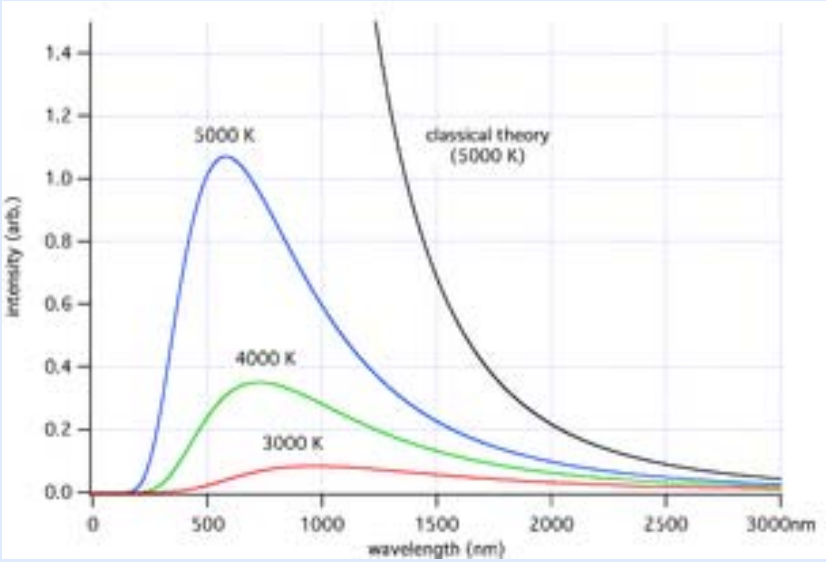
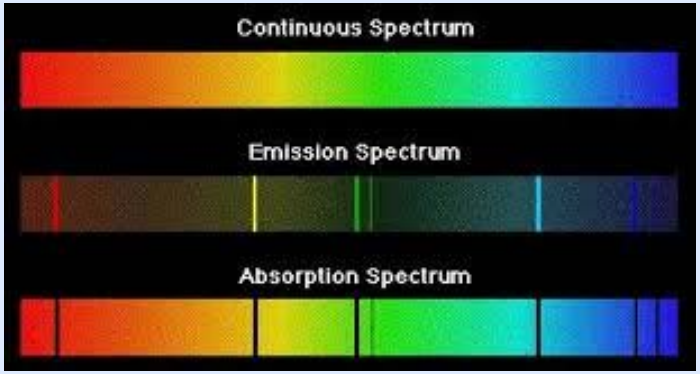
Birth of Quantum Physics
(Early 1900's – big mysteries!)

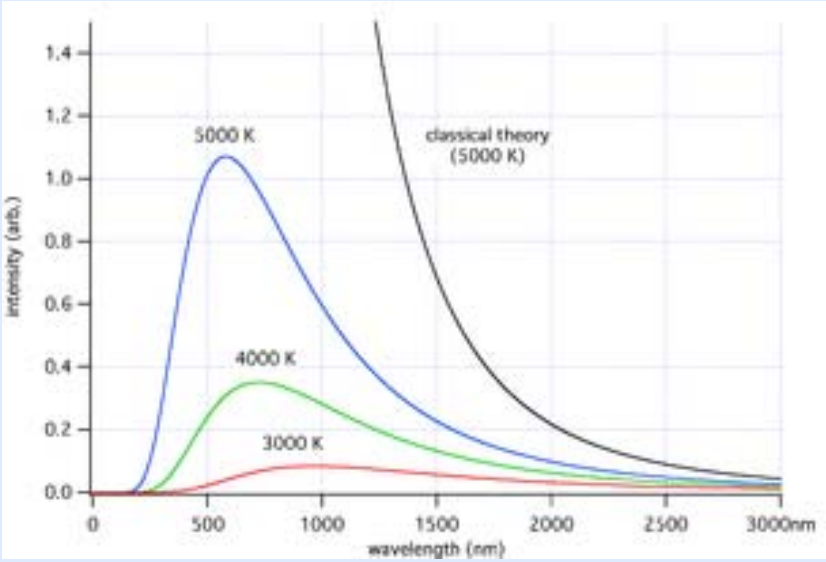




Blackbody radiation
Pure Electromagnetic theory suffered 'Ultraviolet catastrophe'

Each element has its fingerprint spectrum! Light from stars and more.

