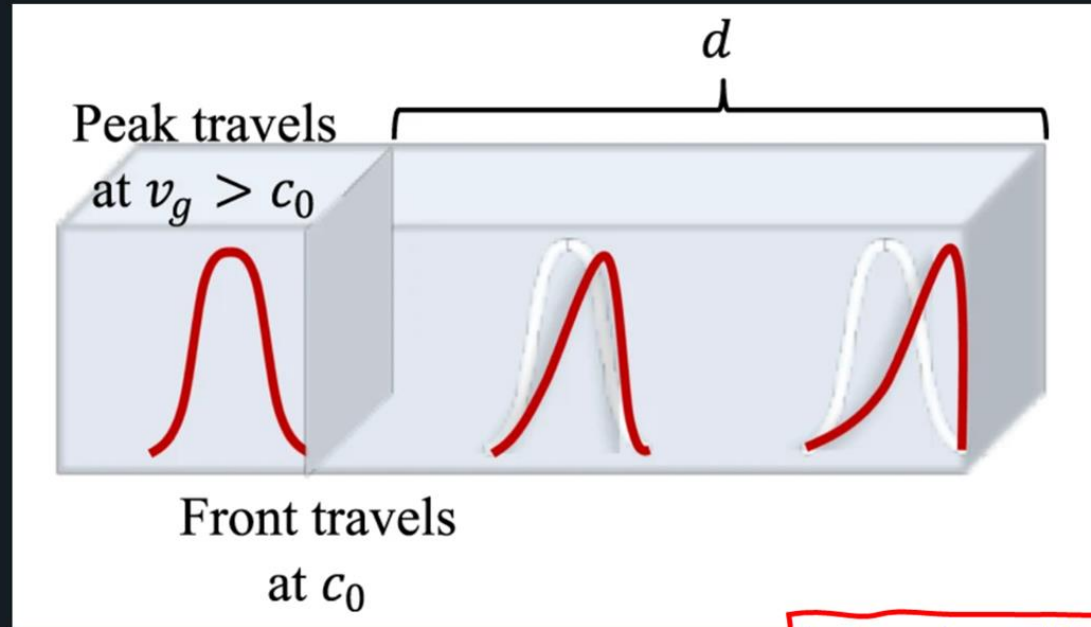


Propagazione superluminale:

Impulsi più veloci della luce

Federico Tommasi (UNIFI)

21/04
15.00



Light on Optics and Optometry

Series of scientific, technological and tutorial webinars

In streaming on Youtube

Directed by
Giovanna Pacini

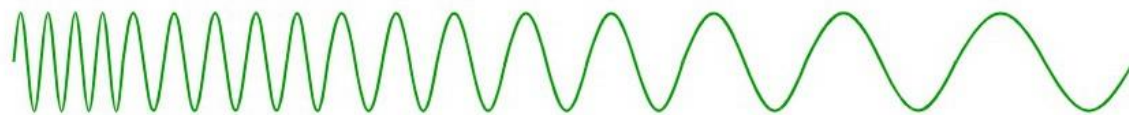


<https://www.youtube.com/user/caffescienza>

La Velocità della Luce

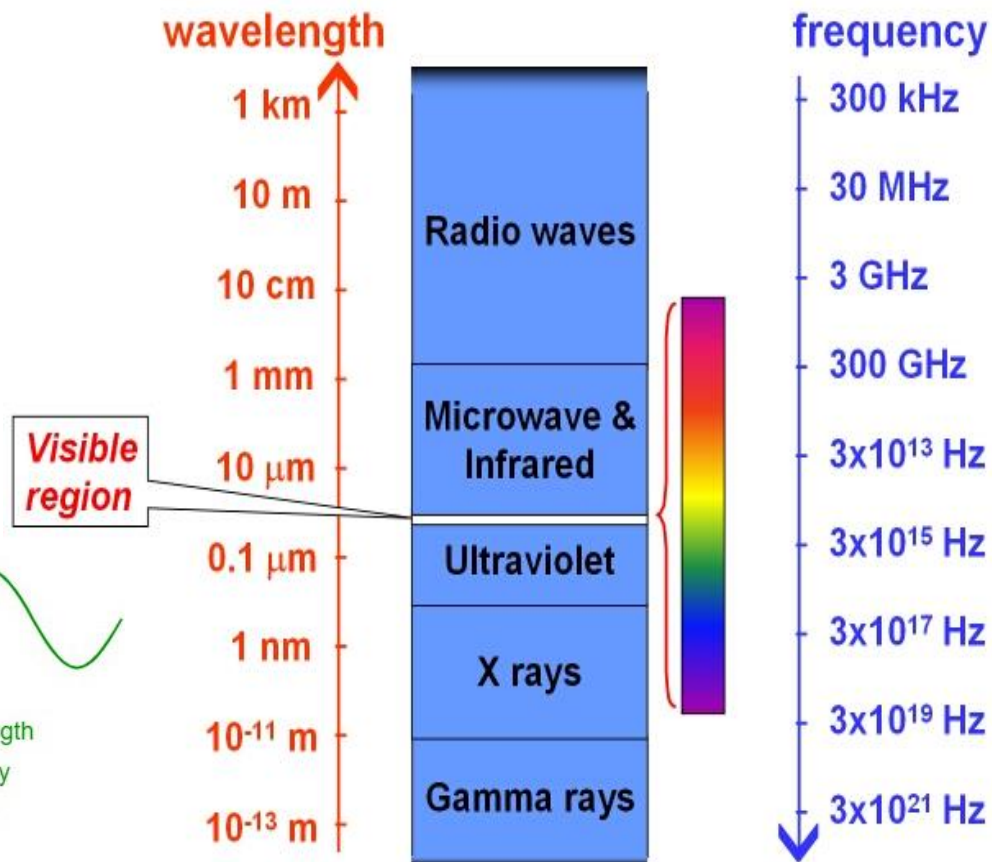
La velocità di un'onda elettromagnetica è determinata da costanti fondamentali dell'elettromagnetismo

