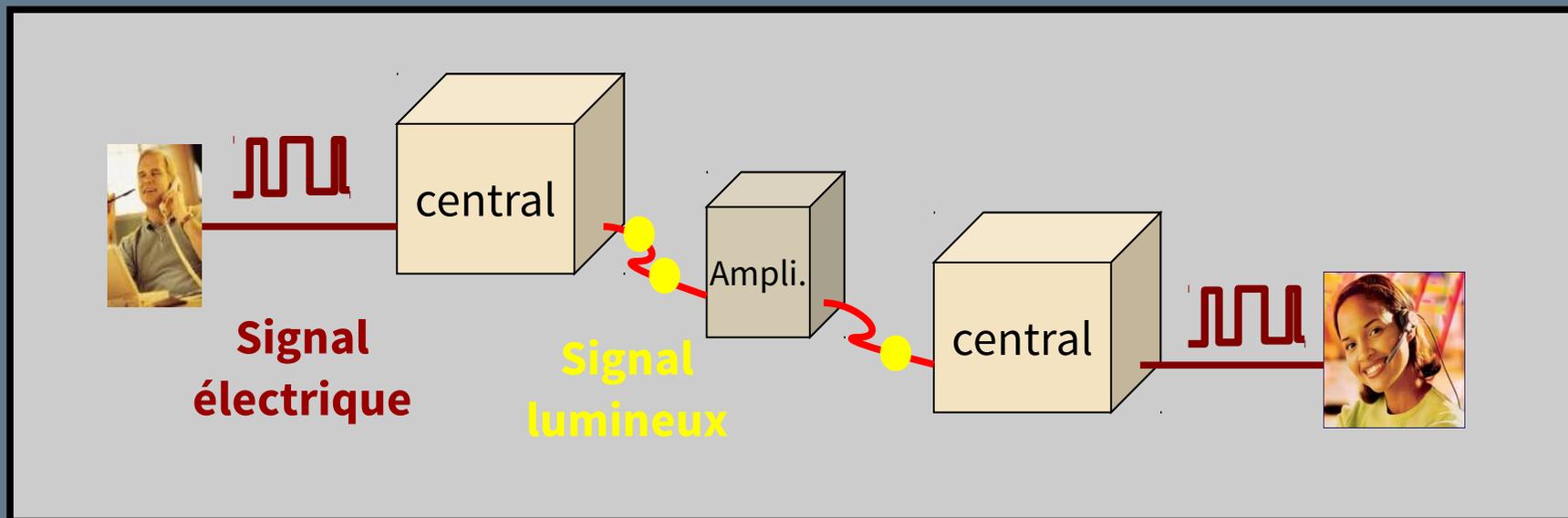


TÉLÉCOMMUNICATIONS ÉLECTRIQUES



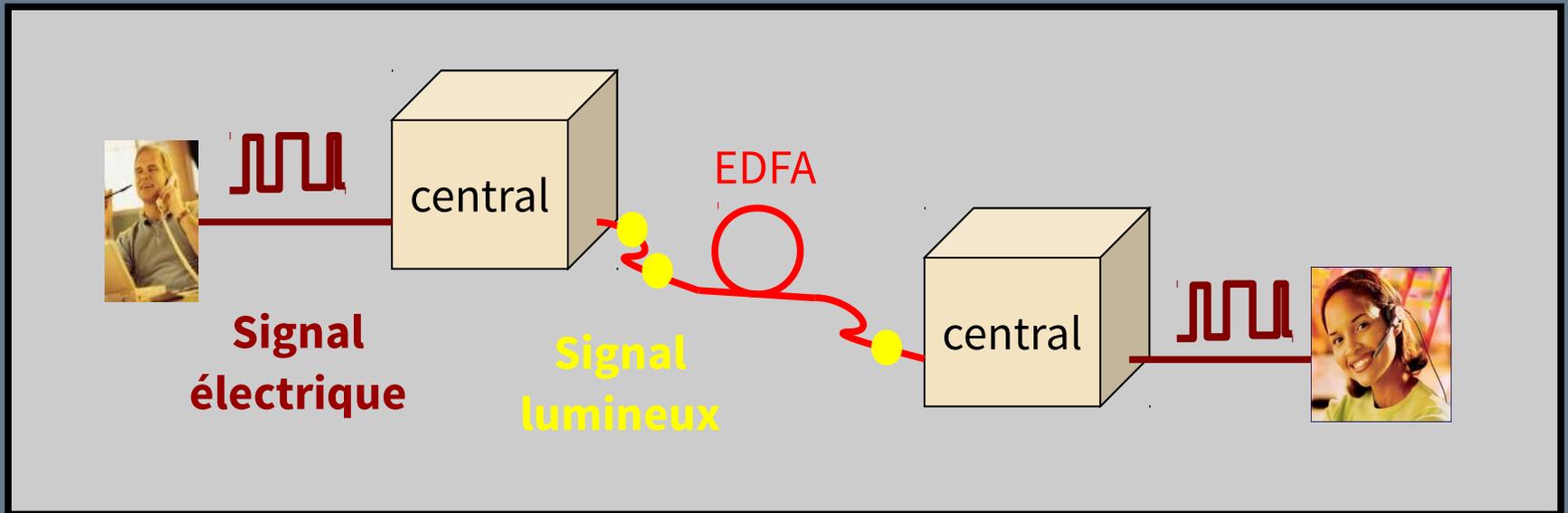
1858 : premier câble transatlantique (cuivre)