Birth of Quantum Physics
(Early 1900's)



Blackbody radiation
Pure Electromagnetic theory
suffered 'Ultraviolet catastrophe'

Max Planck
(1858-1947)

Radiated light can only have discrete amounts of energy that depend on frequency

Planck relation

$$E = h \times f$$

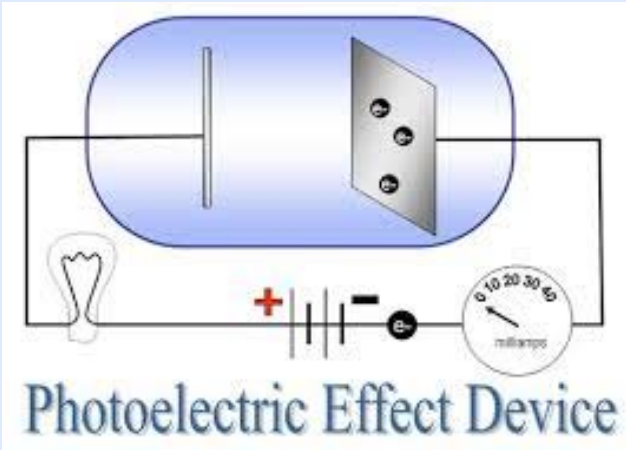
Energy of a photon

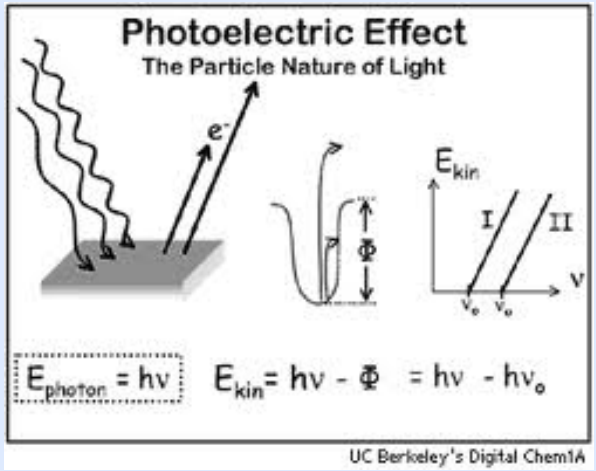
f – frequency (Hz; per sec)
h – Planck's constant
6.6×10^{-34} Joules-sec
4.1×10^{-15} eV-sec