c = velocità della luce nel vuoto
299 792 458 m / s



Shorter wavelength
High frequency
High Energy

Longer wavelength
Low frequency
Low Energy

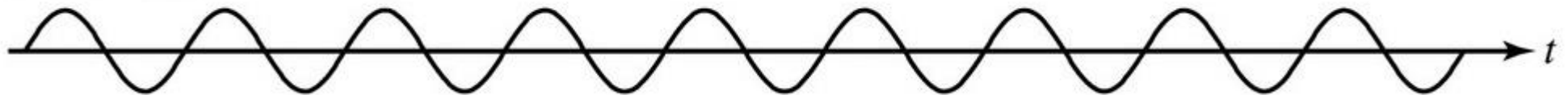
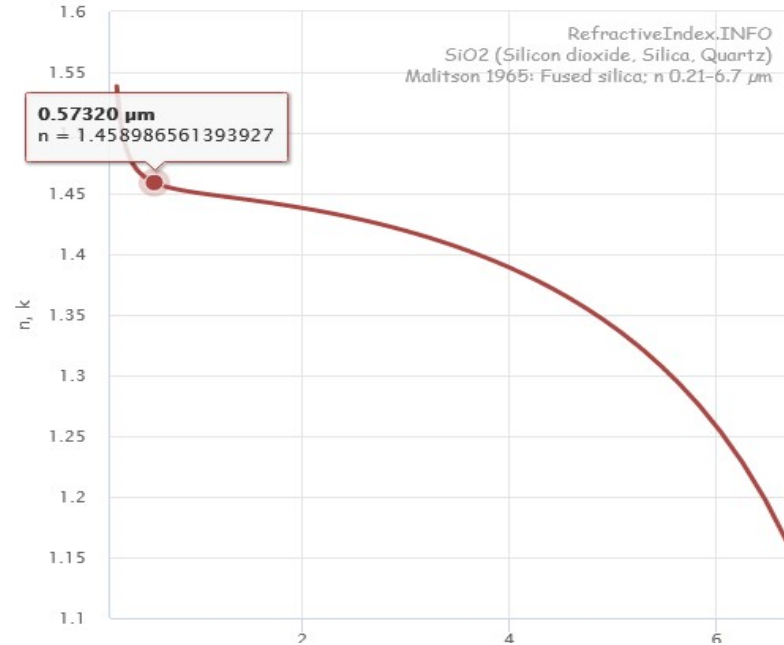
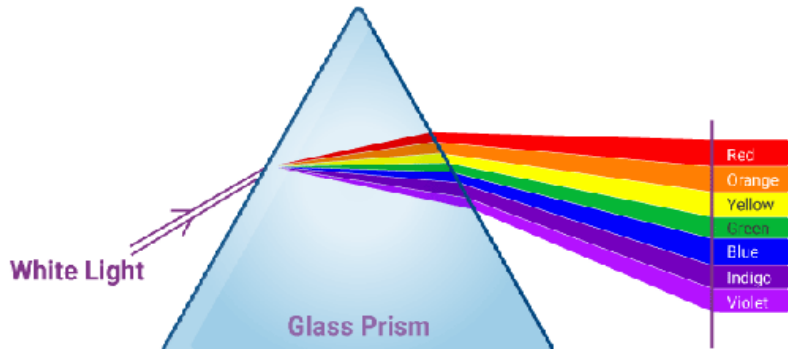


Indice di Rifrazione e Curva di Dispersione

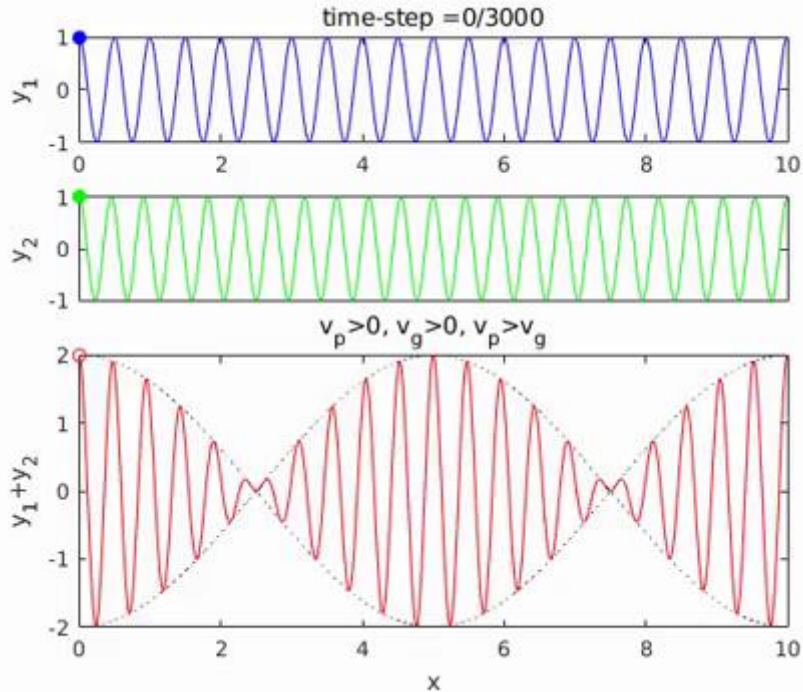
onda monocromatica

Velocità di Fase

$$V_f = \frac{c}{n(\omega)}$$



Velocità di Fase / Velocità di Gruppo



$$S(x, t) = S_o \cos(\omega t - kx)$$

$$v_f = \frac{\omega}{k(\omega)} = \frac{c}{n(\omega)} \quad \left(n(\omega) = \frac{ck}{\omega} \right)$$

Due onde:

$$S_1(x, t) = S_o \cos((\omega + d\omega)t - (k + dk)x)$$

$$S_2(x, t) = S_o \cos((\omega - d\omega)t - (k - dk)x)$$

$$S_1 + S_2 \propto \underbrace{\cos(\omega t - kx)}_{\text{Portante}} \underbrace{\cos(d\omega t - dkx)}_{\text{Modulazione (Gruppo)}}$$

$$v_g = \frac{d\omega}{dk} = \frac{c}{n(\omega) + \omega \frac{dn}{d\omega}}$$

Nel vuoto: $\omega = ck \rightarrow v_f = v_g = c$

Impulso di Luce

Impulso = involuppo di diversi componenti in frequenza che si propaga nello spazio