TÉLÉCOMMUNICATIONS OPTIQUES



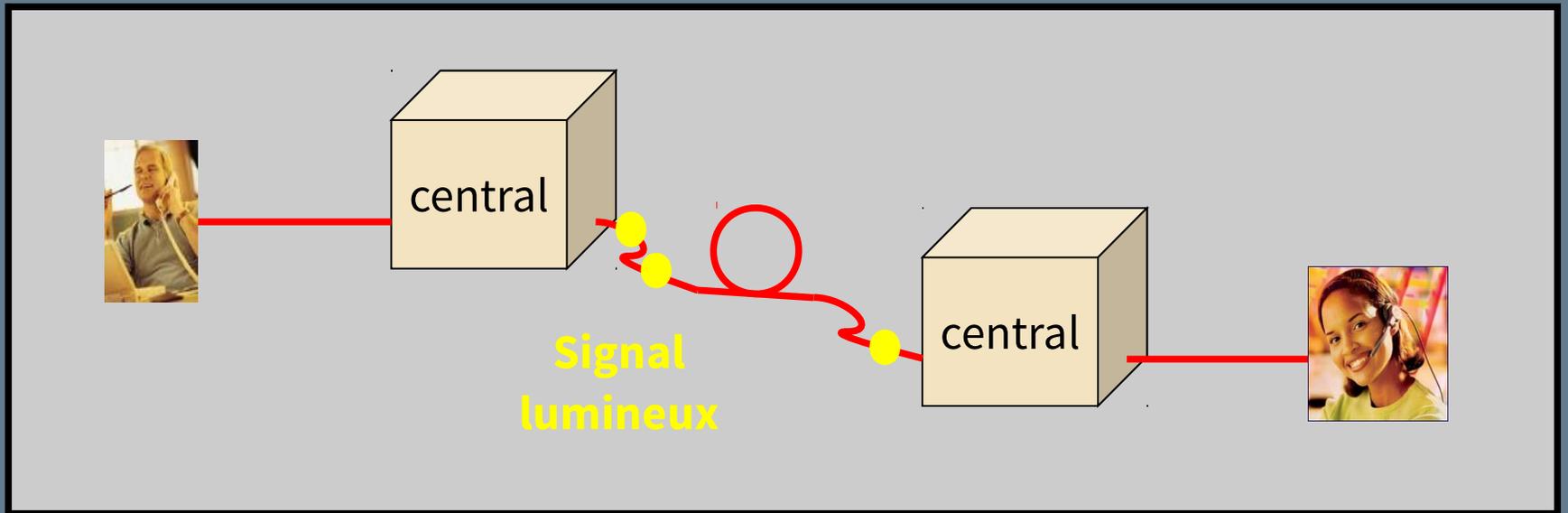
1988 : premier câble transatlantique (TAT8) avec des fibres optiques
560 Mbits/s