Also recall: $c = L \times f$

Speed of light - c: 3×10^8 meters/sec

Photoelectric effect

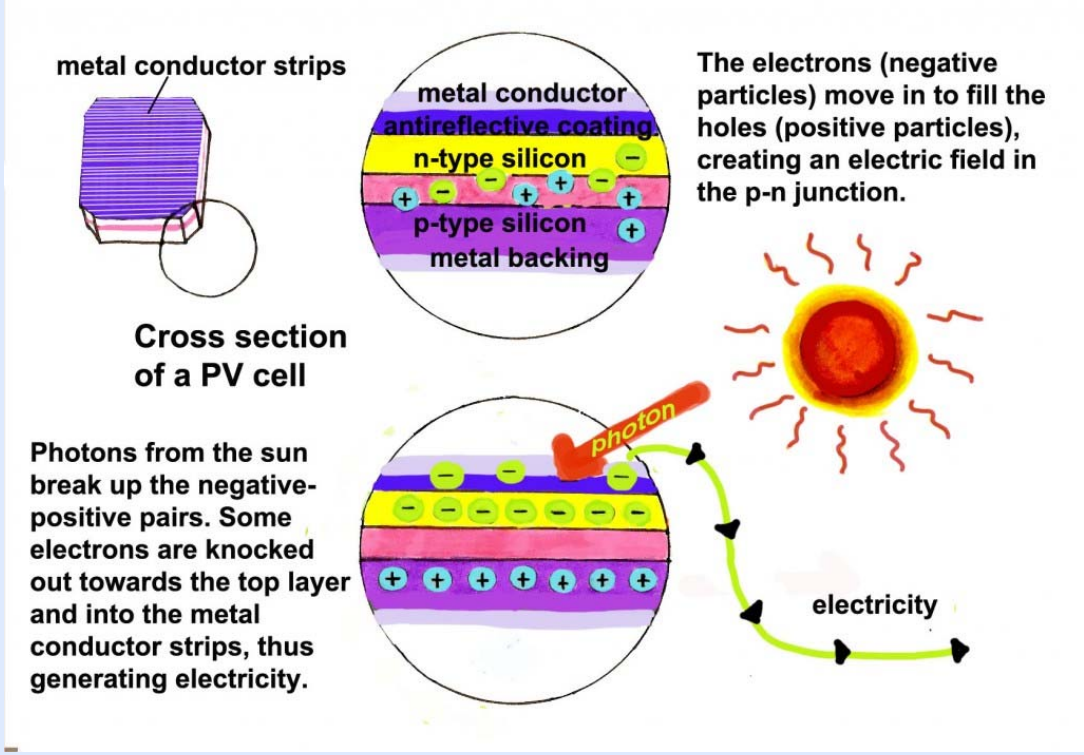




Einstein, Nobel Prize, 1921

Photoelectric effect

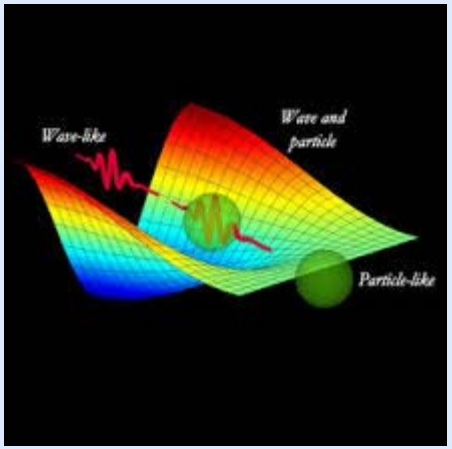
Solar Cell
or Photovoltaic Cell (PV)

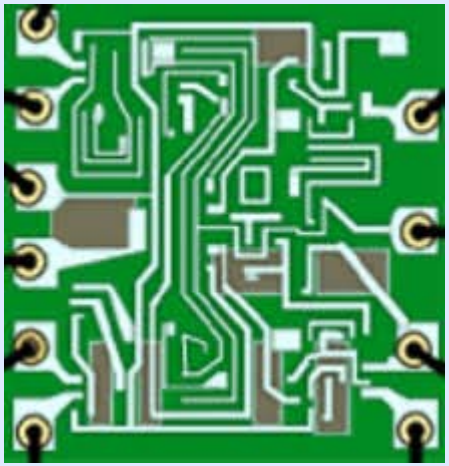


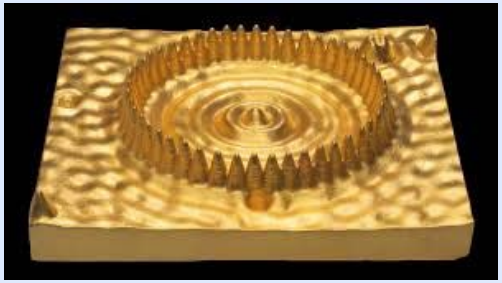
Used in solar panels; Converts light to electricity

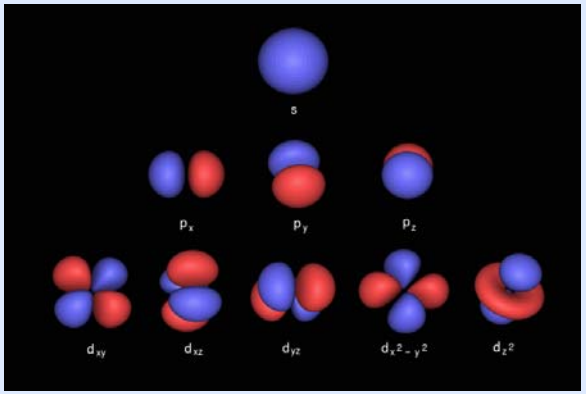
[Juno Solar Panels]
[Juno NASA]

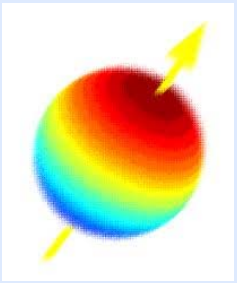
Quantum Revolution!!!