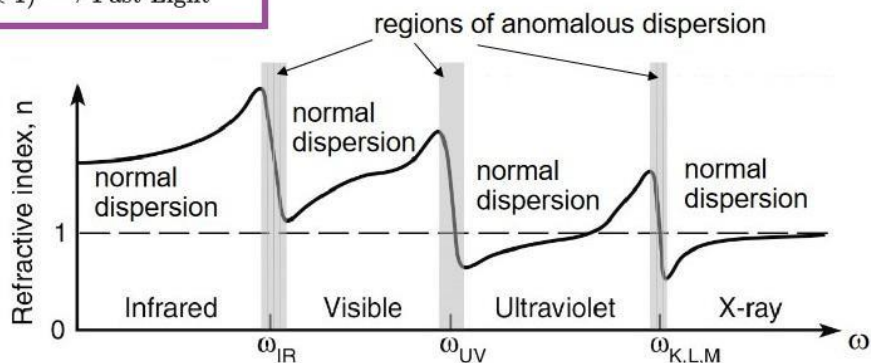
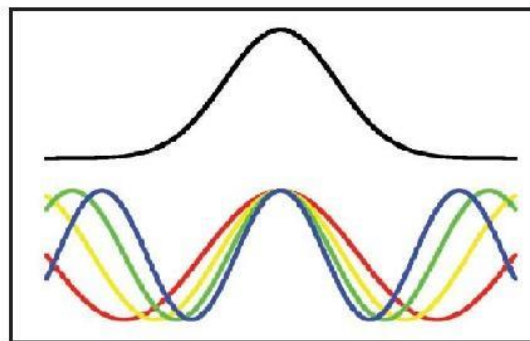
pacchetto d'onda

Velocità di Gruppo

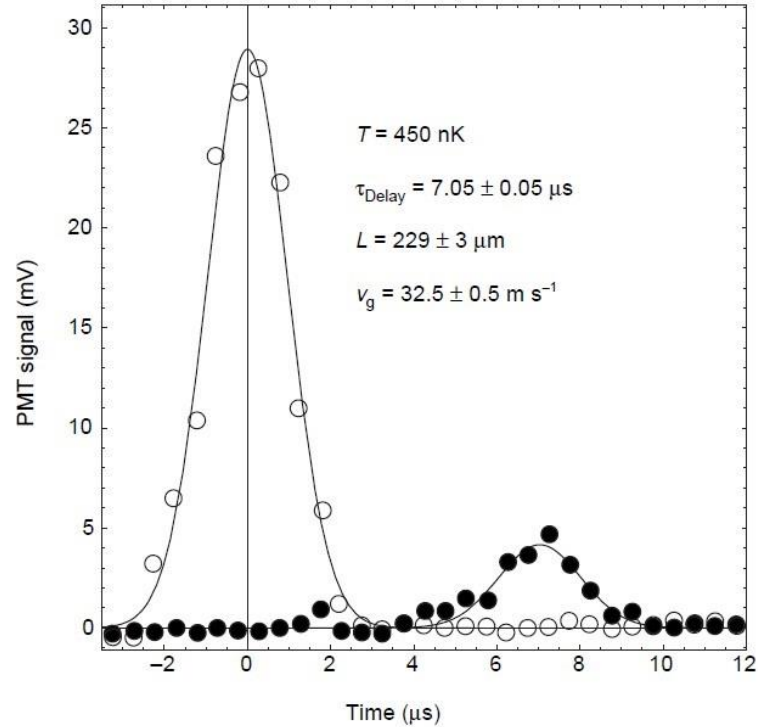
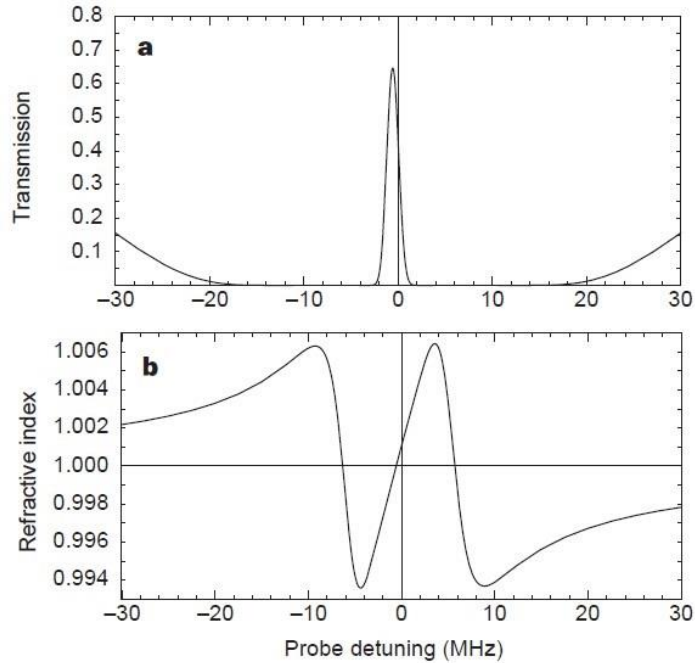
$$V_g = \frac{c}{n(\omega) + \omega \frac{dn(\omega)}{d\omega}} \Big|_{\omega=\omega_c} = \frac{c}{n_g}$$

$$V_g \ll c \quad (n_g \gg 1) \rightarrow \text{Slow-Light}$$

$$V_g > c \quad \text{oppure} \quad V_g < 0 \quad (n_g < 1) \rightarrow \text{Fast-Light}$$

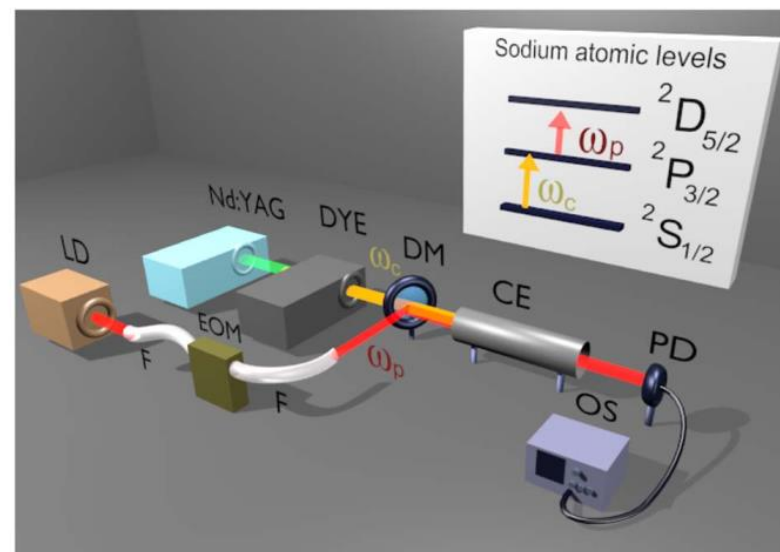
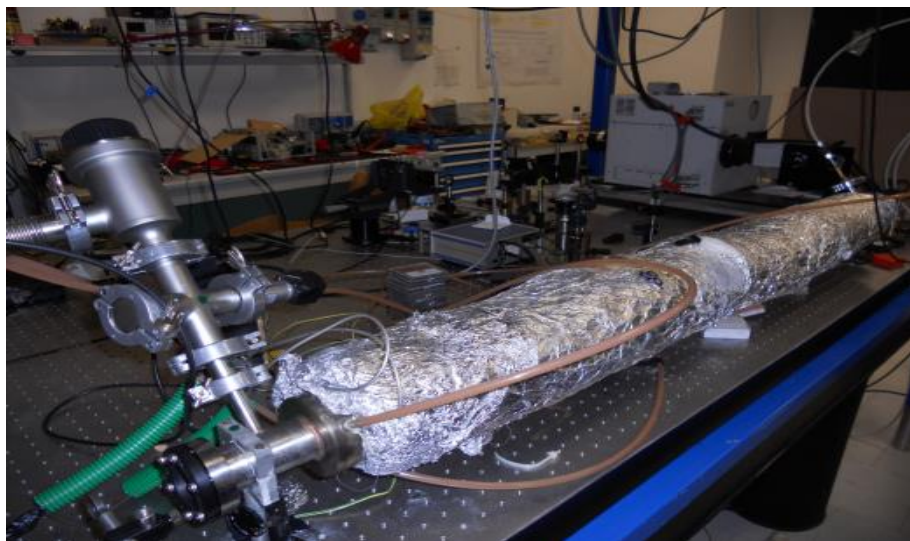