TÉLÉCOMMUNICATIONS OPTIQUES

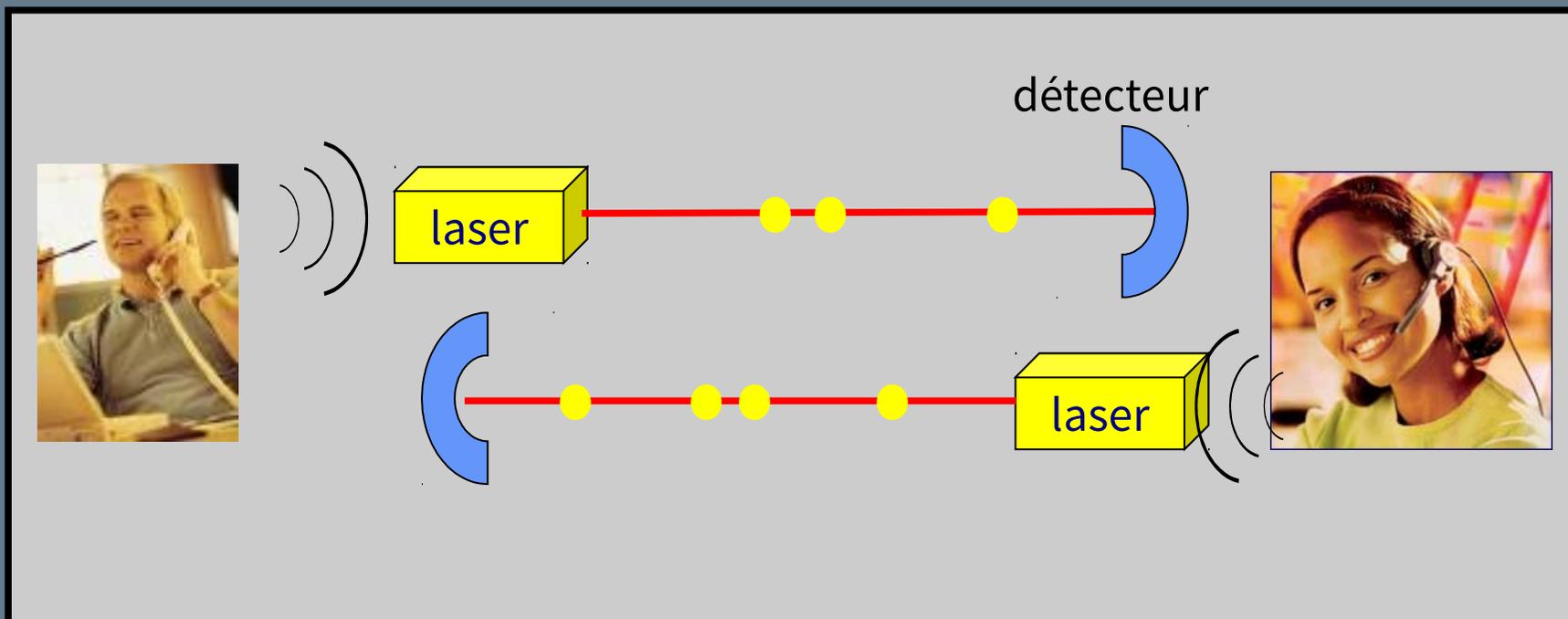


- 1987 : Fibre Amplificatrice dopée Er^{3+} (EDFA)
E. Desurvire et al., Optics Letters 12(1987)888
R.J. Mears et al., Electronics Letters 23(1987)1026
- 1995 : TAT12, premier câble transatlantique avec EDFA

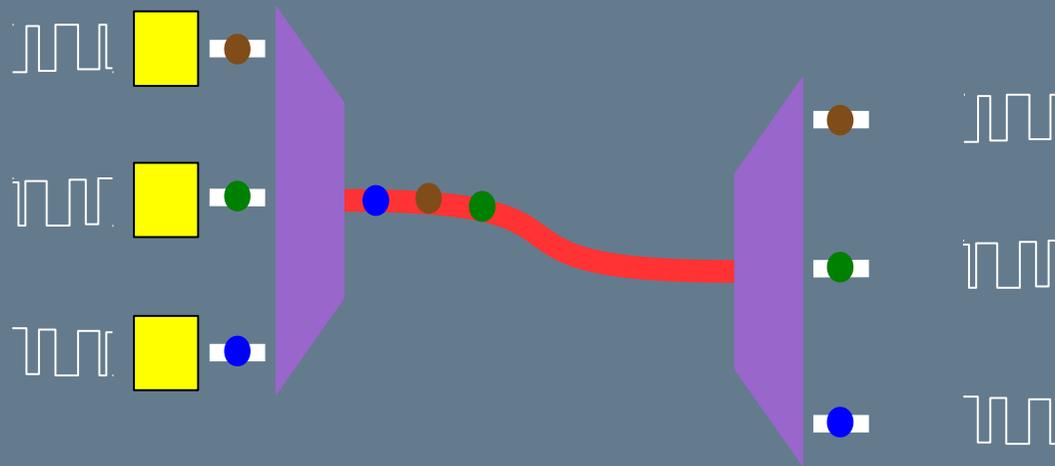
FTTH – FIBRE TO THE HOME



1 CONVERSATION TÉLÉPHONIQUE : 2 FIBRES

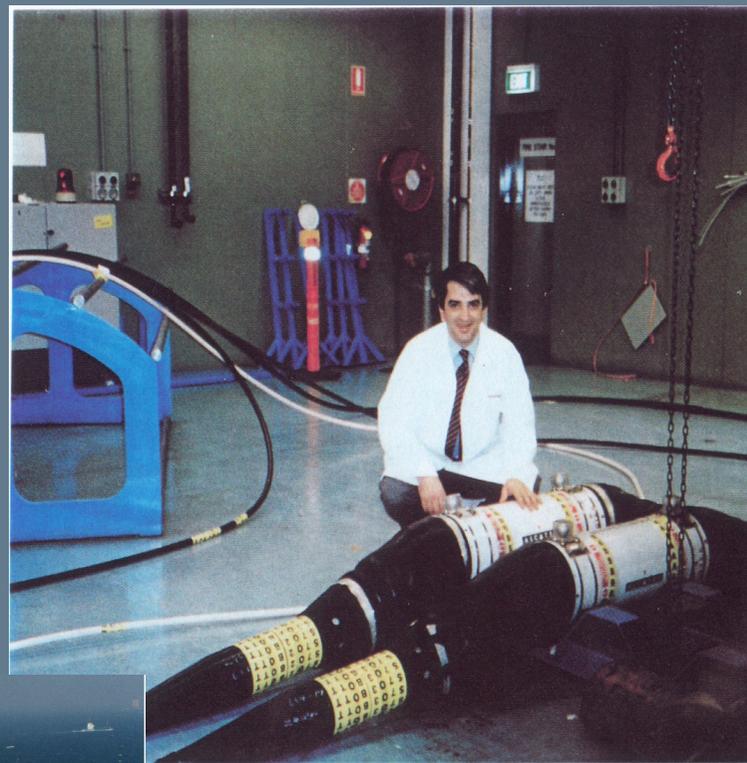
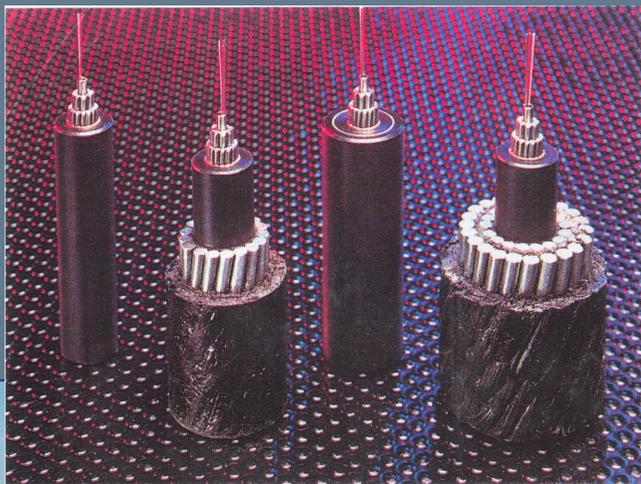


