Fotonica: dalle proteine all’entanglement

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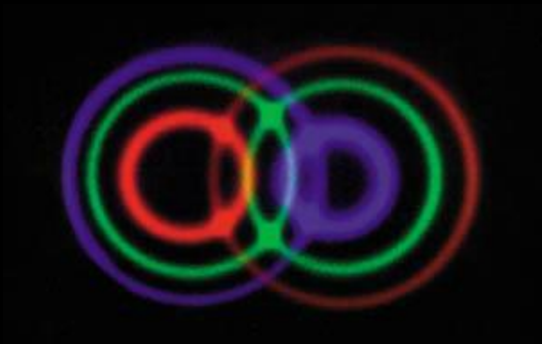
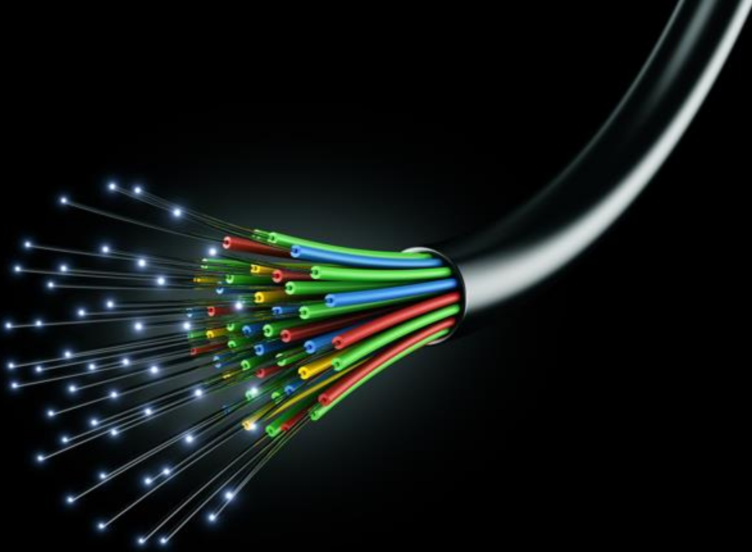
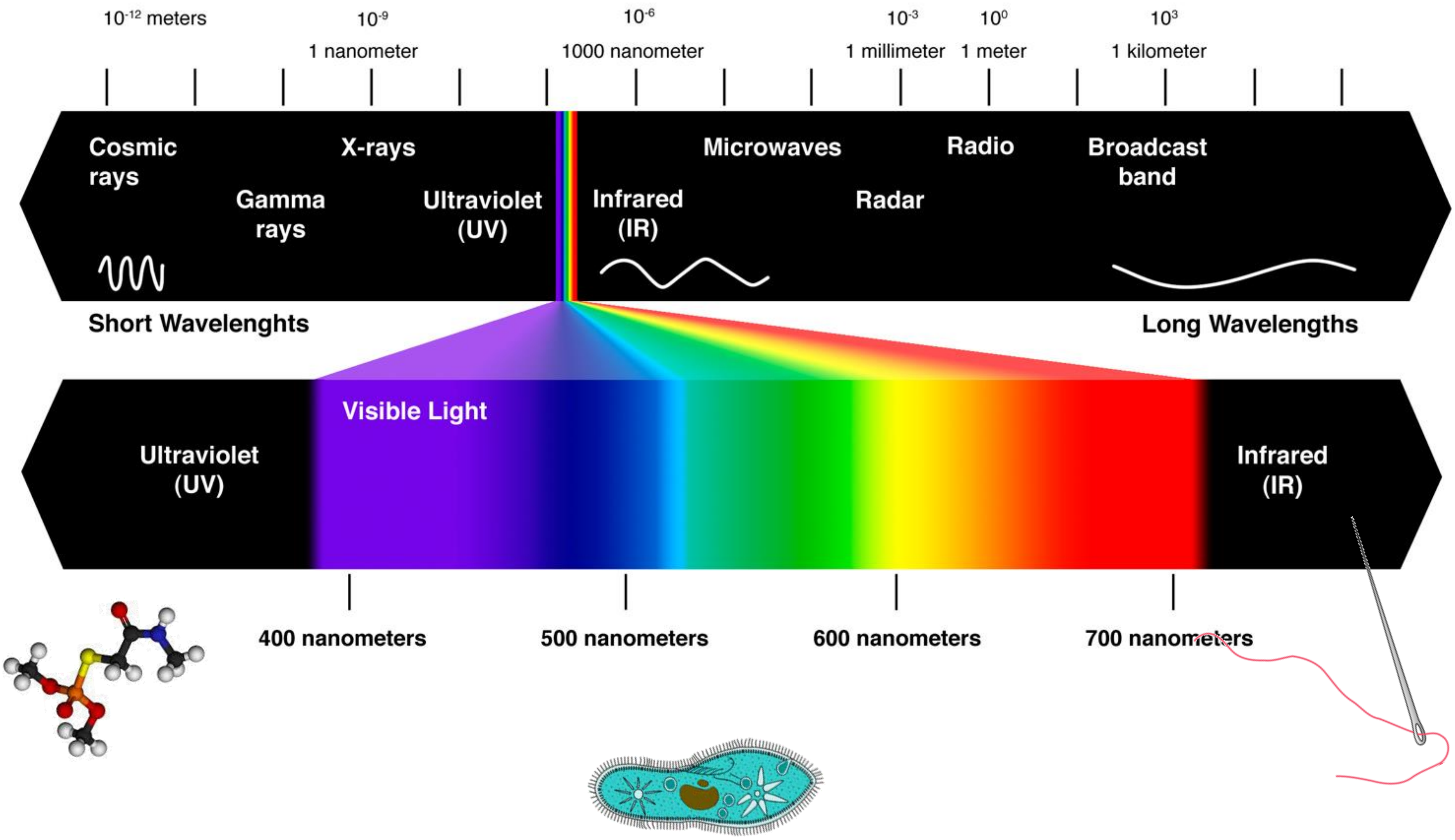
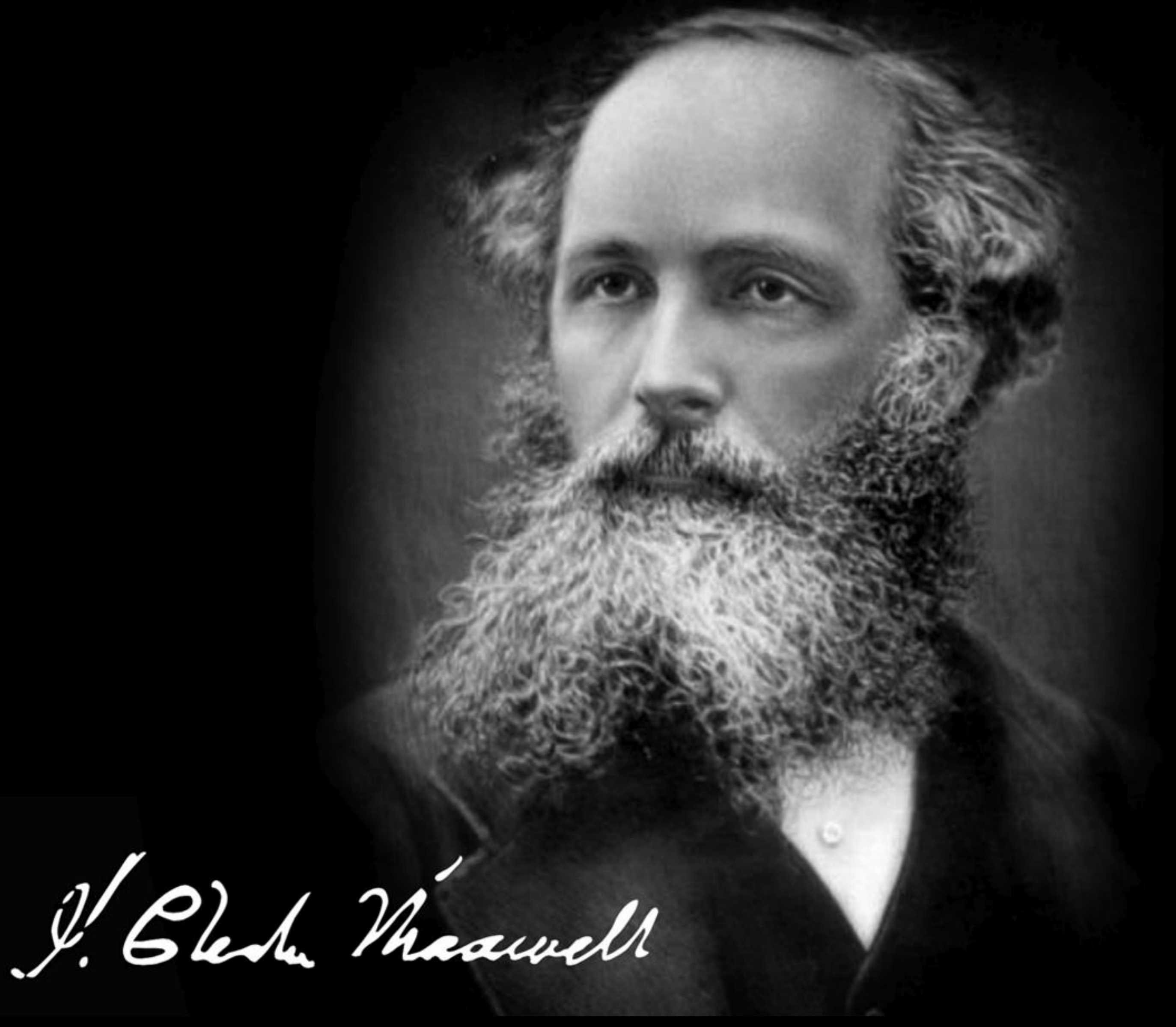