SLOW - LIGHT



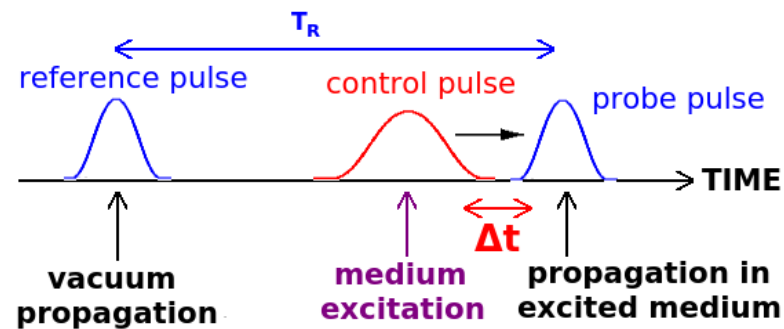
L. Versteergaard Hue, S.E. Harris, Z. Dutton, C.H. Behroozi, *Nature* **397**, 595 (1999)

SLOW LIGHT in UNIFI

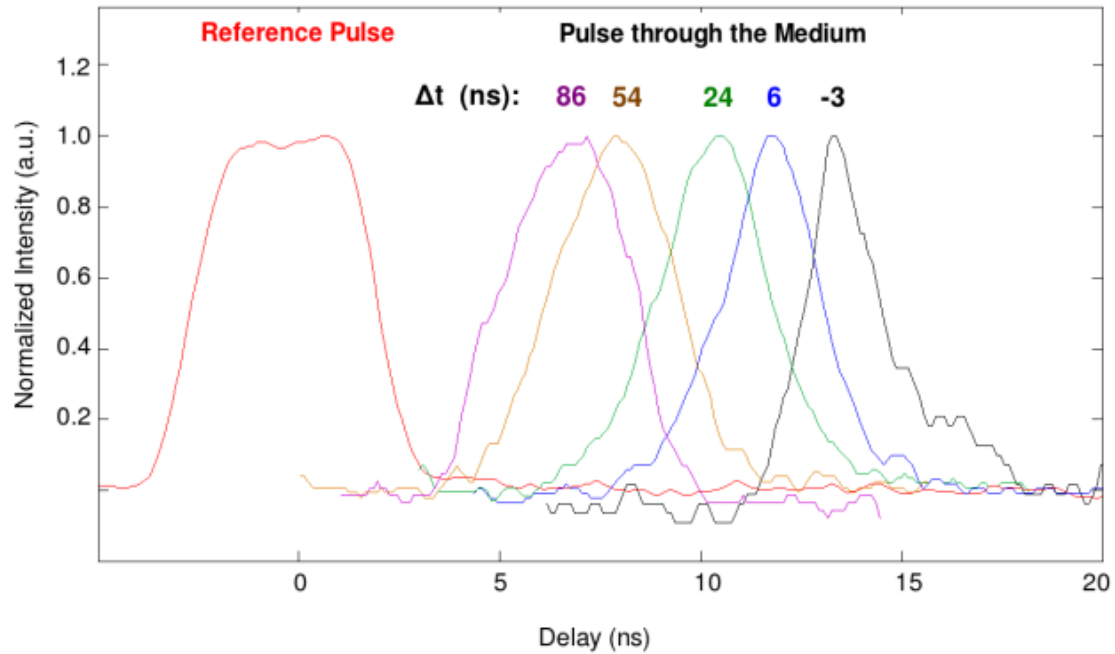


Ritardi fino a circa 90 ns per impulsi dalla durata di 5 ns

E. Ignesti, F. Tommasi, R. Buffa, L. Fini, E. Sali, M.V. Tognetti, S. Cavalieri
Physical Review A **86**, 063818 (2012)



SLOW LIGHT in UNIFI

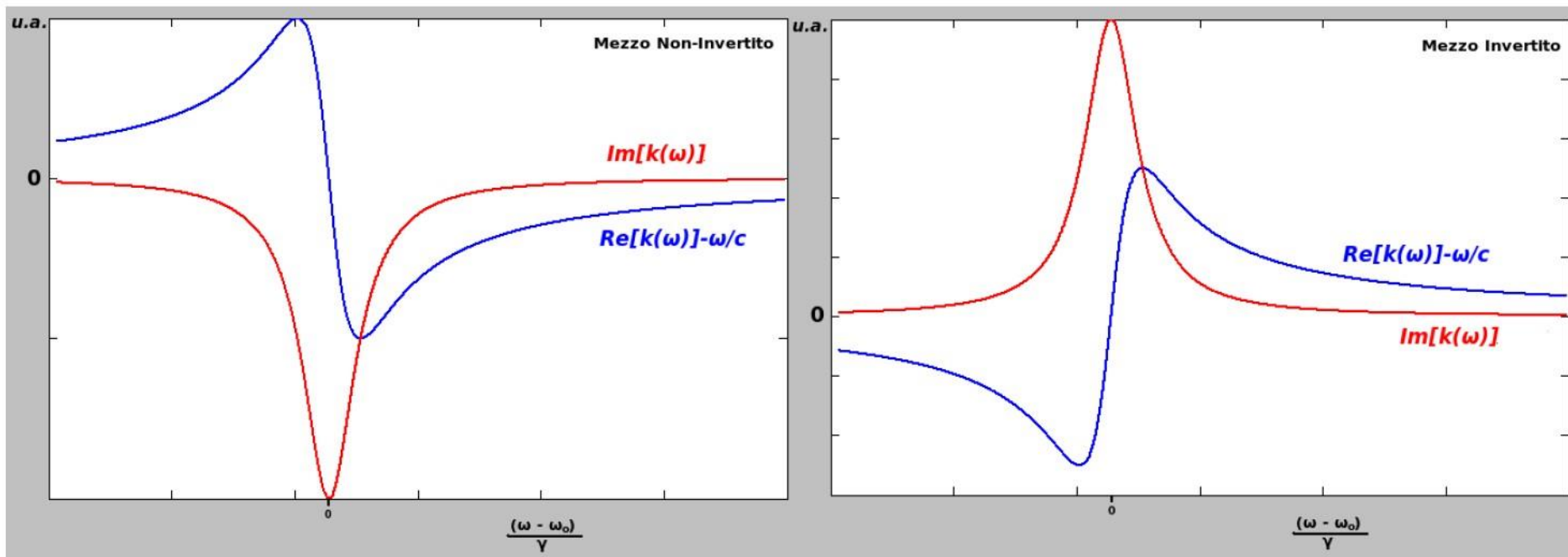