MULTIPLEXAGE EN LONGUEUR D'ONDE



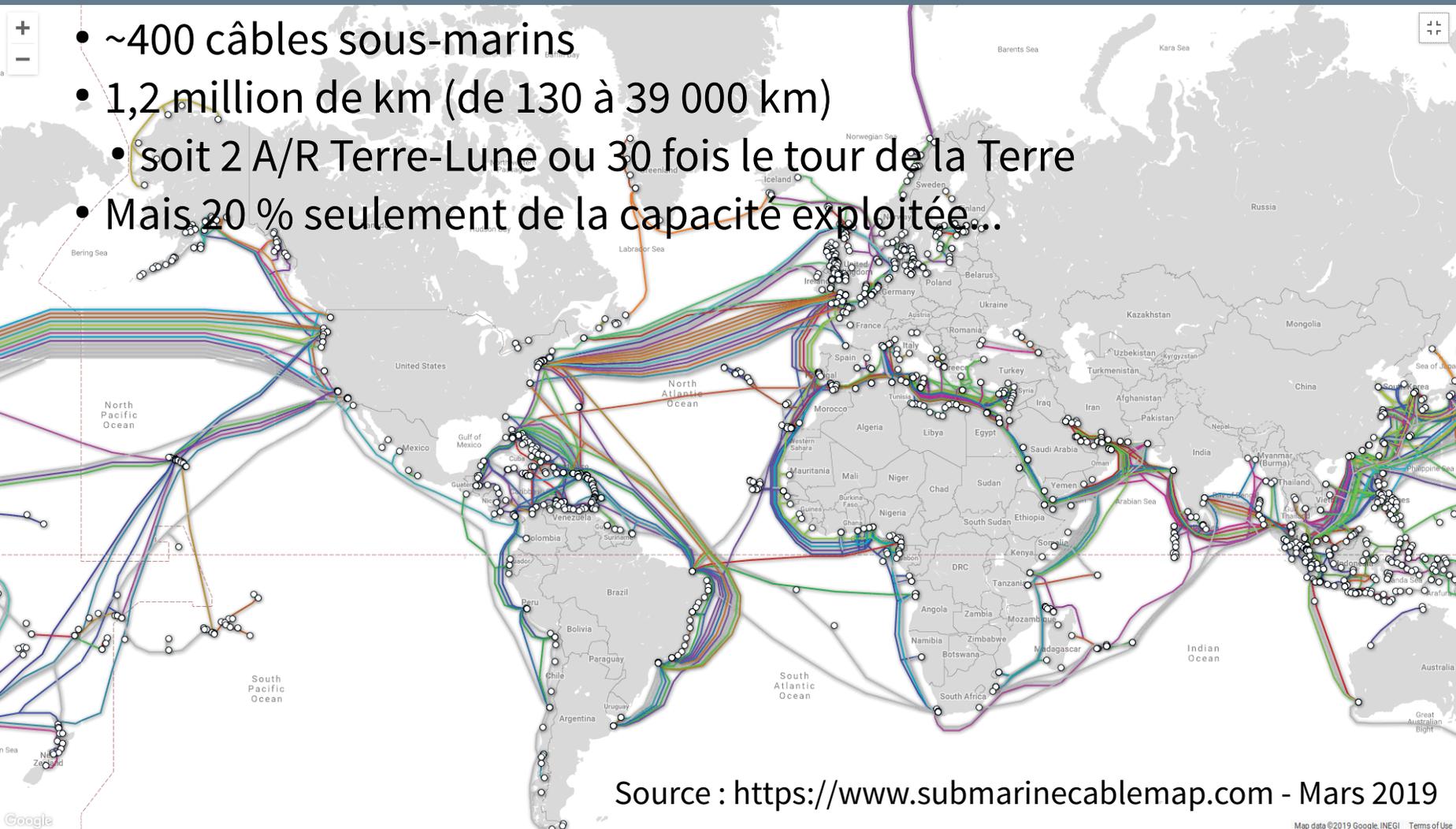
une paire de fibres = des millions de conversations téléphoniques !