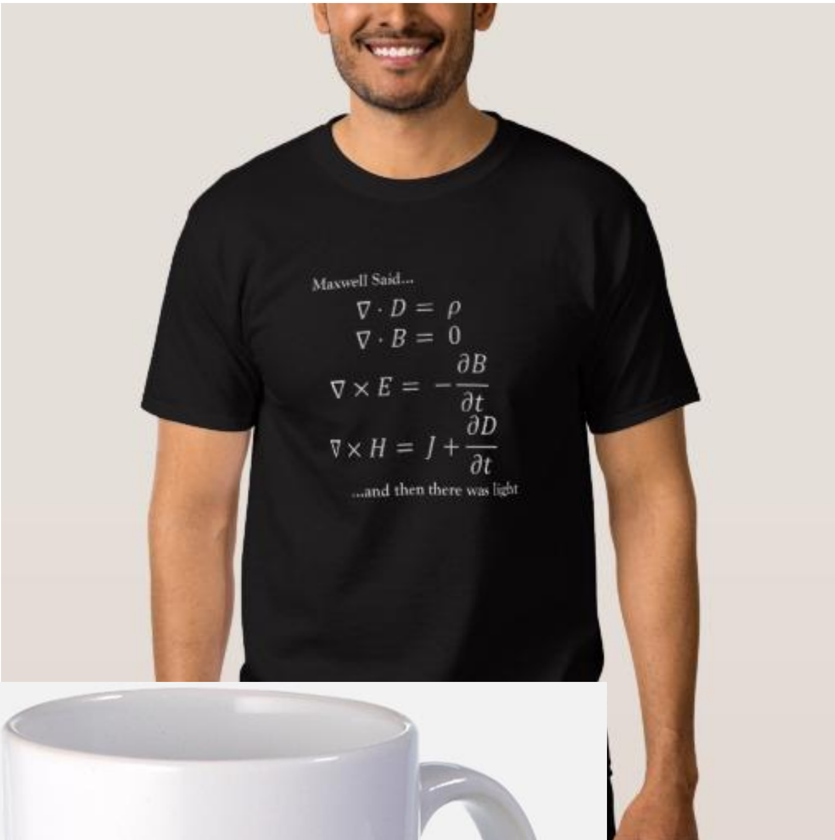


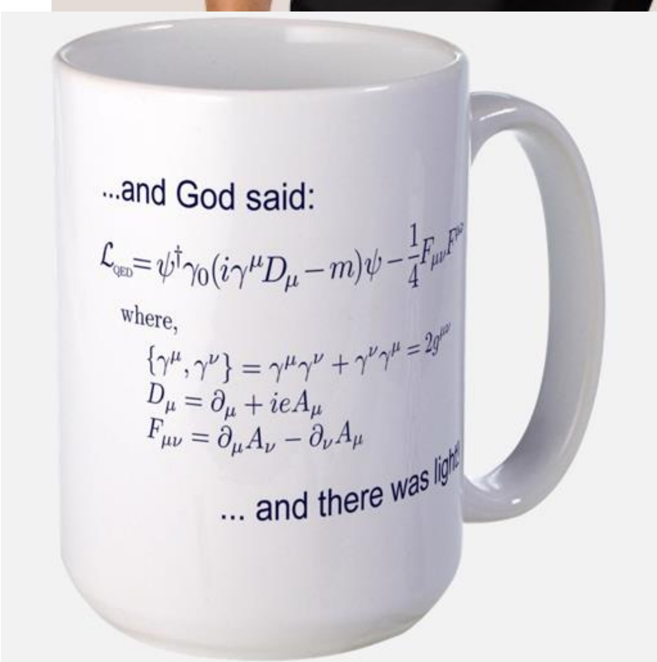
Cos’è la FOTONICA ?



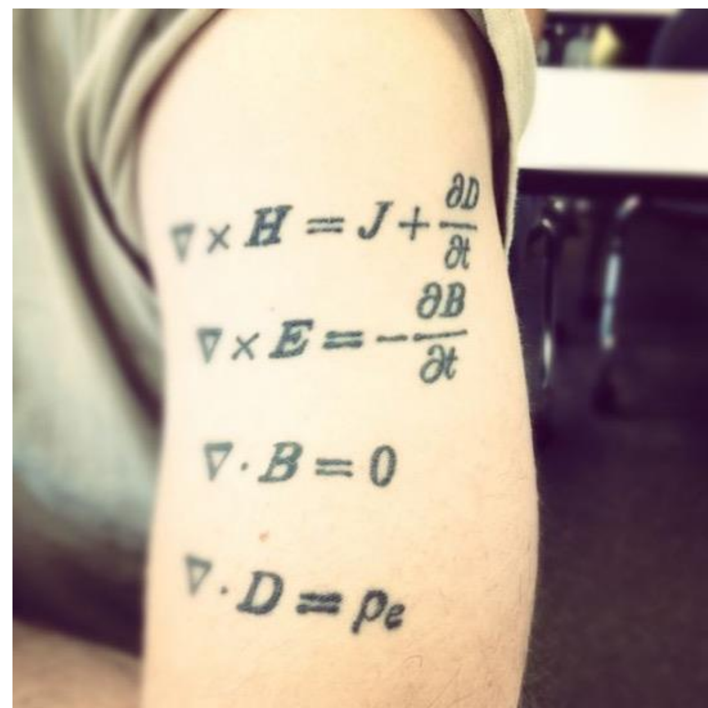
10-12 meters
10-9
1 nanometer
10-6
1000 nanometer
10-3
1 millimeter
100
1 meter
103
1 kilometer
Cosmic rays
X-rays
Microwaves
Radio
Broadcast band
Gamma rays
Ultraviolet (UV)
Infrared (IR)
Radar
Short Wavelenghts
Long Wavelengths
Visible Light
Ultraviolet (UV)
Infrared (IR)
400 nanometers
500 nanometers
600 nanometers
700 nanometers


J. Clerk Maxwell

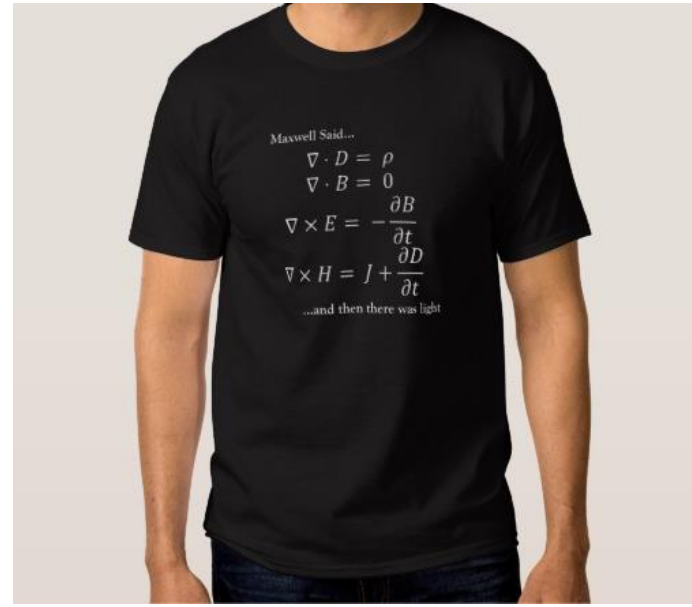

Maxwell Said...
$\nabla \cdot D = \rho$
$\nabla \cdot B = 0$
$\nabla \times E = -\frac{\partial B}{\partial t}$
$\nabla \times H = J + \frac{\partial D}{\partial t}$
...and then there was light


...and God said:
$\mathcal{L}_{QED} = \psi^{\dagger}\gamma_0(i\gamma^{\mu}D_{\mu} - m)\psi - \frac{1}{4}F_{\mu\nu}F^{\mu\nu}$
where,
$\{\gamma^{\mu}, \gamma^{\nu}\} = \gamma^{\mu}\gamma^{\nu} + \gamma^{\nu}\gamma^{\mu} = 2g^{\mu\nu}$
$D_{\mu} = \partial_{\mu} + ieA_{\mu}$
$F_{\mu\nu} = \partial_{\mu}A_{\nu} - \partial_{\nu}A_{\mu}$
... and there was light


$\nabla \times B = \frac{\partial E}{\partial t} +$

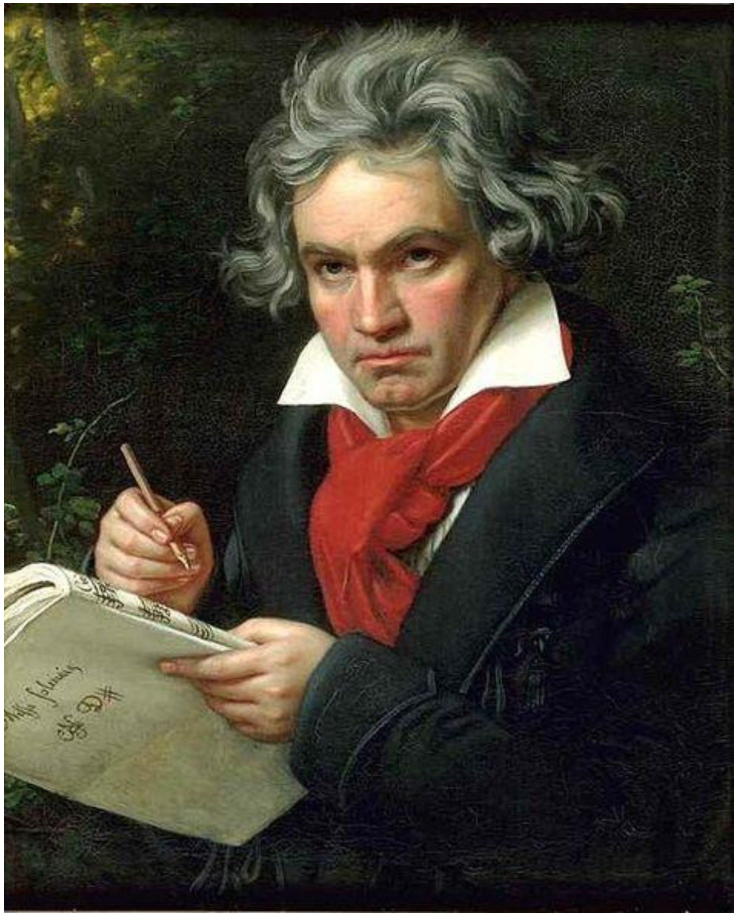

$\nabla \times H = J + \frac{\partial D}{\partial t}$
$\nabla \times E = -\frac{\partial B}{\partial t}$
$\nabla \cdot B = 0$
$\nabla \cdot D = \rho_e$

1979



If you have bought one of those T-shirts with Maxwell’s equations on the front, you may have to worry about its going out of style, but NOT about its becoming false. We will go on teaching Maxwellian electrodynamics as long as there are scientist.