E. Igesti, F. Tommasi, R. Buffa, L. Fini, E. Sali, M.V. Tognetti, S. Cavalieri
Physical Review A **86**, 063818 (2012)

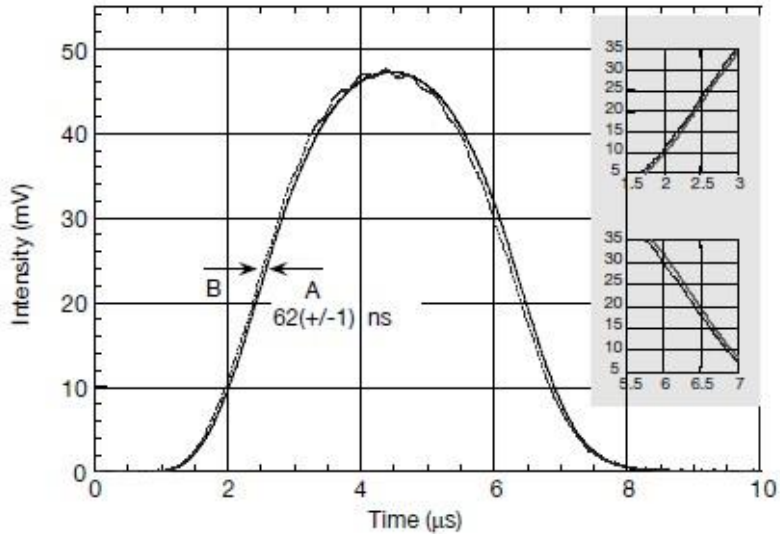
Inversione di Popolazione

L'inversione di popolazione è alla base del funzionamento dei sistemi LASER

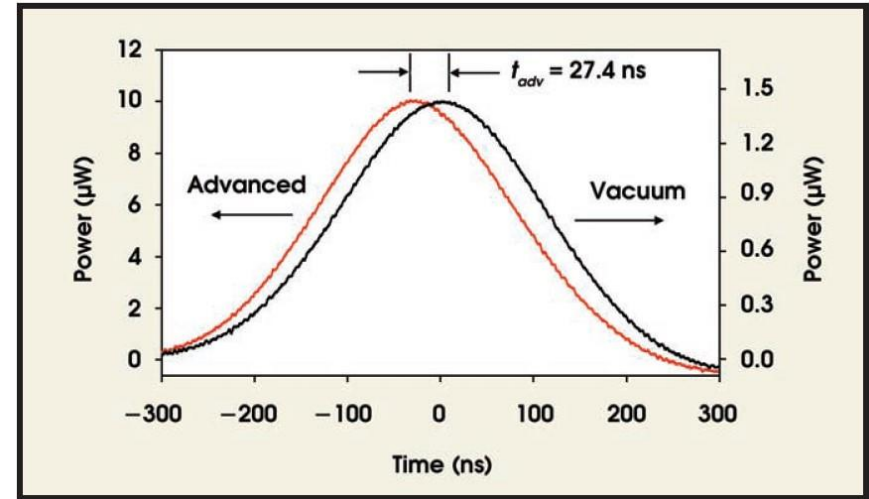
Il mezzo amplifica la radiazione e si inverte la curva di dispersione



Propagazione Superluminale

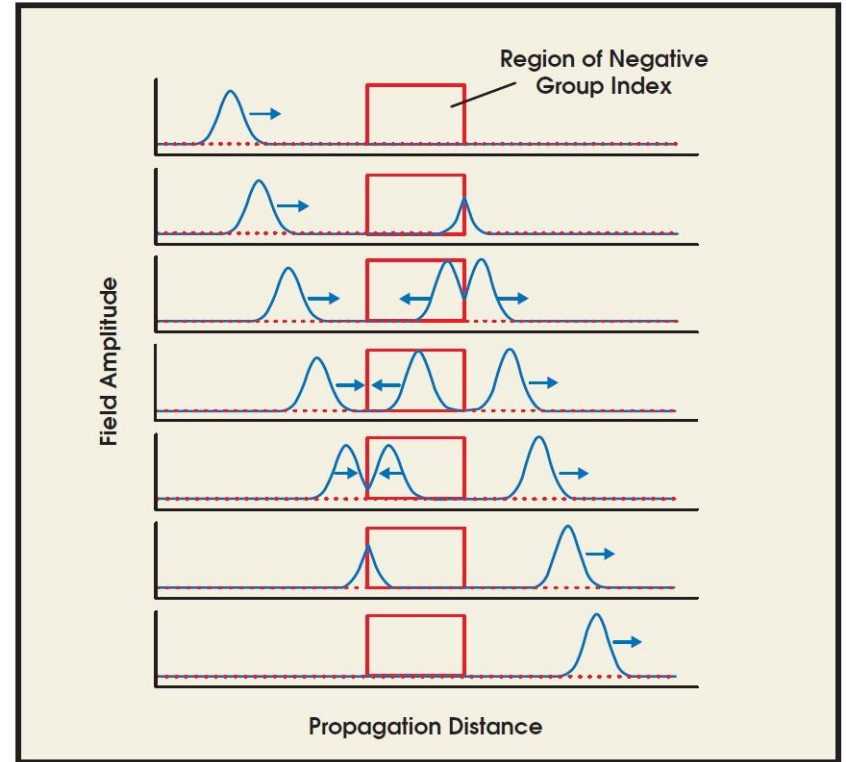
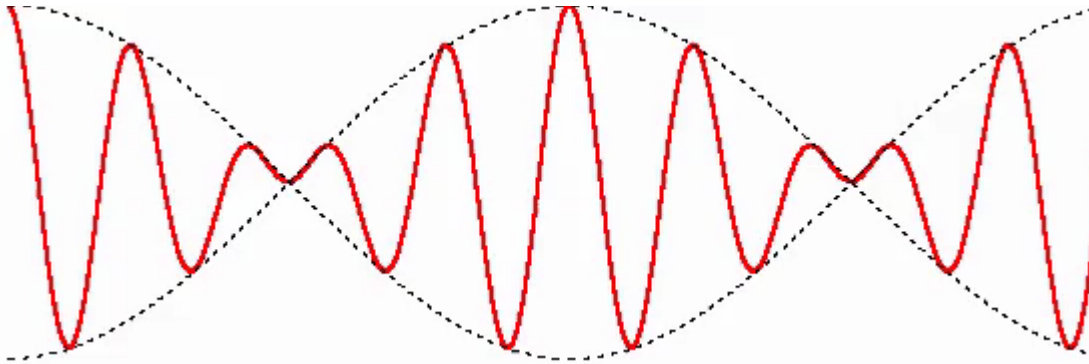