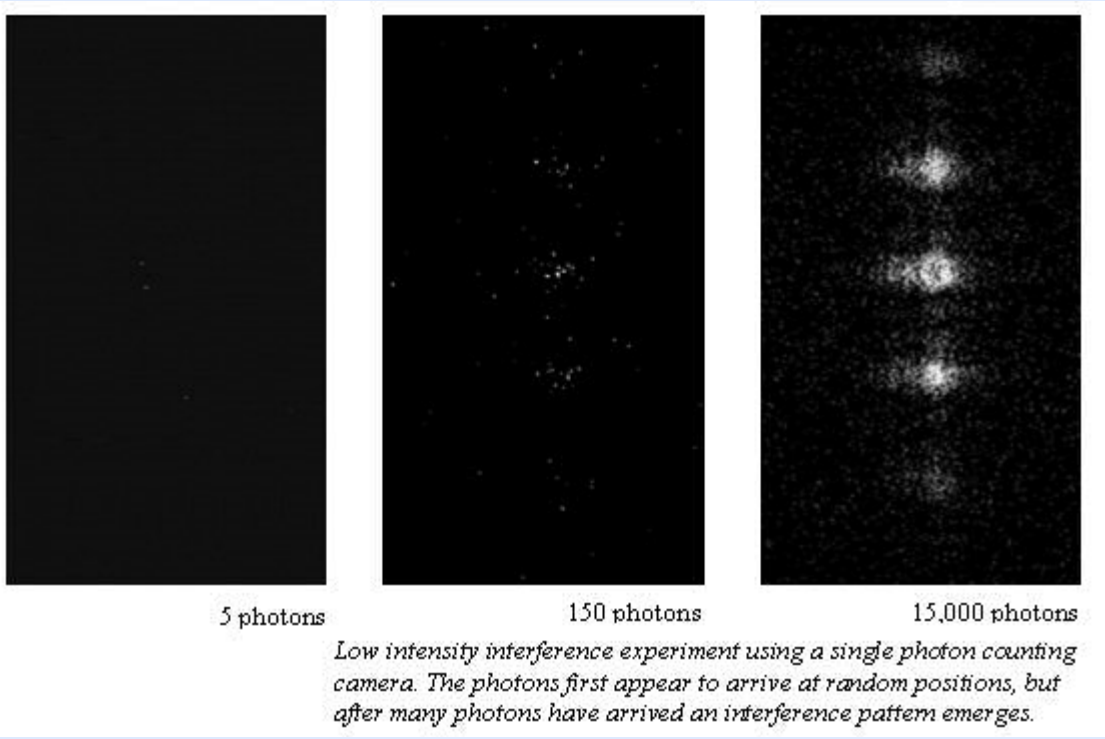








Particle or wave?



Low intensity interference experiment using a single photon counting camera. The photons first appear to arrive at random positions, but after many photons have arrived an interference pattern emerges.

E.g. Wave interference and Photon imaging

It depends!
(always one or another)

Two-slit interference

i>clicker question

Green colored photons have a frequency of about 6×10^{14} Hz. What energy does each of these photons have?

A. 6.3 meV
B. 2.46 eV
C. 2.46 keV
D. 6.3 MeV

$E = hf$
h – Planck's constant
6.6×10^{-34} Joules-sec
4.1×10^{-15} eV-sec
$c = Lf$
$= 3\times10^{8}$ meters/sec

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Green colored photons have a frequency of about 6×10^{14} Hz. What energy does each of these photons have?

A. 6.3 meV

B. 2.46 eV – Use Planck's relation

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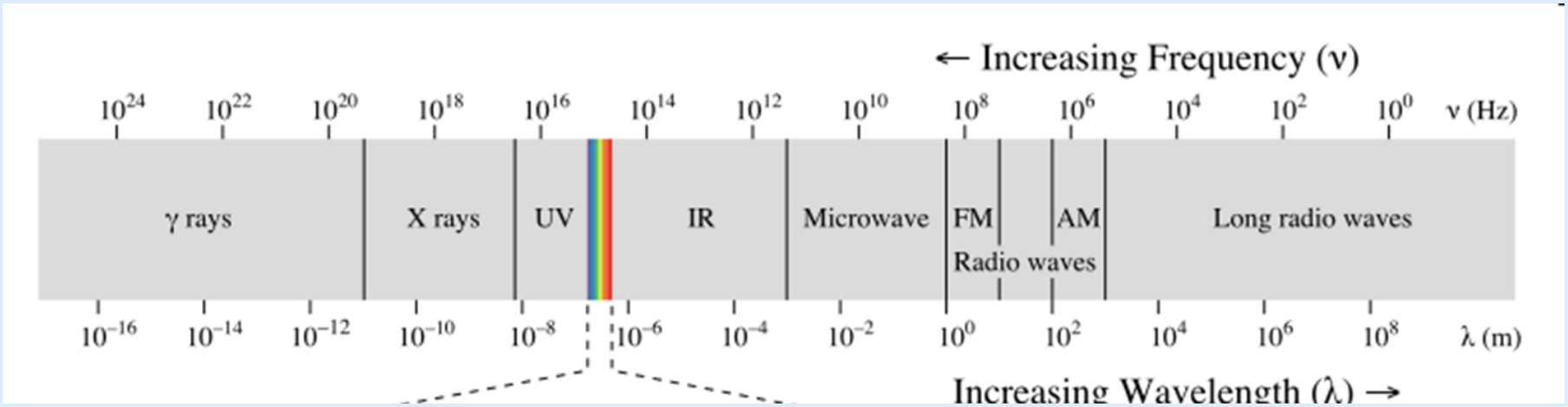
i>clicker question