(Steven Weinberg)

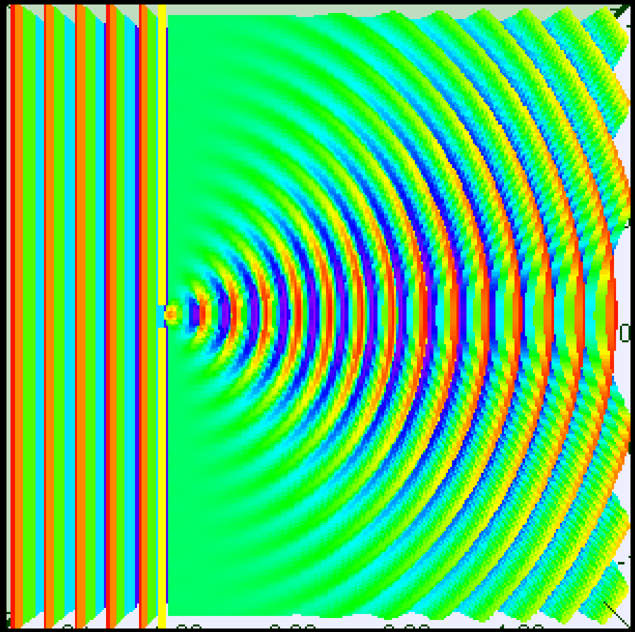


Ottica classica **Ottica quantistica**

Esempio I:

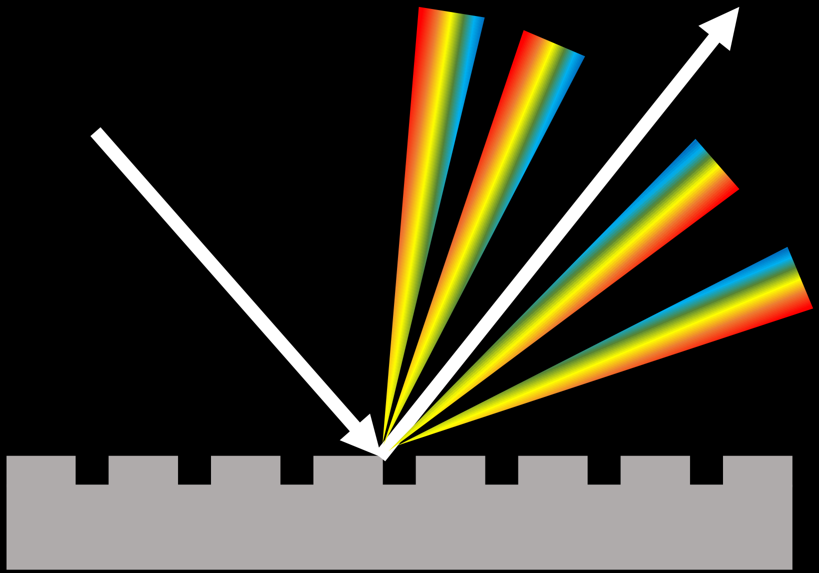
Rilevare proteine con la luce

Diffrazione

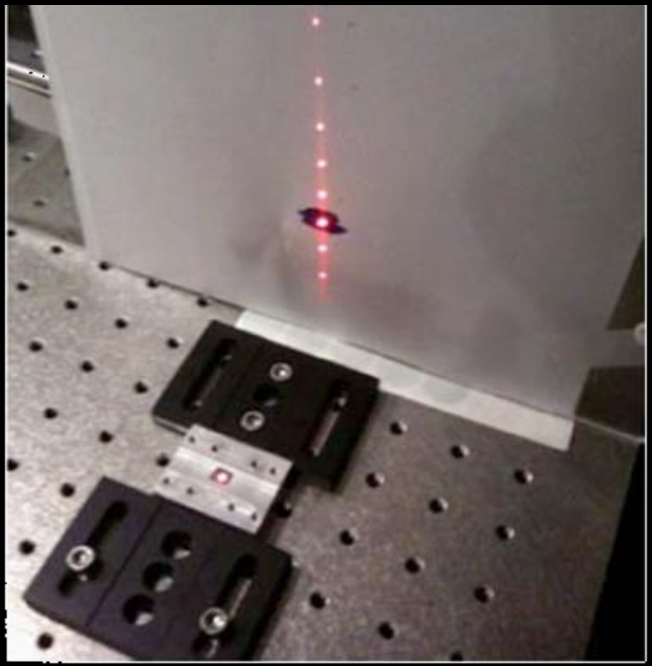


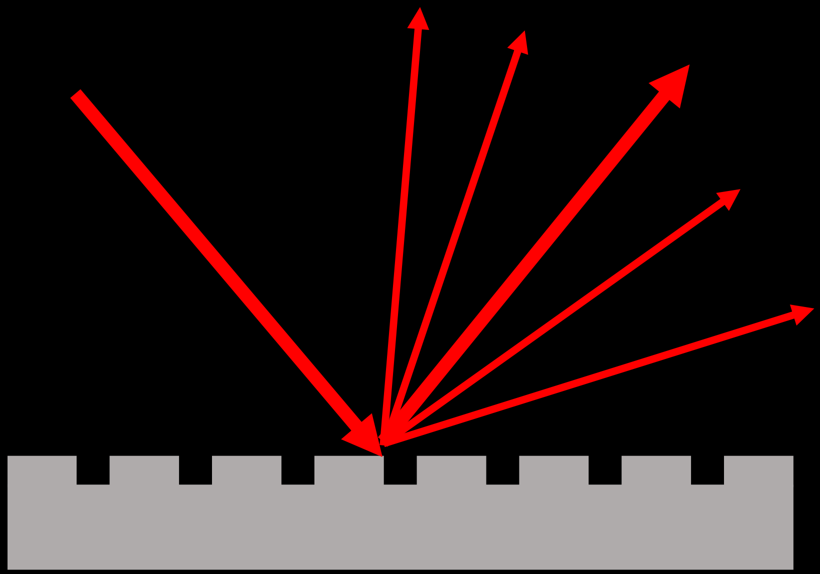
a=λ

Reticoli di Diffrazione



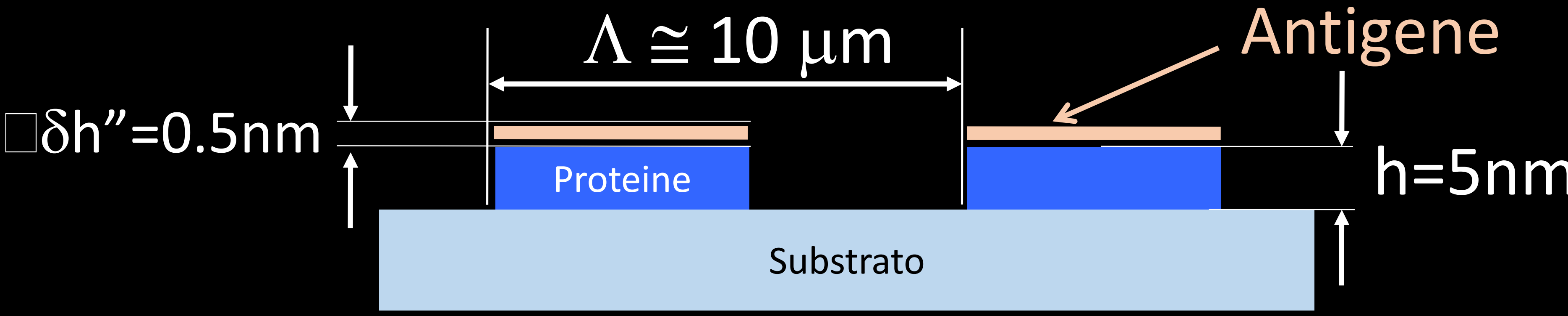
Reticoli di Diffrazione





L'intensità della luce diffratta dipende
dal “materiale” e dall'altezza del reticolo.