L.J. Wang, A. Kuzmich,
A. Dogariu, *Nature* **406**,
277 (2000)

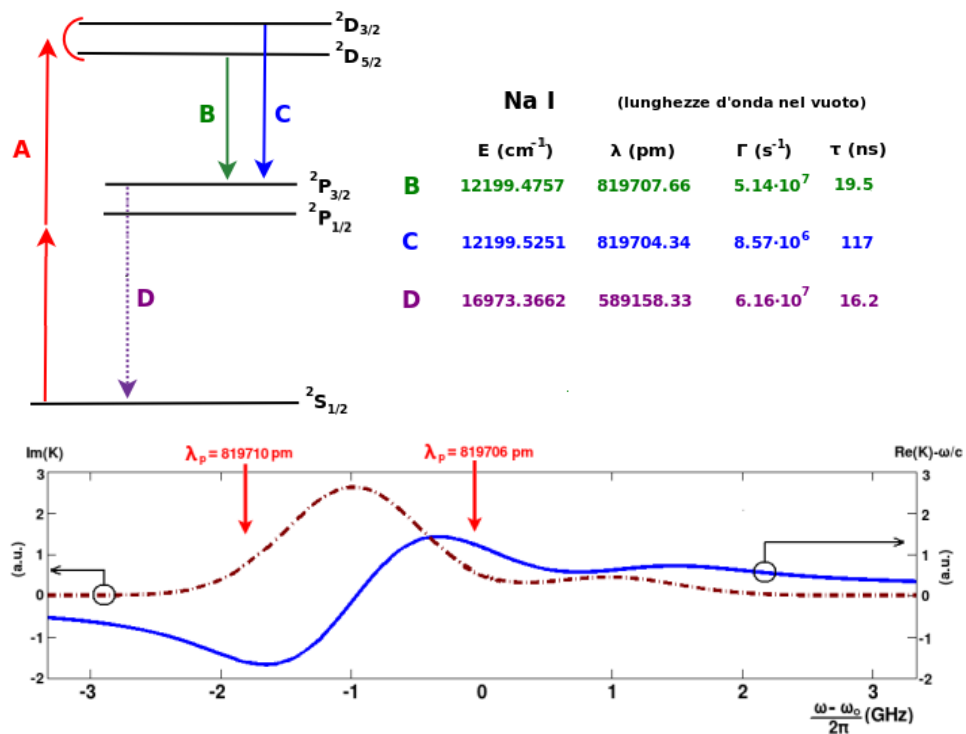


M.D. Stenner, D.J. Gauthier,
M.A. Neifeld, *Nature* **425**,
695 (2005)