About how much more energy does a gamma ray photon have compared to a green photon?

A. 0.0001times or less
B. 1-100 times
C. 100-1000 times
D. 100,000 times or much more



i>clicker question

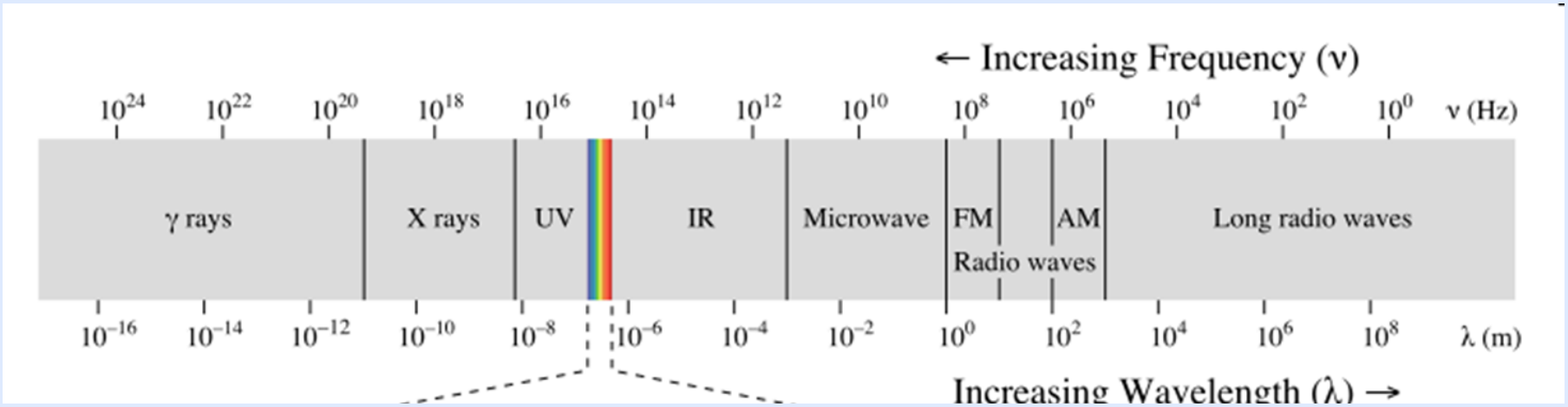
About how much more energy does a gamma ray photon have compared to a green photon?

A. 0.0001times or less

B. 1-100 times

C. 100-1000 times

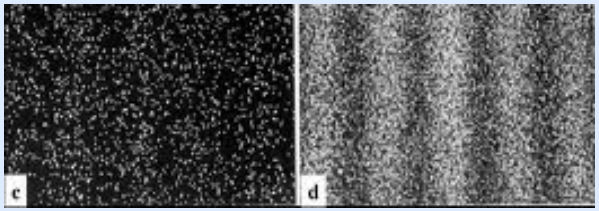
D. 100,000 times or much more: E = hf, proportional to freq.; nuclear decay – few MeV



Probability and chance in the deepest sense

Wave of probability!!

Particle is in a 'superposition' of many places at once….until….it is observed!



Science no longer is in the position of observer of nature, but rather recognizes itself as part of the interplay between man and nature. The scientific method ... changes and transforms its object: the procedure can no longer keep its distance from the object.