RÉSEAU SOUS-MARIN



APERÇU DU RÉSEAU SOUS-MARIN

- ~400 câbles sous-marins
- 1,2 million de km (de 130 à 39 000 km)
- soit 2 A/R Terre-Lune ou 30 fois le tour de la Terre
- Mais 20 % seulement de la capacité exploitée...



QUELLE MASSE DE VERRE ?

6500 km de fibre optique (liaison transatlantique de TAT8 (1988)) :
Quelle masse de verre ?

Diamètre de la fibre : 125 μm , diamètre du cœur : 8 μm

Densité de la silice : 2,2 g/cm^3

- Masse : 176 kg au total, dont 720 g pour le cœur (0,4%)

Soit ~3 baie vitrée (5 $\text{m}^2 \times 2 \times 2,4 \text{ mm} \rightarrow 53 \text{ kg}$)

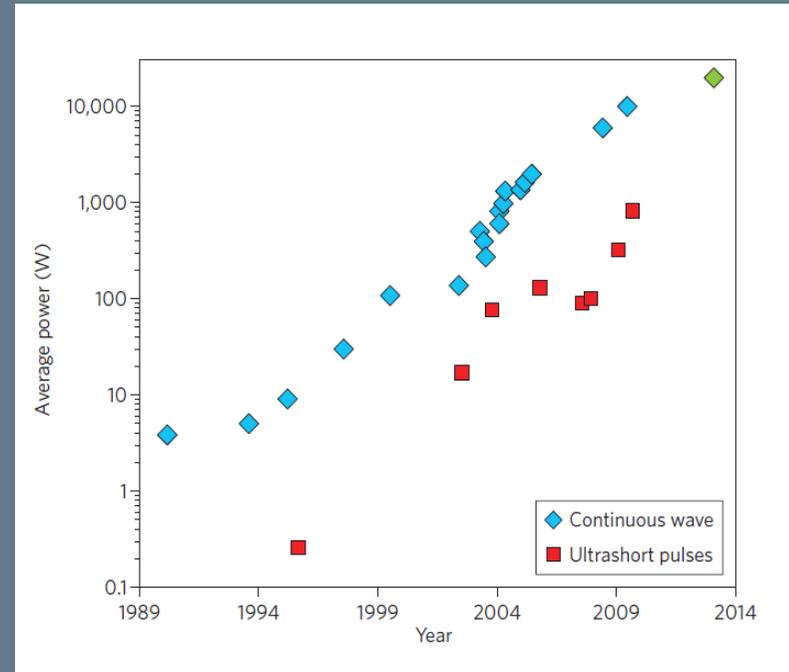
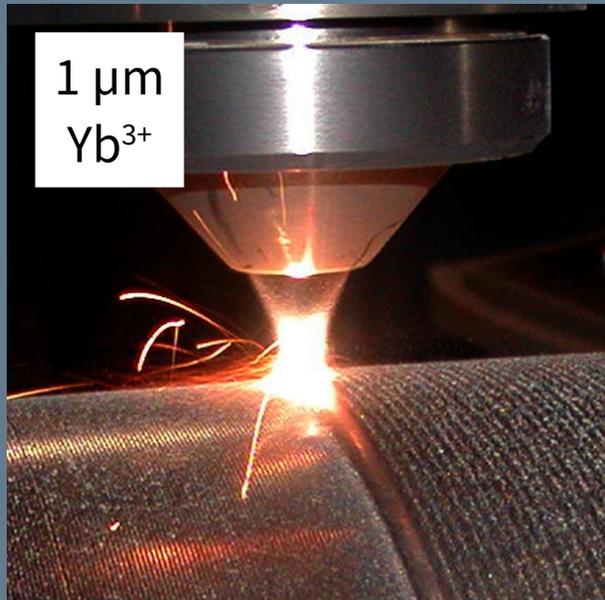
- Volume : 0,08 m^3

\rightarrow cube de 43 cm de côté, ~7 cm pour le cœur



UNE PLAGE DE RÉVOLUTIONS !