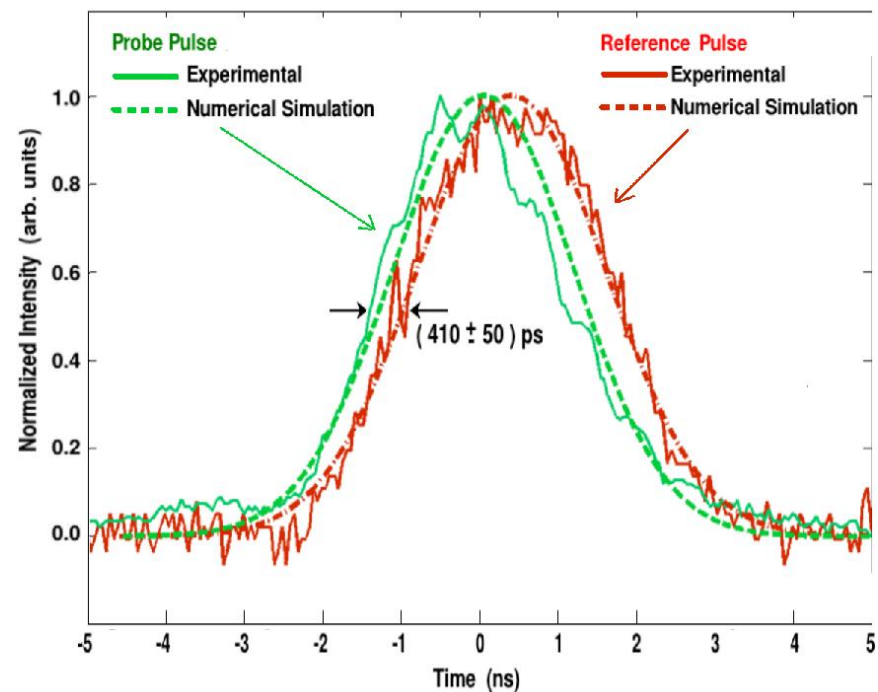
Velocità di Gruppo Negativa



FAST LIGHT in UNIFI

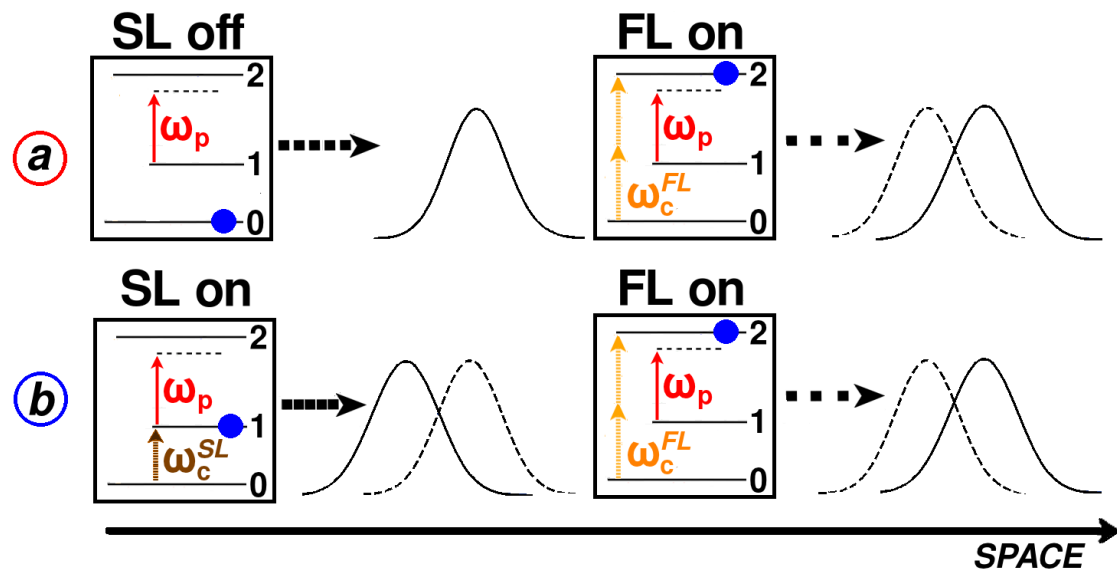


Anticipi fino a circa 0.5 ns per impulsi dalla durata di 3 ns rispetto alla propagazione a c

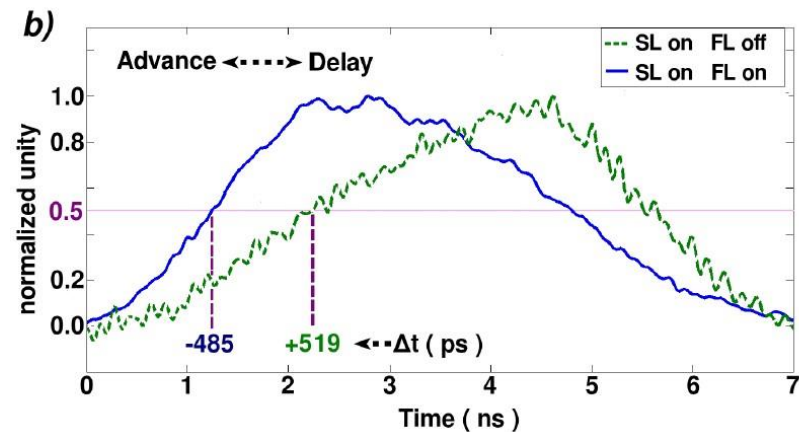
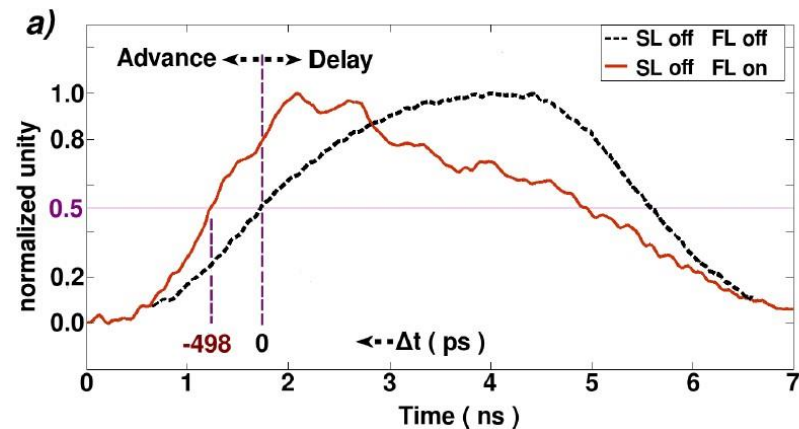