- Heisenberg

I like to think the moon is there even if I am not looking at it.

- Einstein

Anyone not shocked by quantum mechanics has not yet understood it.

- Bohr

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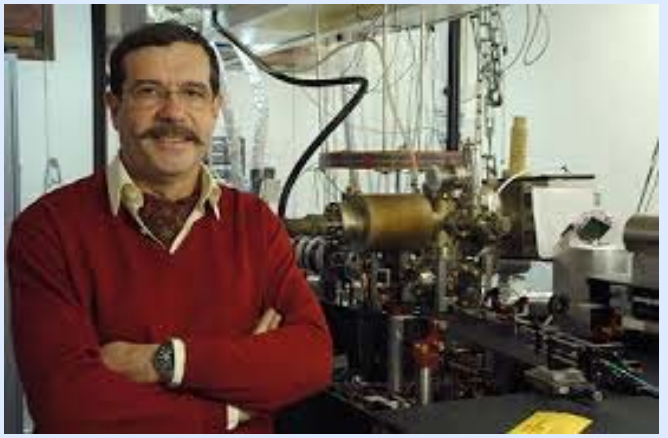
B.P. 147, 91403 Orsay Cedex

DUALITÉ ONDE-PARTICULE POUR UN PHOTON UNIQUE (*)

A. ASPECT, P. GRANGIER, G. ROGER



J. Optics (Paris), 1989, vol. *20*, n° 3

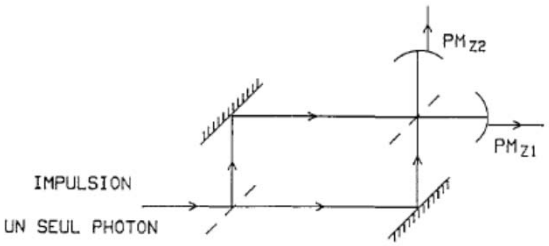


FIG. 5. — *Interféromètre de Mach-Zehnder. Les photomultiplicateurs PM_{z_1} et PM_{z_2} sont validés par les portes w, comme sur la figure 2, pour isoler les impulsions à un seul photon. La différence de marche δ est contrôlée par le déplacement des miroirs.*

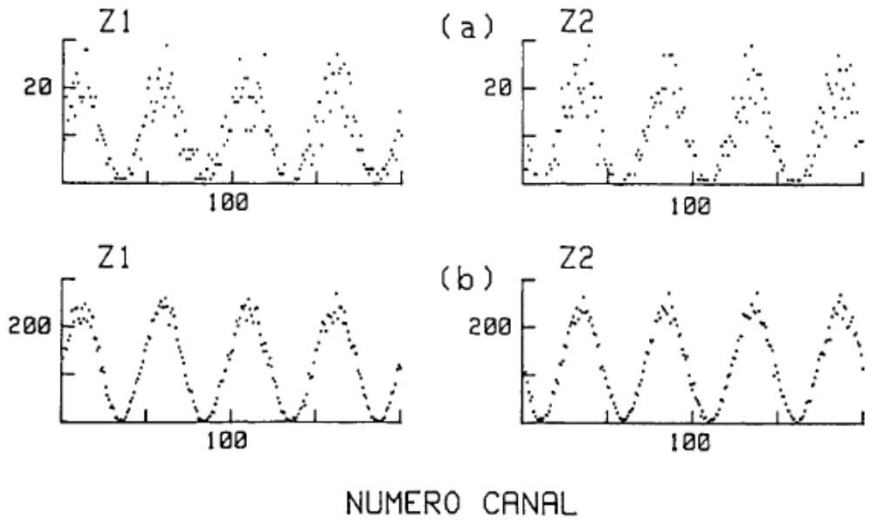
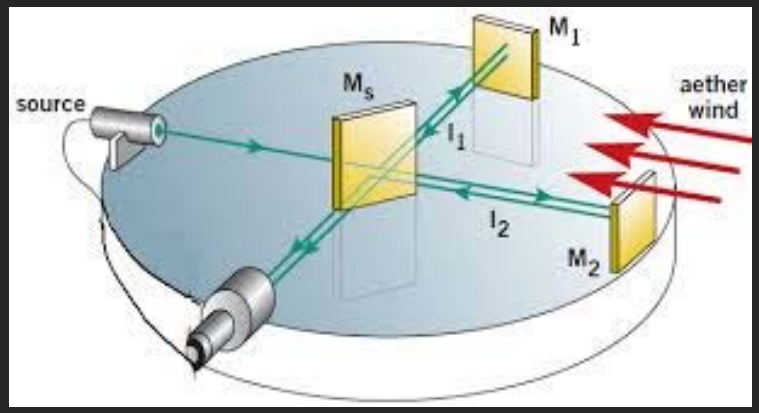
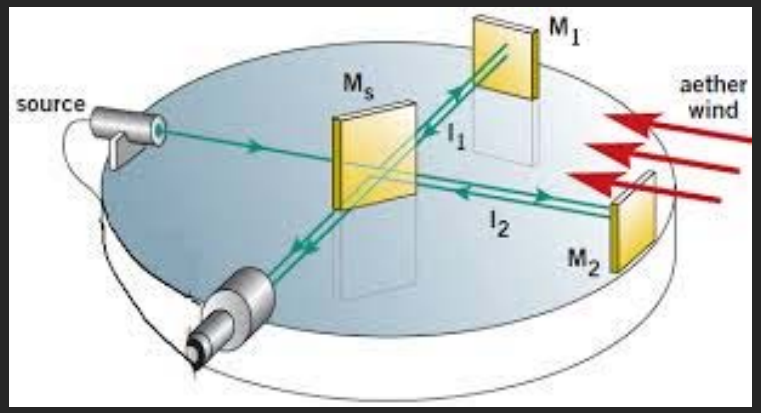