LASERS À FIBRE DE PUISSANCE



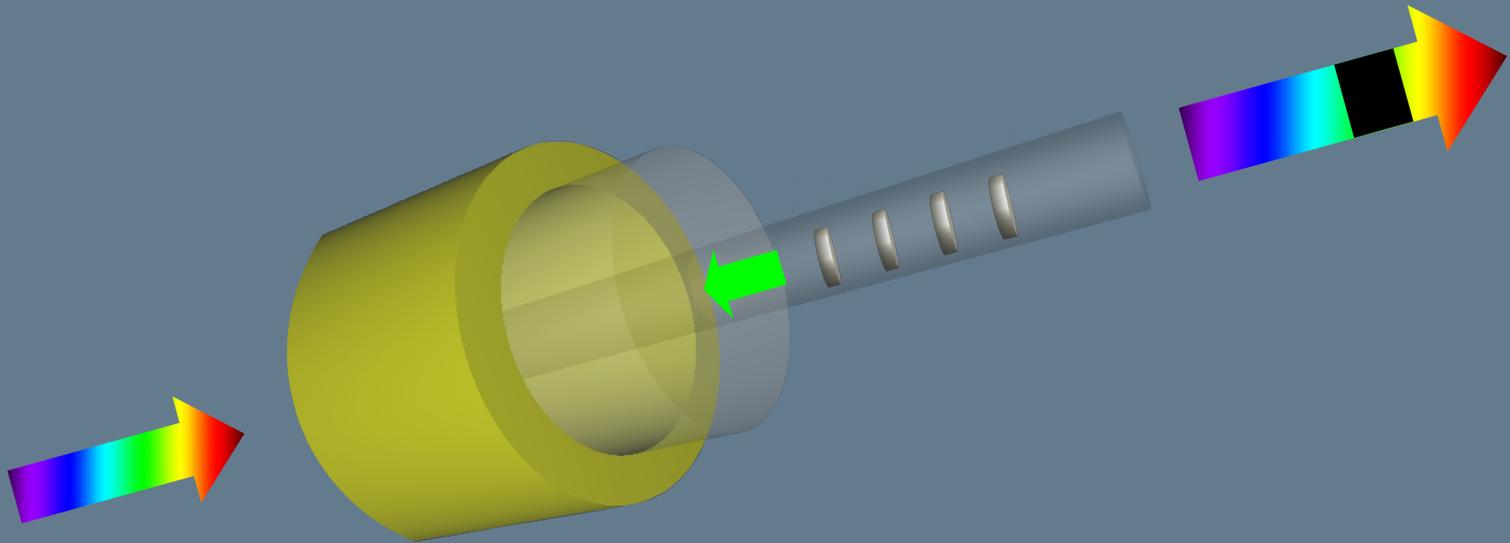
Découpe, soudure, perforation, usinage, marquage, etc

CAPTEURS



Pont de la confédération (Canada)

RÉSEAU DE BRAGG



$$\lambda_{\text{réfléchié}} = 2 \times n_{\text{eff}} \times \Lambda$$

Capteurs, cavités laser, etc

ÉCLAIRAGE

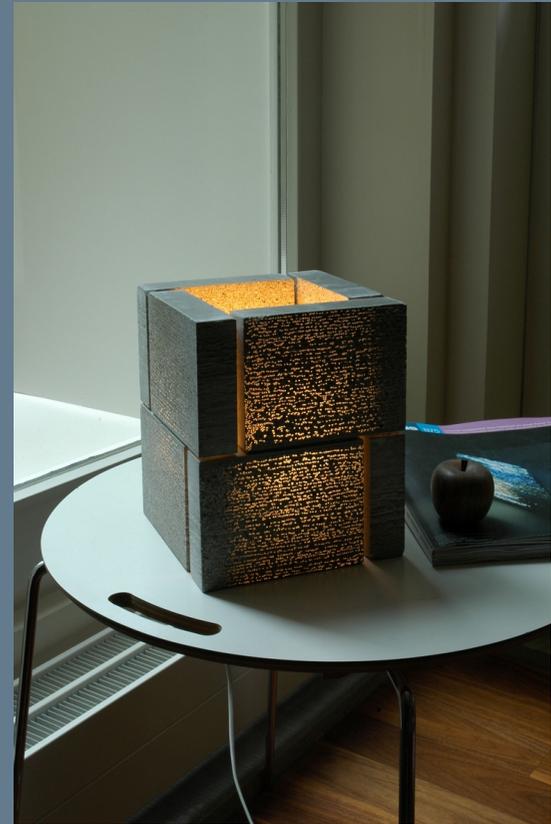


= 14
ampoules
de 40 W à incandescence



Systemes commercialises (Echy , Parans, ...)