Sensori a Diffrazione



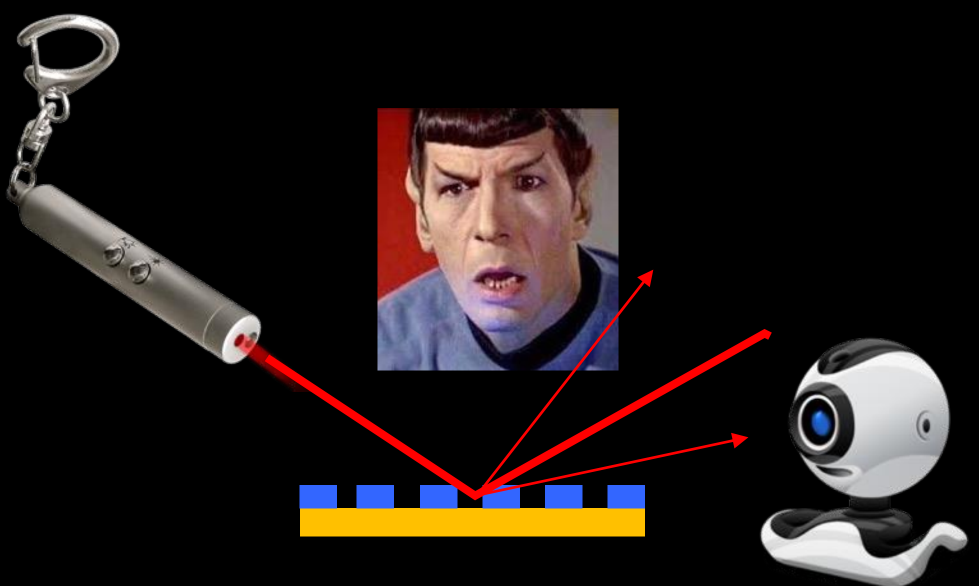
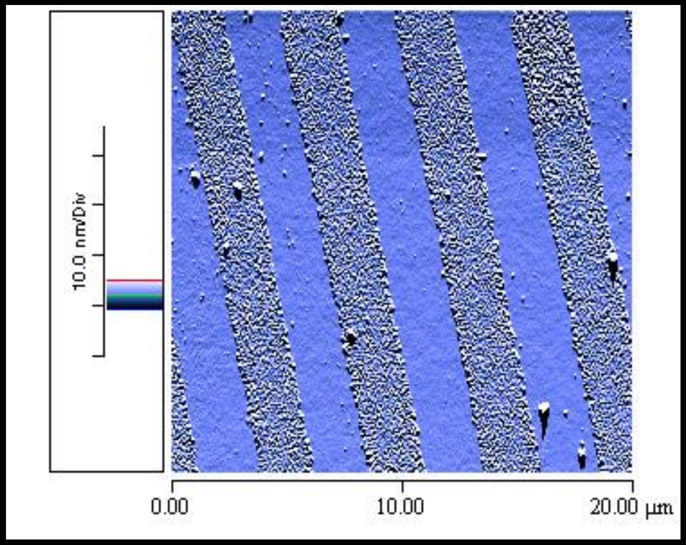
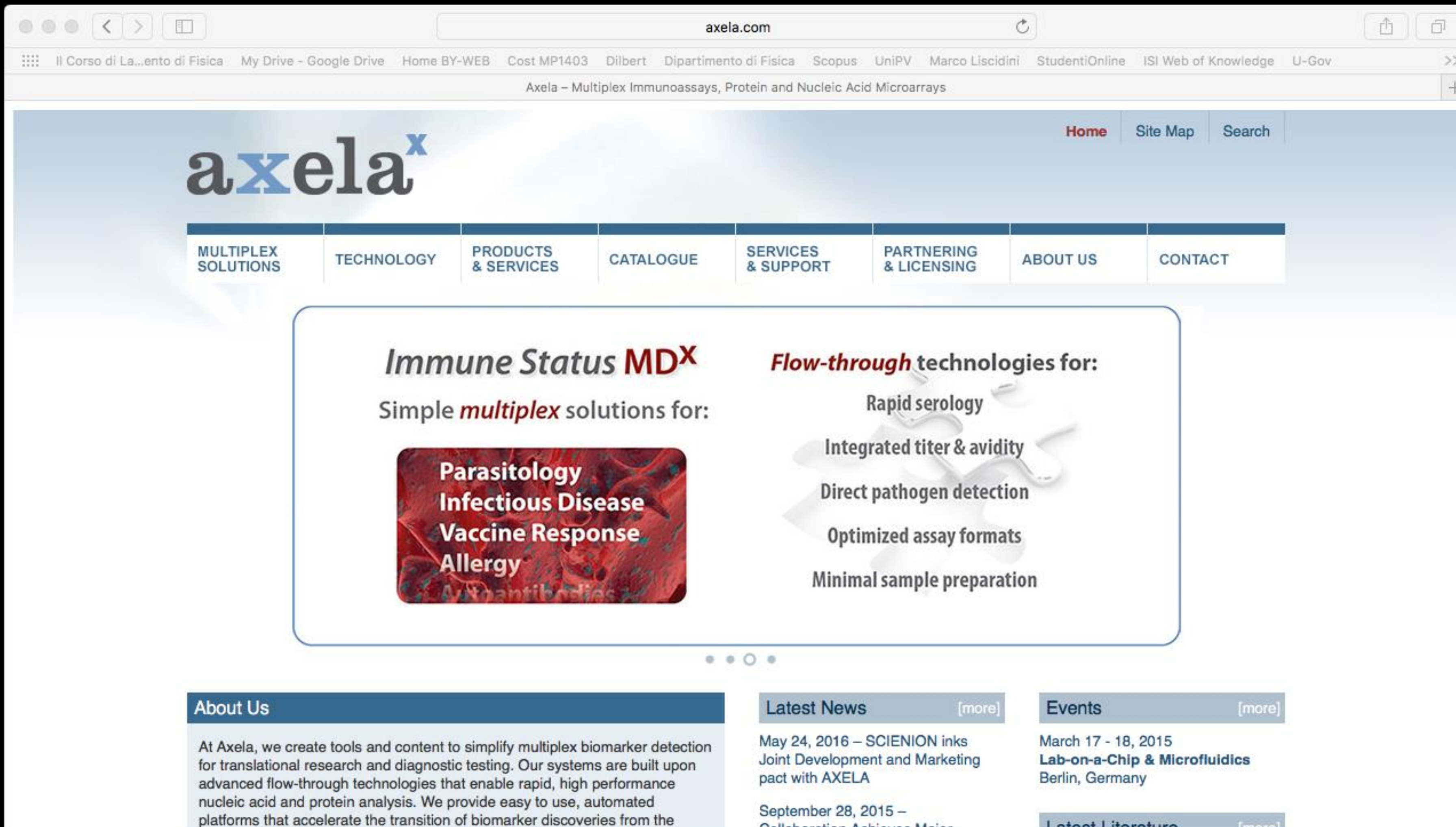


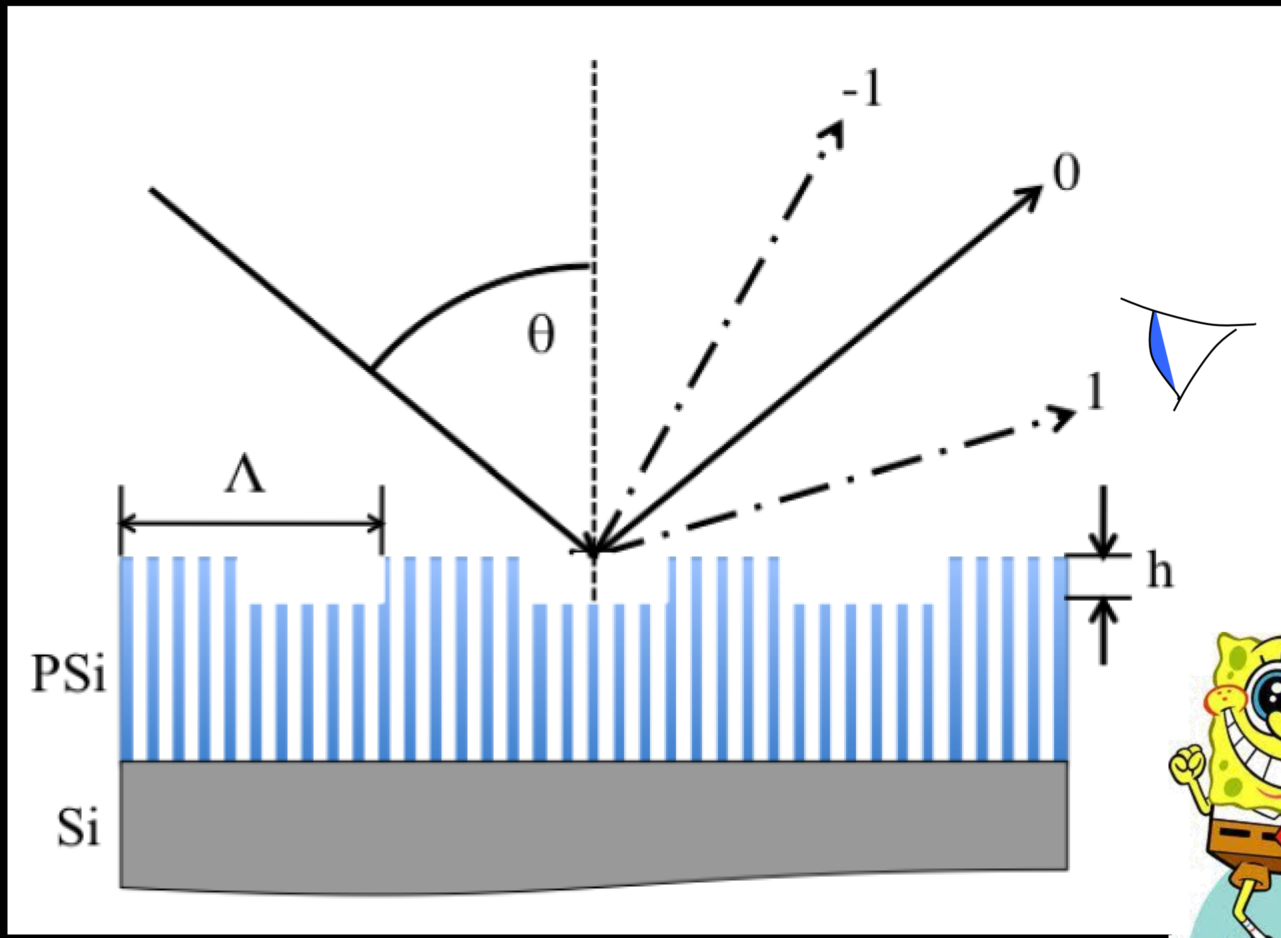
Immagine AFM (Prof. Patrini)