E. Ignesti, F. Tommasi, R. Buffa, L. Fini, E. Sali, S. Cavalieri, *Physical Review A* **87**, 033828 (2013)

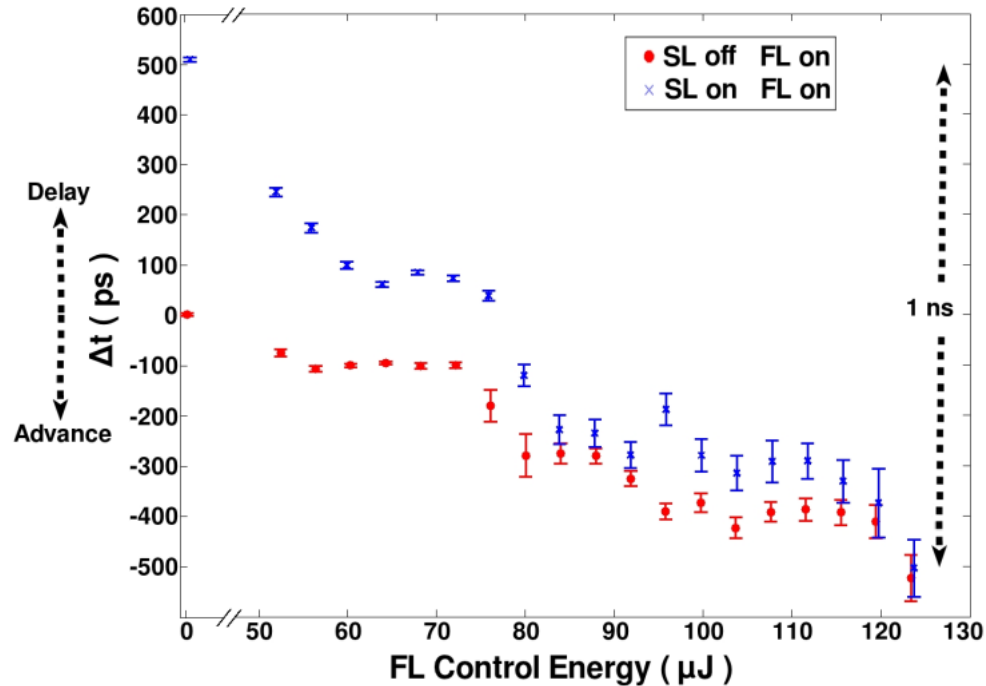
RECUPERO DI UN RITARDO



F. Tommasi, E. Ignesti, L. Fini, S. Cavaliere,
Optics Express **22**, 28566 (2013)



RECUPERO DI UN RITARDO



F. Tommasi, E. Ignesti, L. Fini, S. Cavalieri,
Optics Express **22**, 28566 (2013)

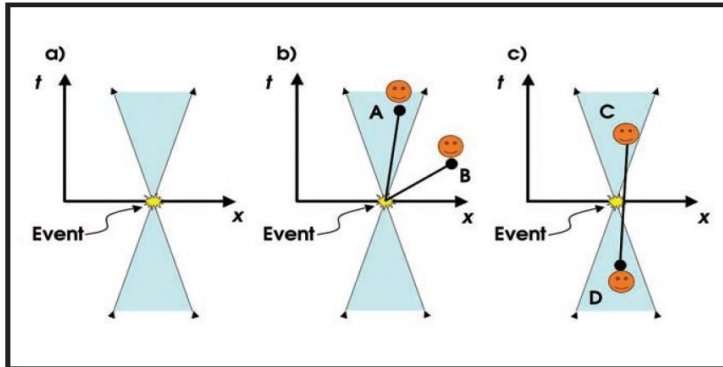
FAST-LIGHT = PARADOSSO ?

La Relatività Speciale e il Principio di Causalità impediscono l'invio di informazione a velocità superluminale !

Intervalli temporali misurati in due sistemi di riferimento diversi tra eventi connessi da una relazione di causalità

$$\Delta t' = \Delta t \frac{1 - u_s v/c^2}{\sqrt{1 - (v/c)^2}}$$

v = velocità relativa dei sistemi di riferimento
 u_s = velocità del segnale



L. Brillouin, *Wave Propagation and Group Velocity*, New York: Academic (1960)

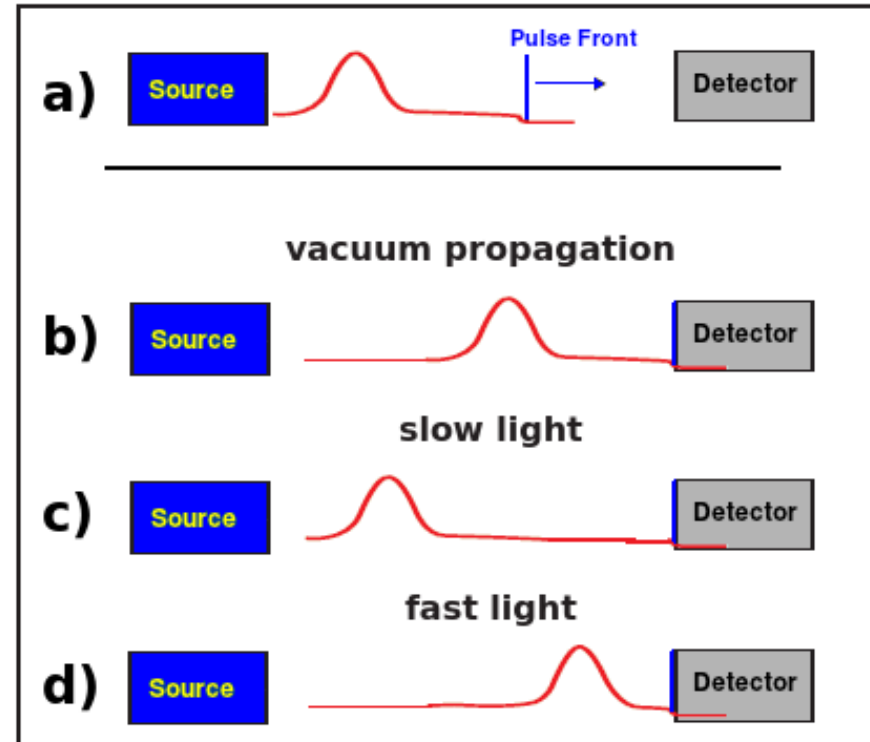
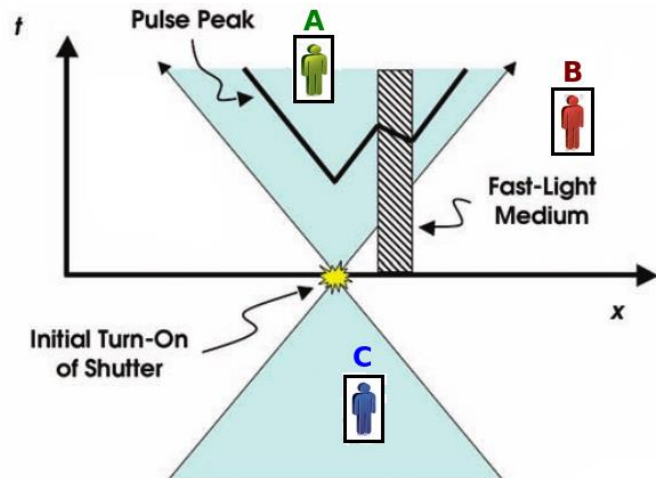
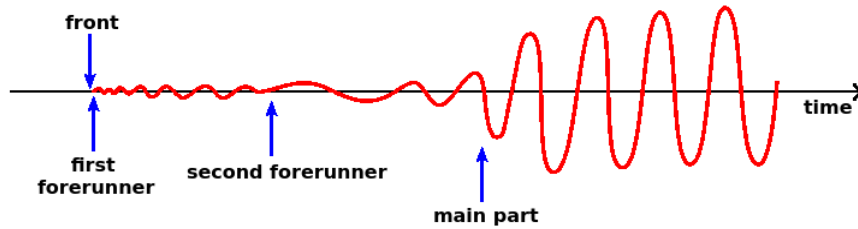
P. W. Milonni, *J. Phys. B: At. Mol. Opt. Phys.* **35** R31 (2002)

D. Gauthier, R. Boyd, *Photonics Spectra*, 82-90 (2007)



Velocità del Fronte dell'Impulso

Il Fronte dell'Impulso si muove sempre a Velocità c e induce la risposta del mezzo: non può essere superato !





GRAZIE PER L'ATTENZIONE