FIBRES DANS LE BÉTON



Béton Litracon inventé en 2001

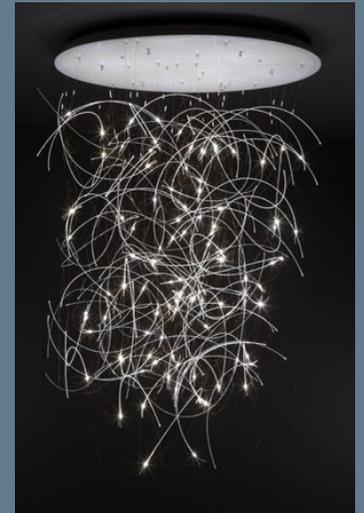
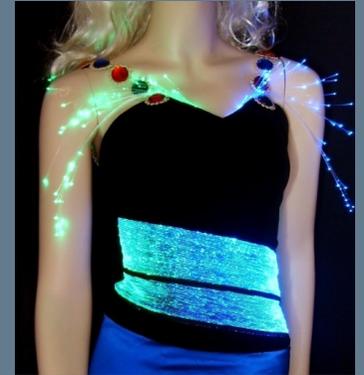
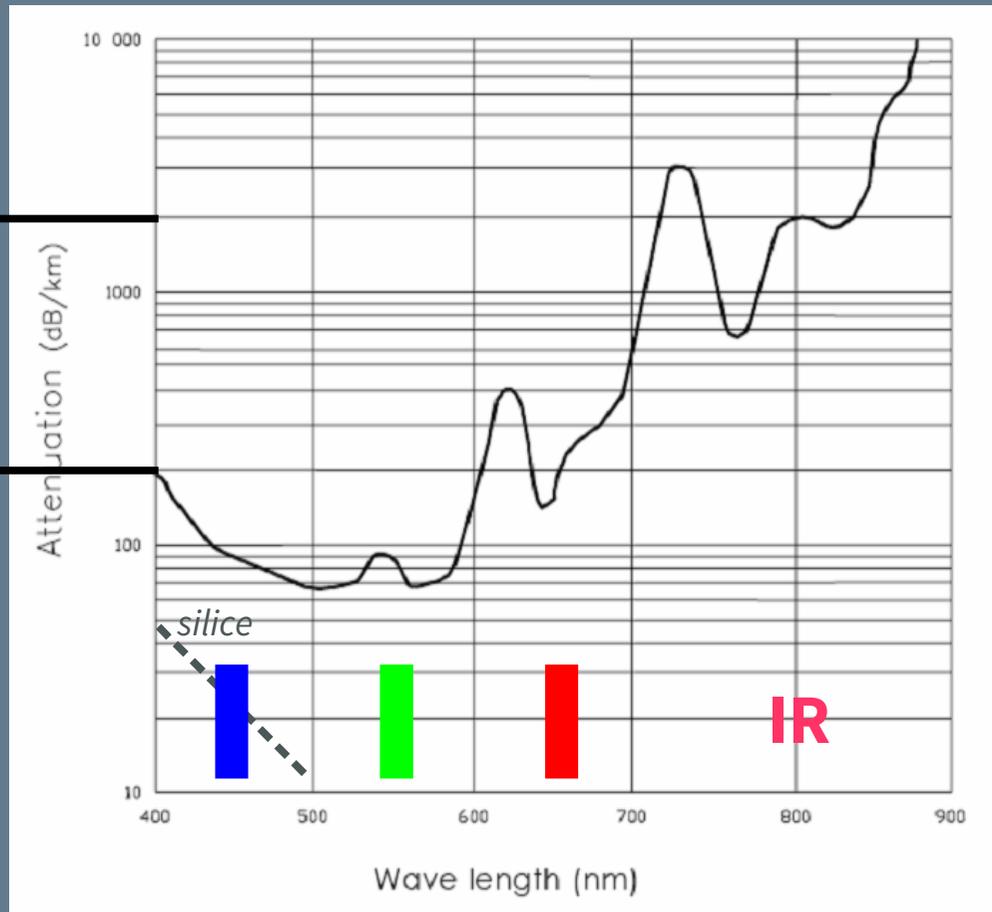
FIBRES EN PLASTIQUE

1 % du signal après:

10 m

100 m

250 m



FIBRES « MADE IN SPACE »

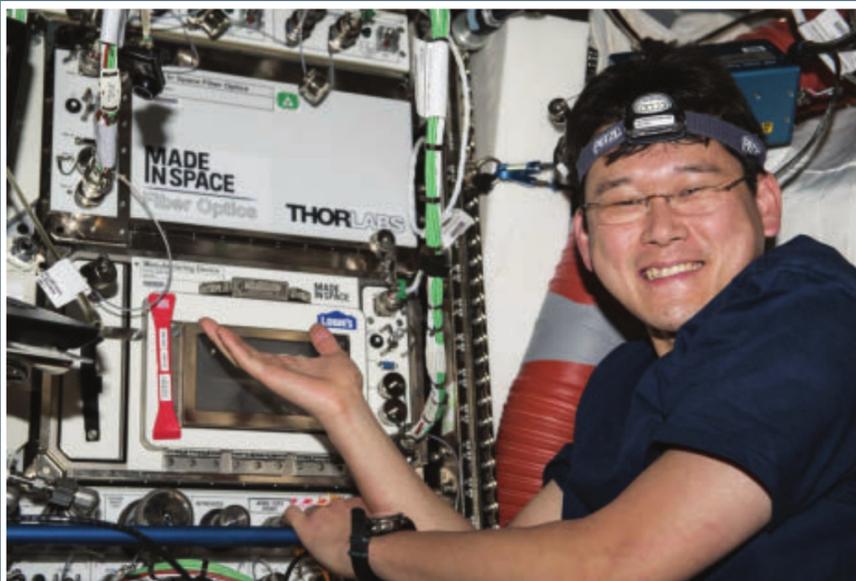


FIGURE 5. Japan Aerospace Exploration Agency (JAXA) astronaut Norishige Kanai presents two MIS payloads onboard the International Space Station: the Additive Manufacturing Facility (AMF) and Made In Space Fiber Optics. *(Image credit: JAXA)*