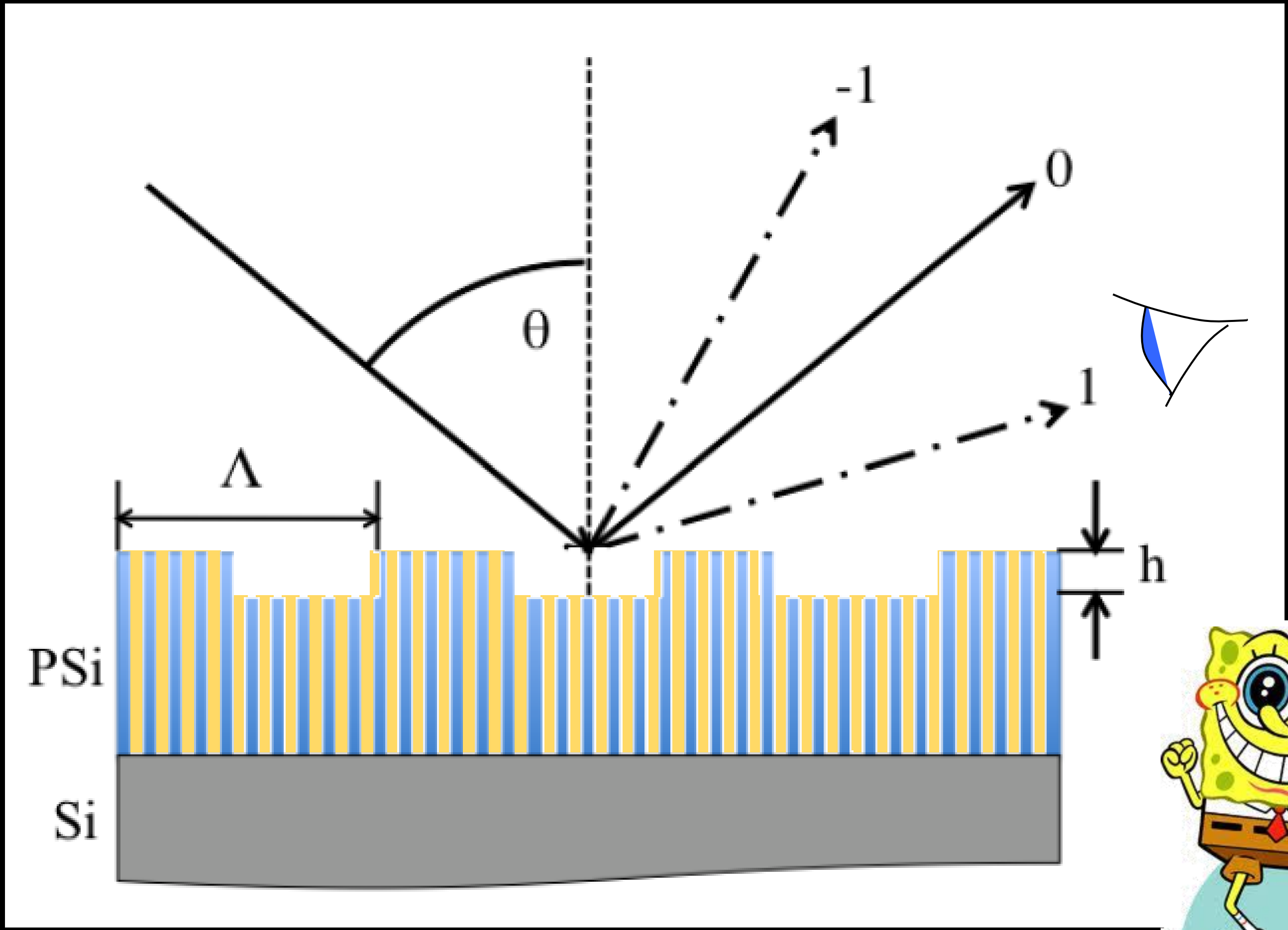


www.axela.com

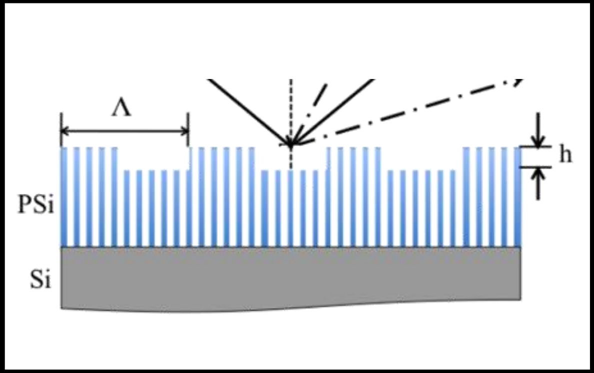
Sensori a diffrazione porosi



Sensori a diffrazione porosi



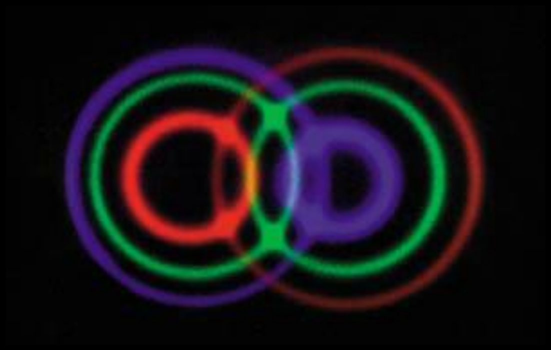
Facciamo una prova...



U.S. Patent 8,349,617

Esempio II:

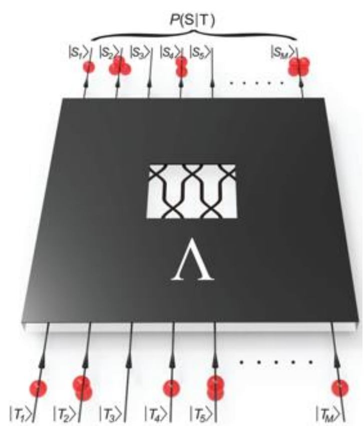
Generazione di coppie di fotoni entangled



Ottica quantistica

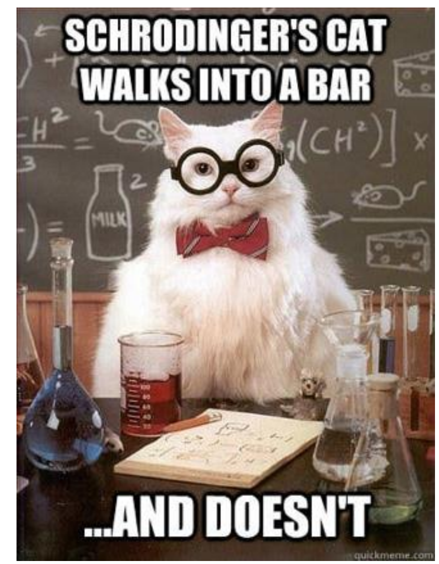
Perché generare luce non classica?

Quantum information



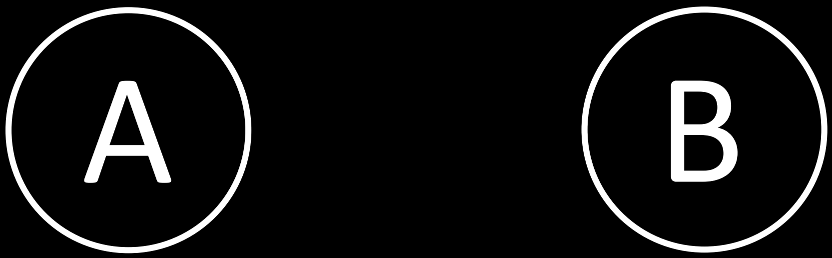
Quantum computation/simulation

Quantum Metrology

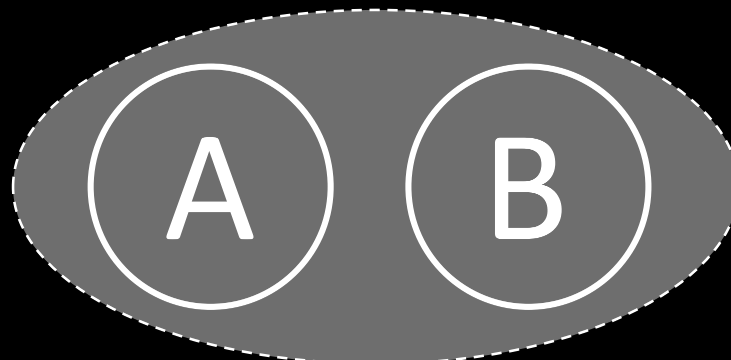


Quantum Mechanics

Entanglement



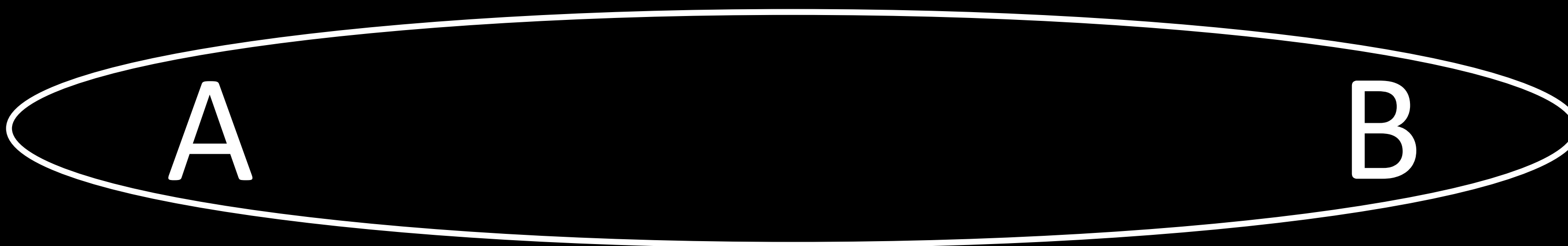
Entanglement



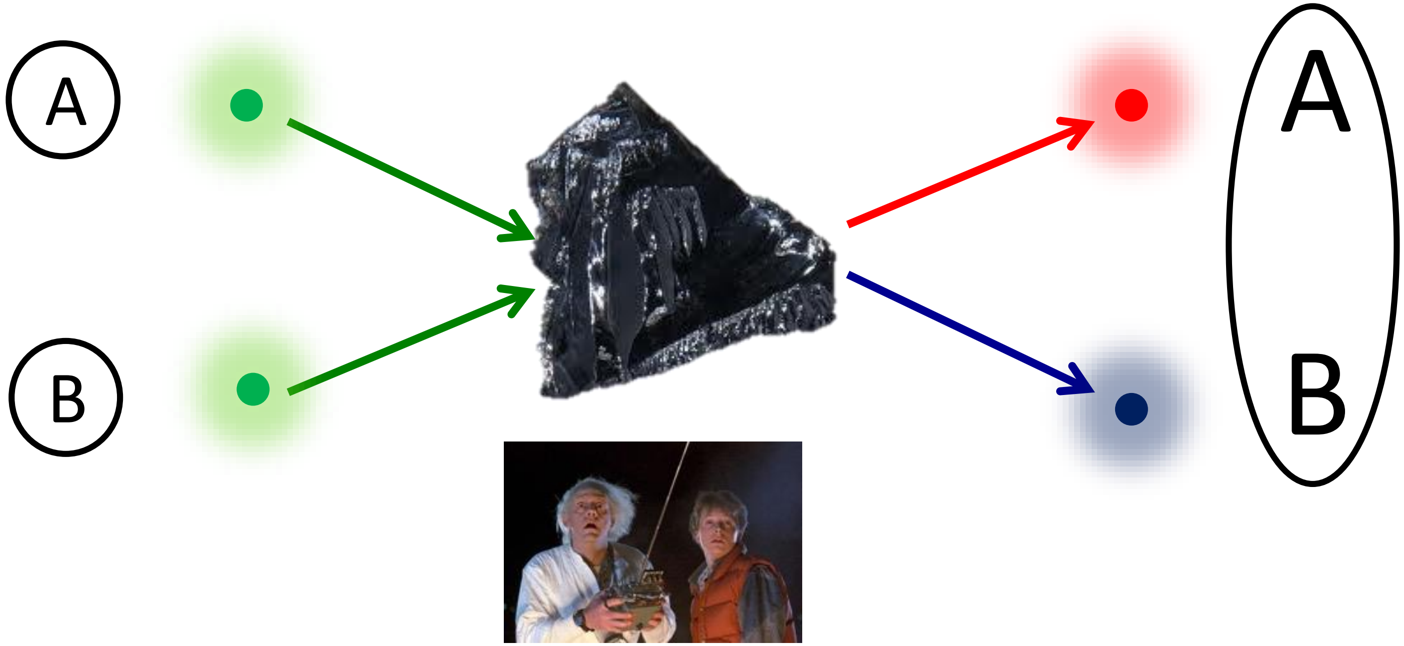
Interazione : generatore di “entanglement”