FIG. 6. — *Nombre de coups validés dans les sorties complémentaires z_1 et z_2, en fonction de la différence de marche δ (1 canal = λ/50) : (a) durée de comptage = 1 s/canal ; (b) durée de comptage = 15 s/canal. Source dans le régime à un seul photon ($w\mathcal{N}_e$ correspondant à $\alpha = 0{,}18$).*

Michelson-Morley Interferometer & variants

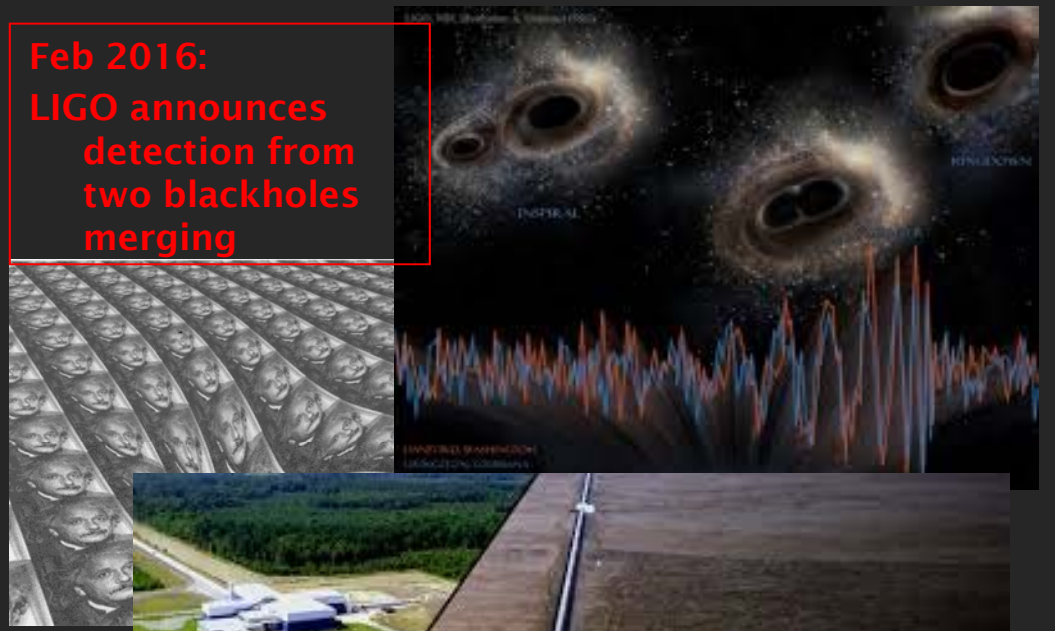


Michelson-Morley Interferometer & variants



Feb 2016:

LIGO announces detection from two blackholes merging



Space-time curvature and ripples

Gravitational Waves!!!!

If light can behave as a particle….

1924, PhD thesis