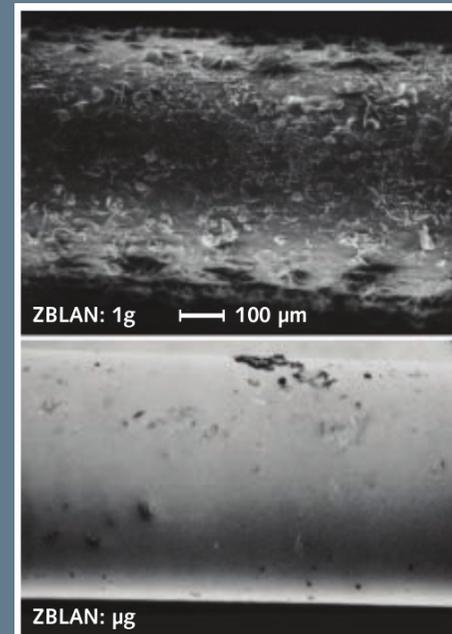
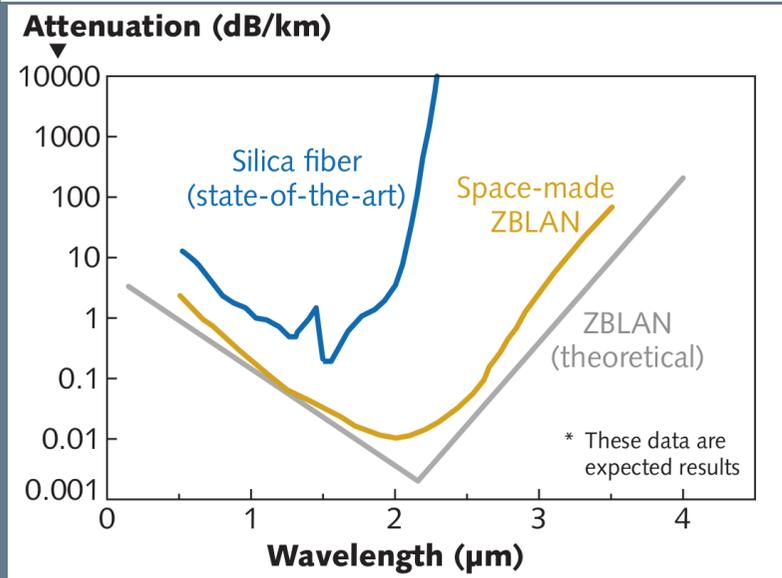


FIGURE 4. Images show ZBLAN optical fiber processed in 1g (Earth's gravity) and ZBLAN processed in approximately 0g (microgravity). *(Image credit: NASA)*



Laser Focus World, 2019

FIBRES OPTIQUES NATURELLES

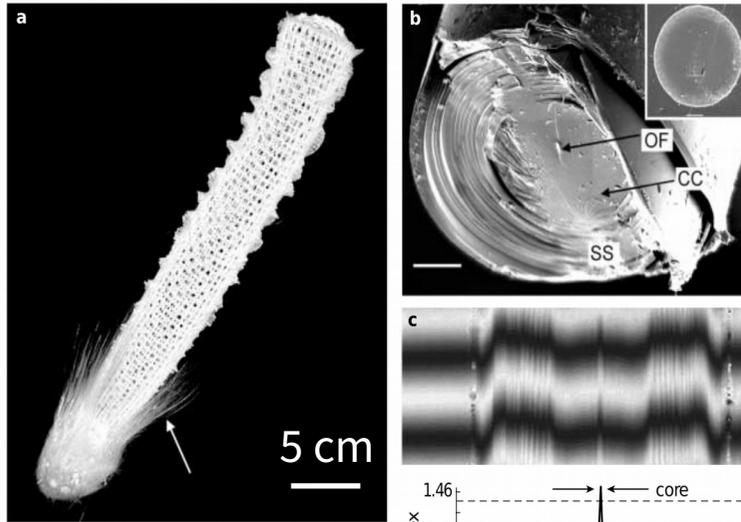
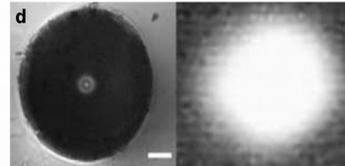
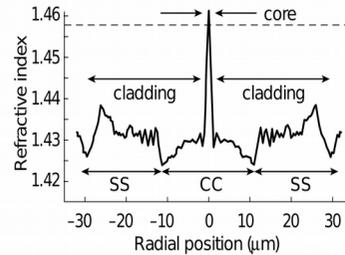


Figure 1 Structure and fibre-optical properties of spicules in the sponge *Euplectella*. **a**, The glass sponge, showing the basket-like cage structure and basalia spicules (arrow). Scale bar, 5 cm. **b**, Mechanically cleaved spicules show three structural regions. OF, organic filament; SS, outer striated shell; CC, central cylinder. Inset: smooth cross-section of a stress-free spicule. **c**, Interferogram (top) and corresponding refractive-index profile (bottom) of a spicule. Dashed line indicates the refractive index of vitreous silica. **d**, Wave guiding by individual spicules upon coupling with white light. Spicules embedded in epoxide act as single-mode or few-mode waveguides (left); free-standing spicules act as multi-mode waveguides (right). Scale bar, 10 μm . Further details are available from the authors.



- Éponge *Euplectella* des grandes profondeurs
- À -50 m : plus que 1% de lumière
- Spicules:
 - 5-15 cm de long
 - 40-70 μm de diamètre

Nature, 2003

CONCLUSION

- Verre → *vitrum*, transparent, mais pas invisible
- Verre et lumière sont intimement liés
- Nombreuses applications visibles et invisibles dans notre quotidien
- Bel exemple de recherche "longue"

Le verre n'a pas fini de nous en faire voir !