Entanglement

Entanglement



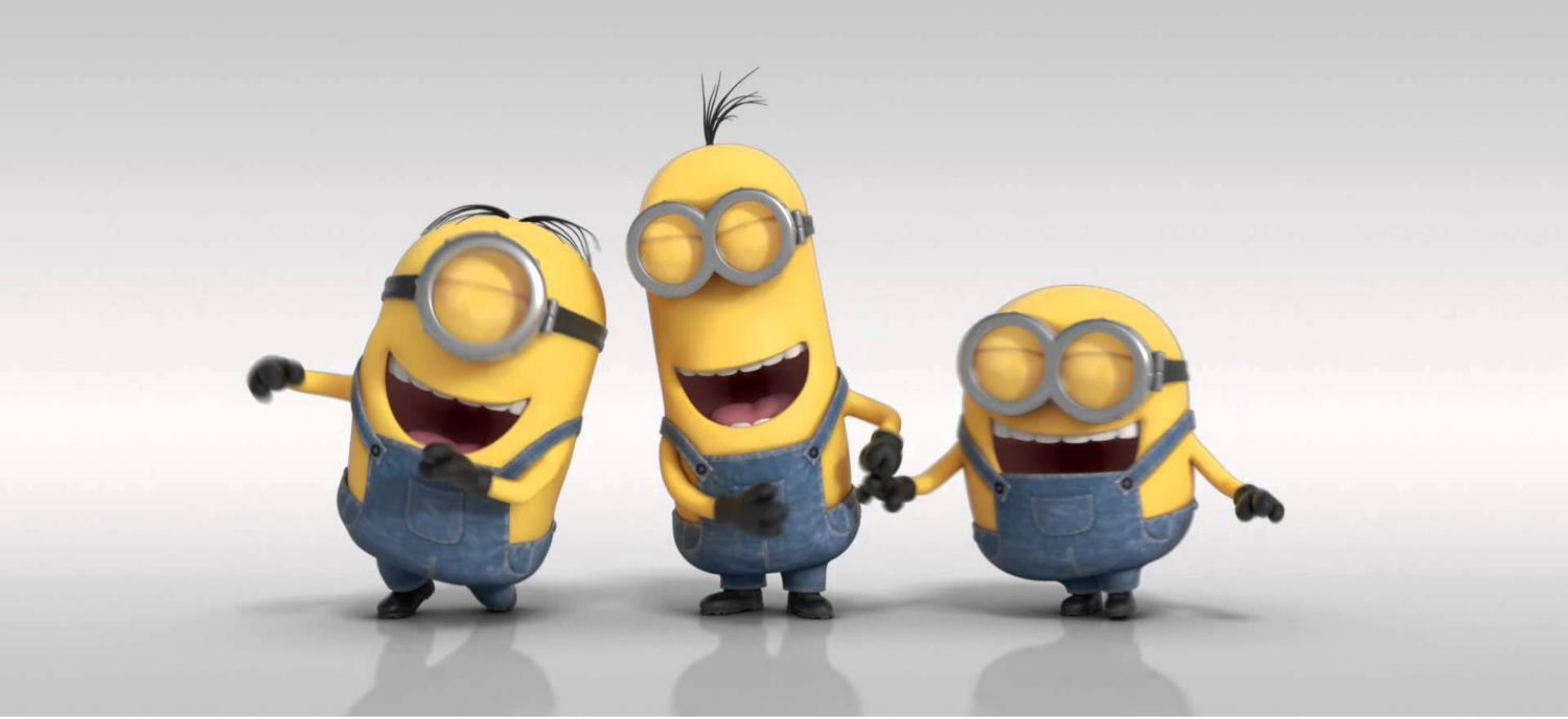
Coppie di fotoni entangled



Spontaneous Four-Wave-Mixing

Pompa (1 mW, @ 1μm)
10^{16} fotoni/s

→ 50 coppie/s



Aumentare l'interazione radiazione-materia

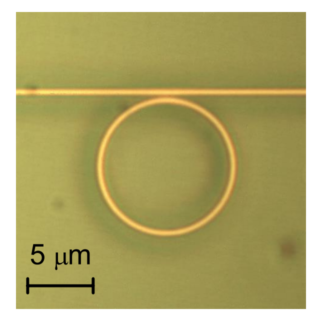
Guide d'onda

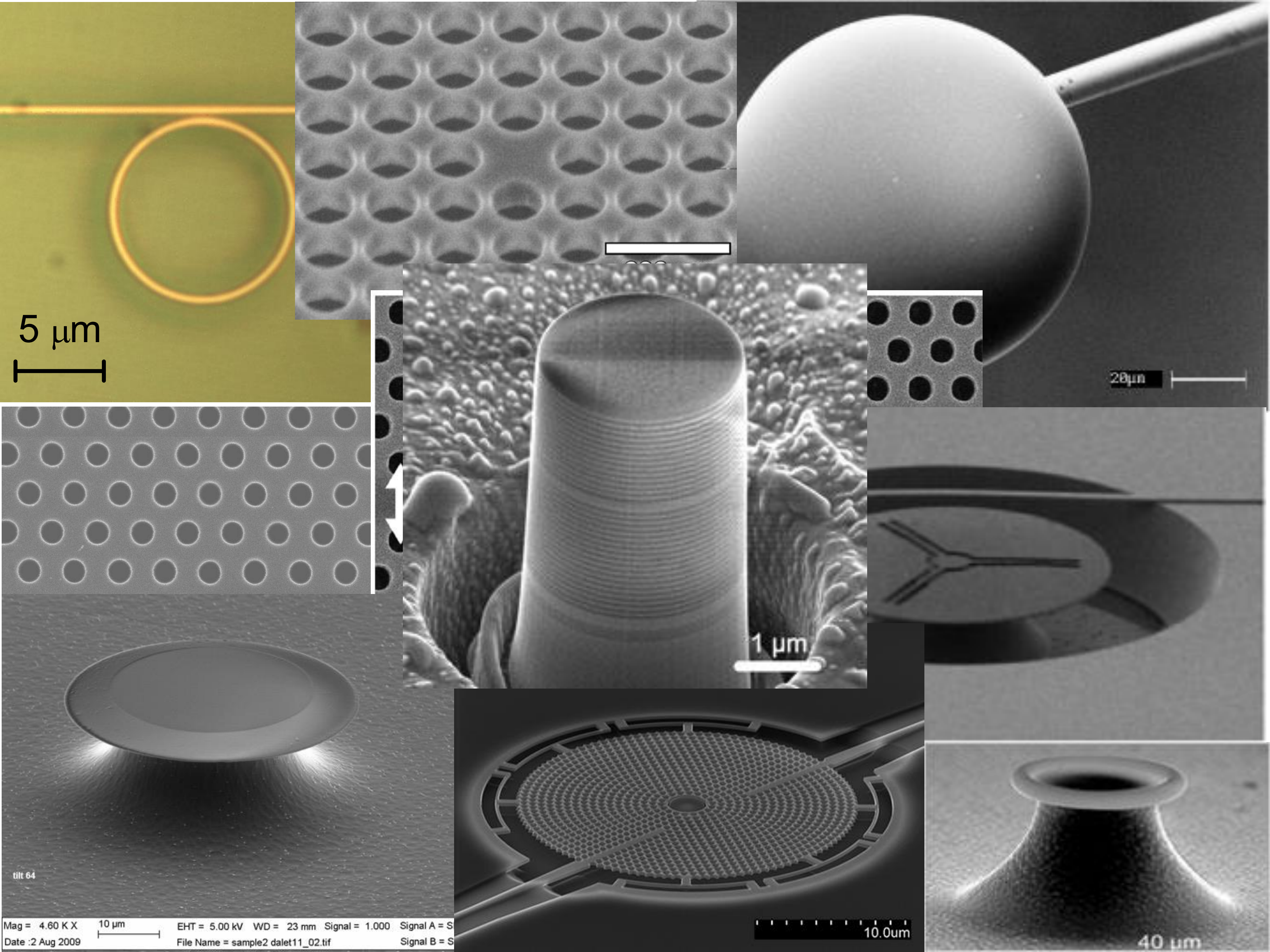
$$\frac{1}{A}\frac{L}{v_g}$$

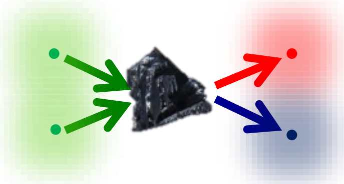
Risuonatori

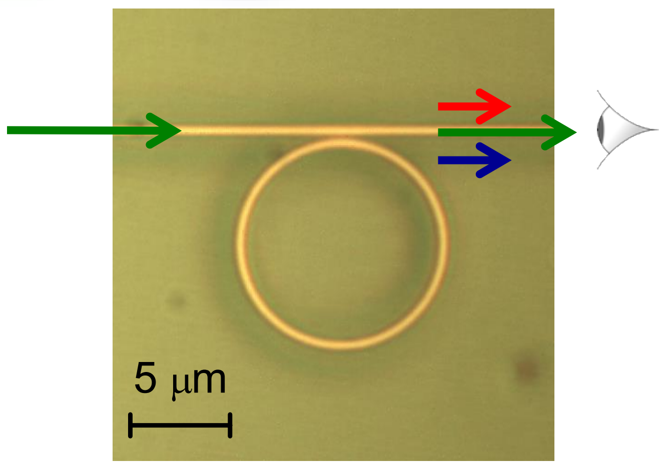
$$\frac{\tau}{V}$$

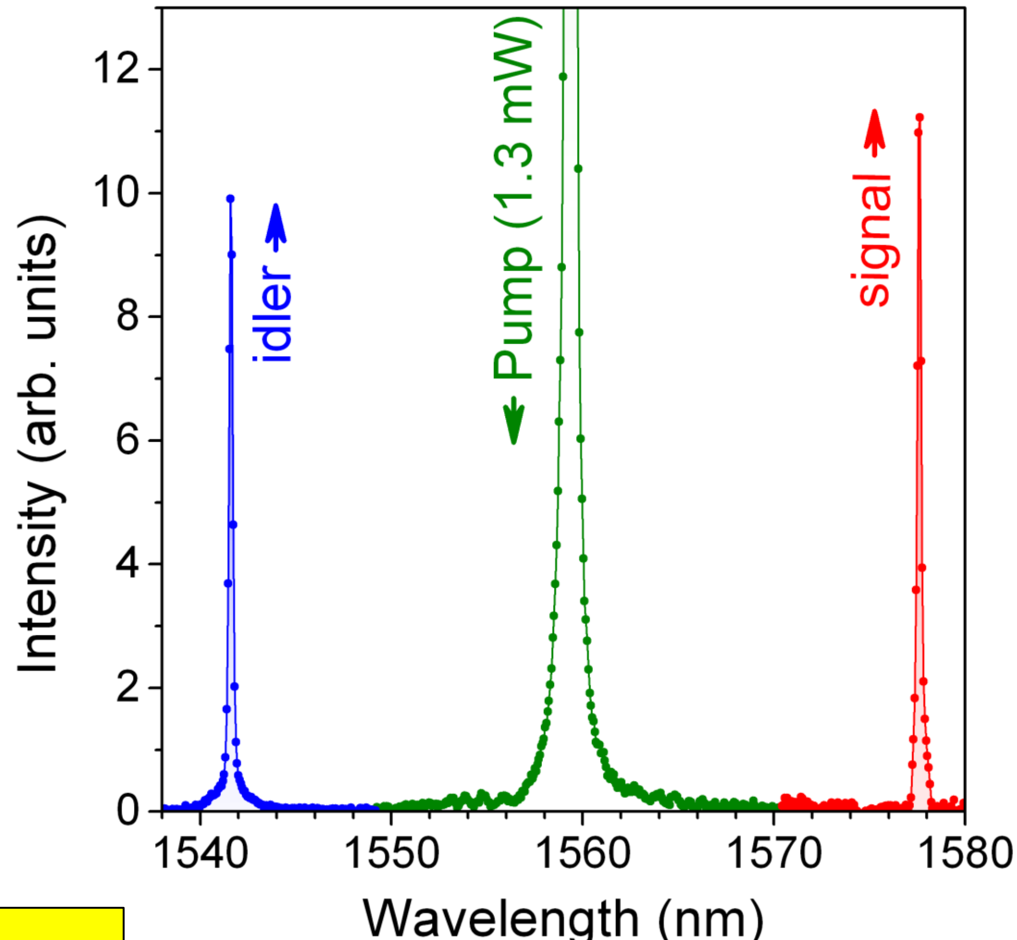
Confinamento <u>spaziale</u> e <u>temporale</u>




5 µm
20µm
1 µm
tilt 64
Mag = 4.60 K X
10 µm
EHT = 5.00 kV
WD = 23 mm
Signal = 1.000
Signal A = S
Date :2 Aug 2009
File Name = sample2 dalet11_02.tif
Signal B = S
10.0um
40 µm





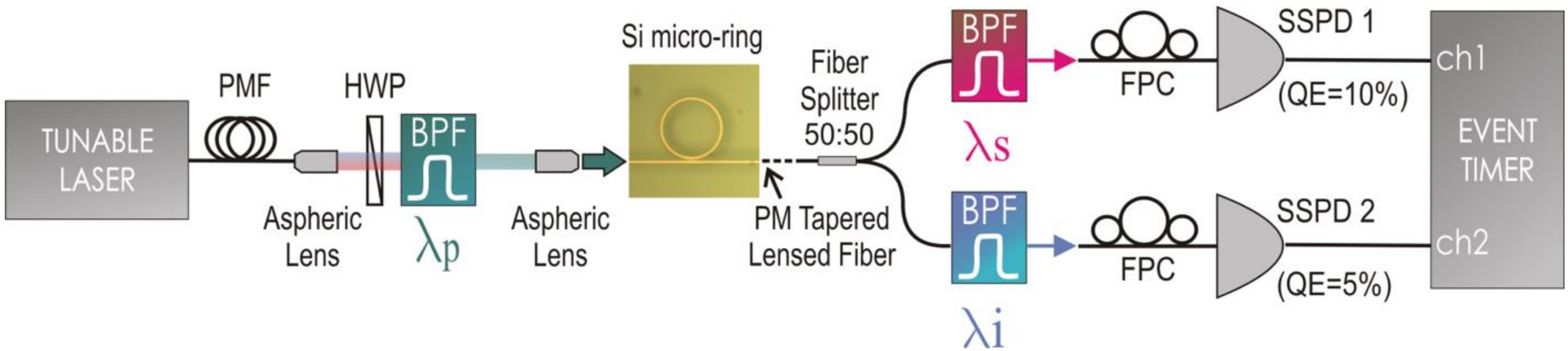


R=5μm (31.4μm)
Q=8000

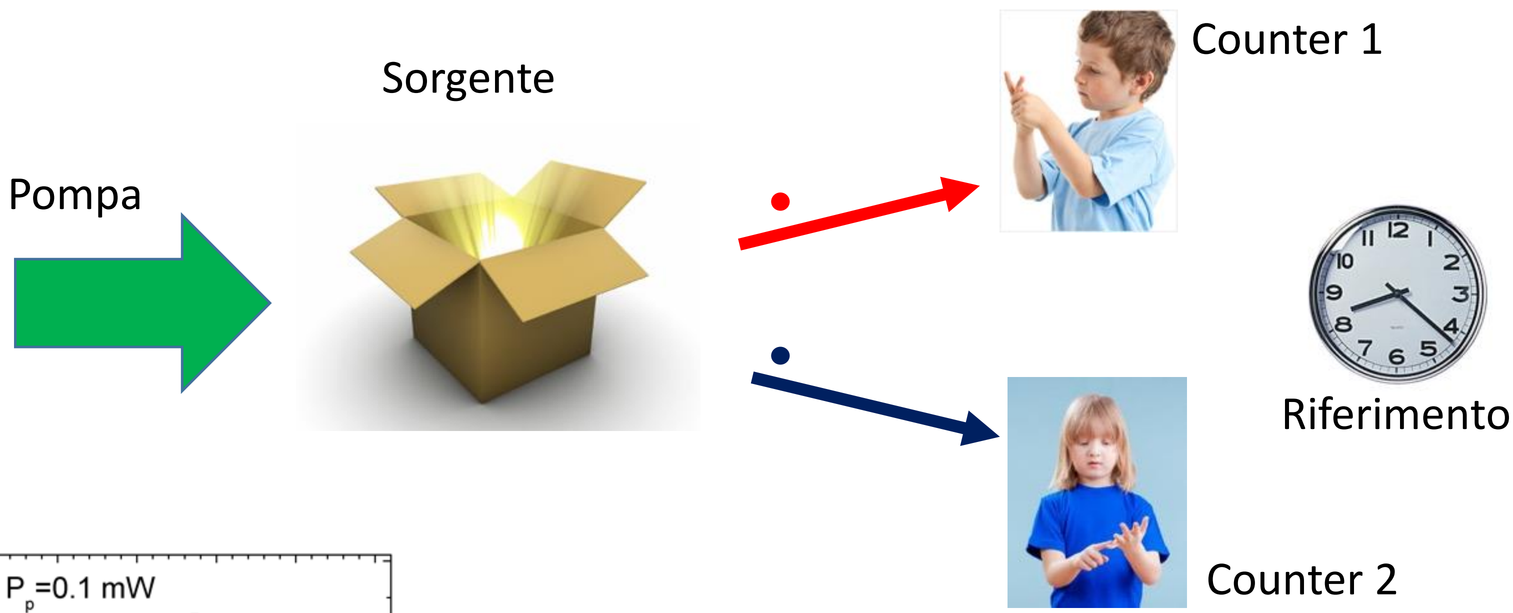
1mW → 4x10^6 pair/s
(≅0.6 pW)

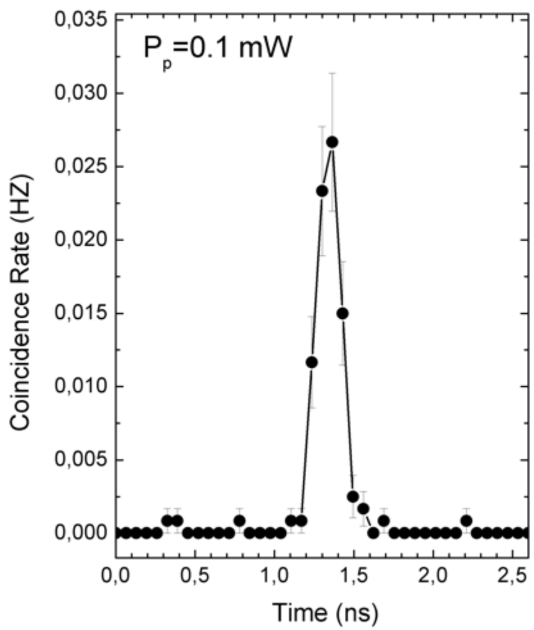
(S. Azzini, et al., Opt. Lett. 2012)

Stiamo generando coppie di fotoni?



Stiamo generando coppie di fotoni?



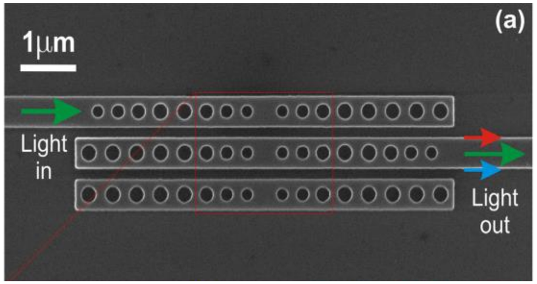


Generazione contemporanea di un fotone rosso ed un fotone blu

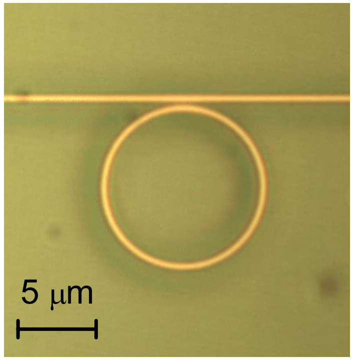
E come funziona la dimostrazione dell’entanglement?

Benissimo, grazie!

SFWM e microrisuonatori



(S. Azzini, et al. APL 2013)



D. Grassani, et al. Optica 2015

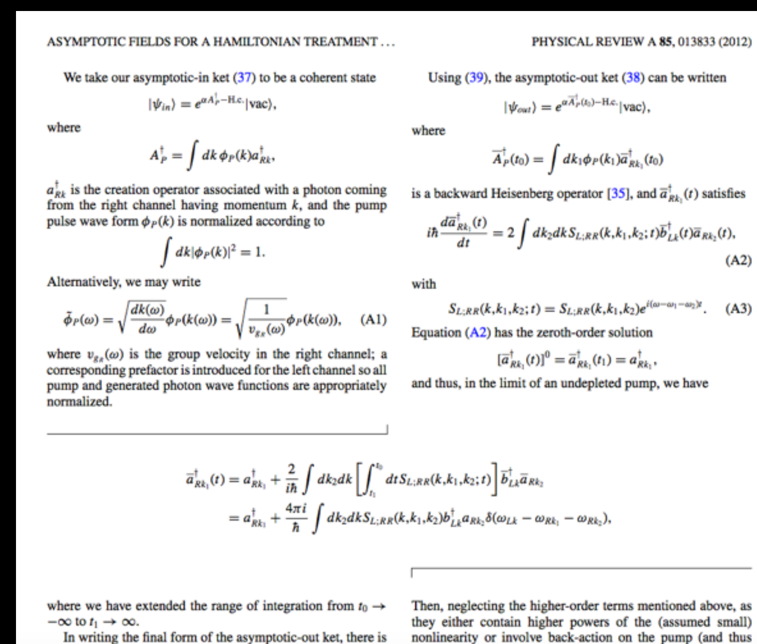
A <u>Pavia</u> si è dimostrato un aumento di efficienza del processo fino a
9 ordini di grandezza

10^9

Come si fa ricerca
(teorica)
in fotonica ?

Approccio **numerico**

Approccio *analitico*



ASYMPTOTIC FIELDS FOR A HAMILTONIAN TREATMENT . . . PHYSICAL REVIEW A **85**, 013833 (2012)

We take our asymptotic-in ket (37) to be a coherent state

$$|\psi_{in}\rangle = e^{\alpha A_P^\dagger - \mathrm{H.c.}}|\mathrm{vac}\rangle,$$

where

$$A_P^\dagger = \int dk\,\phi_P(k) a_{Rk}^\dagger,$$

$a_{Rk}^\dagger$ is the creation operator associated with a photon coming from the right channel having momentum k, and the pump pulse wave form $\phi_P(k)$ is normalized according to

$$\int dk|\phi_P(k)|^2 = 1.$$

Alternatively, we may write

$$\bar{\phi}_P(\omega) = \sqrt{\frac{dk(\omega)}{d\omega}}\phi_P(k(\omega)) = \sqrt{\frac{1}{v_{g_R}(\omega)}}\phi_P(k(\omega)), \quad \text{(A1)}$$

where $v_{g_R}(\omega)$ is the group velocity in the right channel; a corresponding prefactor is introduced for the left channel so all pump and generated photon wave functions are appropriately normalized.

Using (39), the asymptotic-out ket (38) can be written

$$|\psi_{out}\rangle = e^{\alpha \overline{A}_P^\dagger(t_0) - \mathrm{H.c.}}|\mathrm{vac}\rangle,$$

where

$$\overline{A}_P^\dagger(t_0) = \int dk_1 \phi_P(k_1)\overline{a}_{Rk_1}^\dagger(t_0)$$

is a backward Heisenberg operator [35], and $\overline{a}_{Rk_1}^\dagger(t)$ satisfies

$$i\hbar\frac{d\overline{a}_{Rk_1}^\dagger(t)}{dt} = 2\int dk_2 dk\, S_{L;RR}(k,k_1,k_2;t)\overline{b}_{Lk}^\dagger(t)\overline{a}_{Rk_2}(t), \quad \text{(A2)}$$

with

$$S_{L;RR}(k,k_1,k_2;t) = S_{L;RR}(k,k_1,k_2)e^{i(\omega-\omega_1-\omega_2)t}. \quad \text{(A3)}$$

Equation (A2) has the zeroth-order solution

$$[\overline{a}_{Rk_1}^\dagger(t)]^0 = \overline{a}_{Rk_1}^\dagger(t_1) = a_{Rk_1}^\dagger,$$

and thus, in the limit of an undepleted pump, we have

$$\begin{aligned}\overline{a}_{Rk_1}^\dagger(t) &= a_{Rk_1}^\dagger + \frac{2}{i\hbar}\int dk_2 dk\left[\int_{t_1}^{t_0} dt\, S_{L;RR}(k,k_1,k_2;t)\right]\overline{b}_{Lk}^\dagger\overline{a}_{Rk_2} \\ &= a_{Rk_1}^\dagger + \frac{4\pi i}{\hbar}\int dk_2 dk S_{L;RR}(k,k_1,k_2)b_{Lk}^\dagger a_{Rk_2}\delta(\omega_{Lk} - \omega_{Rk_1} - \omega_{Rk_2}),\end{aligned}$$

where we have extended the range of integration from $t_0 \to -\infty$ to $t_1 \to \infty$.

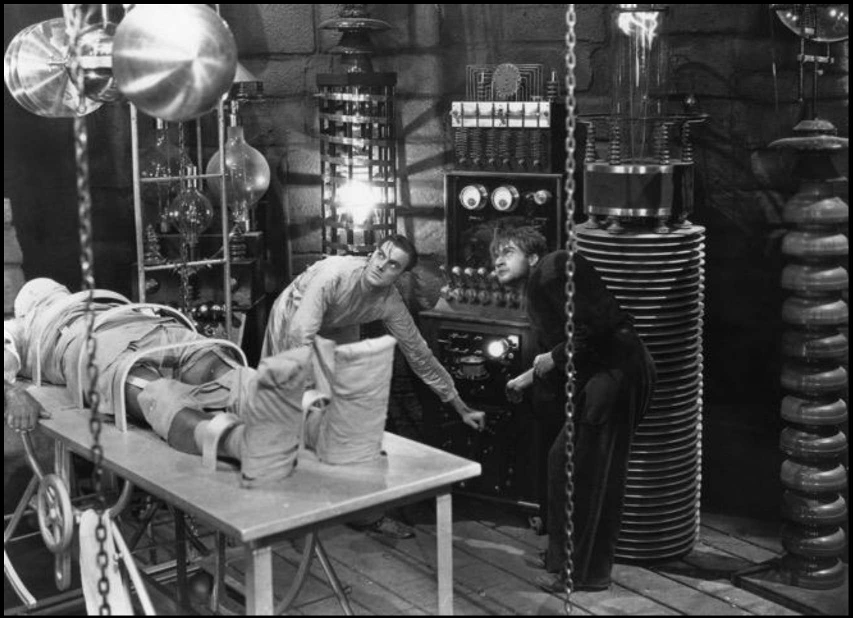
In writing the final form of the asymptotic-out ket, there is an additional subtlety that arises for SHG compared to SPDC

Then, neglecting the higher-order terms mentioned above, as they either contain higher powers of the (assumed small) nonlinearity or involve back-action on the pump (and thus violate the undepleted pump approximation), we can write the

da solo…

…o in piccoli gruppi

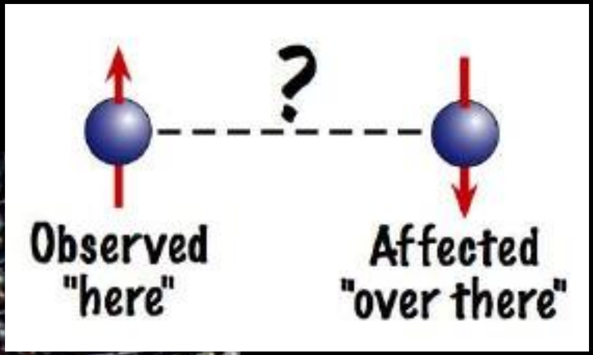
Interagendo con gruppi sperimentali



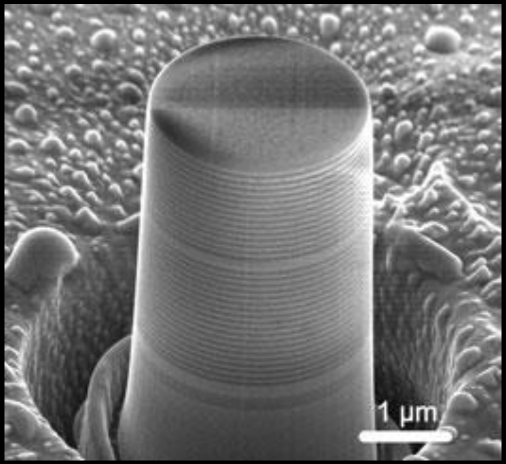
Take-home messages

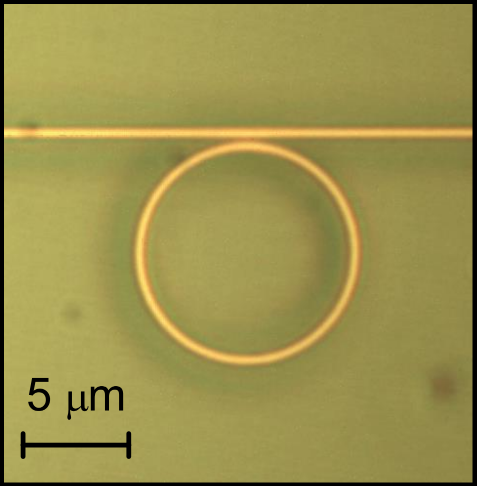
1. La fotonica è <u>sviluppo tecnologico</u>

2. La fotonica è studio della fisica fondamentale



3. Il futuro della fotonica è nelle nanotecnologie.





4. La fotonica è come l'aria

Grazie per la vostra attenzione!