PHOTONICS FOR QUANTUM

SPIE. RIT Rochester Institute of Technology

Paper # SPIE 12243-3

Understanding the *physical processes* behind the photoelectric current pulse (PCP) statistics and designing better sources

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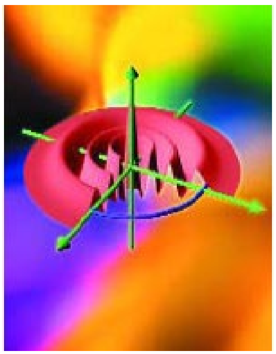
Download papers of CR from: http://www.natureoflight.org/CP/

Starting from 2003, the speaker has been promoting forums on: “What is a photon?”

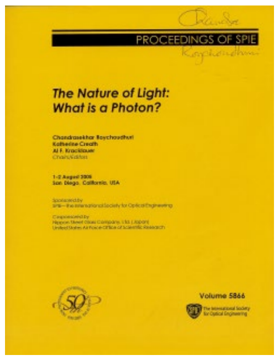
2003



Optics & Photonics News

Special Issue; October 2003:

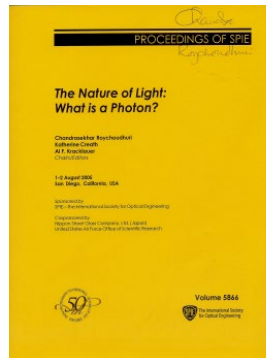
2005-2015



SPIE – Annual Conf.

Biennial conference series.

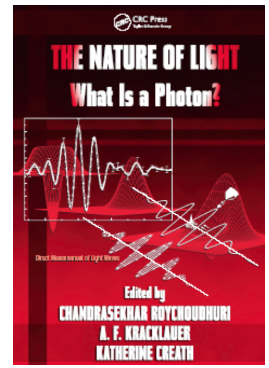
2010-2019



SPIE Photonics West

Annual evening workshop series

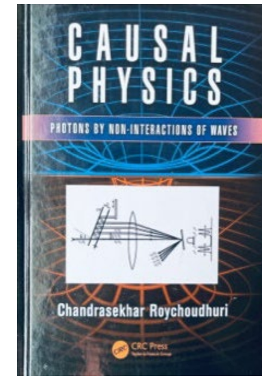
2008



CRC **What is a Photon?**

Edited book

2014



Taylor & Francis. Single author book.

Summary of the talk

We are proposing a semi-classical model of light as exponential pulses and then suggest the use of a high finesse Fabry-Perot etalon to generate relatively smoother amplitude and phase stable light suitable to obtain sub-Poissonian photoelectric current pulse (PCP) statistics.

Outline

1. The challenges: (i) "What is a photon?"- is still a lingering issue. (ii) A deeper understanding should open up possibilities of inventing simpler source-solutions to "Quantum for Photonics".
2. We suggest a semiclassical structure of photon – all atom/molecule emitted light propagate as classical pulses. So the superposition phenomena is more important than the "bullet photon" model can imply.
3. Maxwell and Schrodinger equations also imply need to incorporate Superposition Principle in Einstein's photoelectric equation.
4. Understanding the origin of spatial & temporal granularity in photo detection data.
5. We use the proposed semi-classical photon model to generate the temporal "granularity" in photoelectric current pulses (PCP), which are amplitude & phase fluctuations between the photon pulses.
6. Recognizing the amplitude and phase smoothing power of Fabry-Perot etalons, which can carry out the classical Superposition Effect on replicated pulses that they generate.
7. Proposed experiments to test the PCP smoothing capability of Fabry-Perot etalons.

Enhanced model of light

History

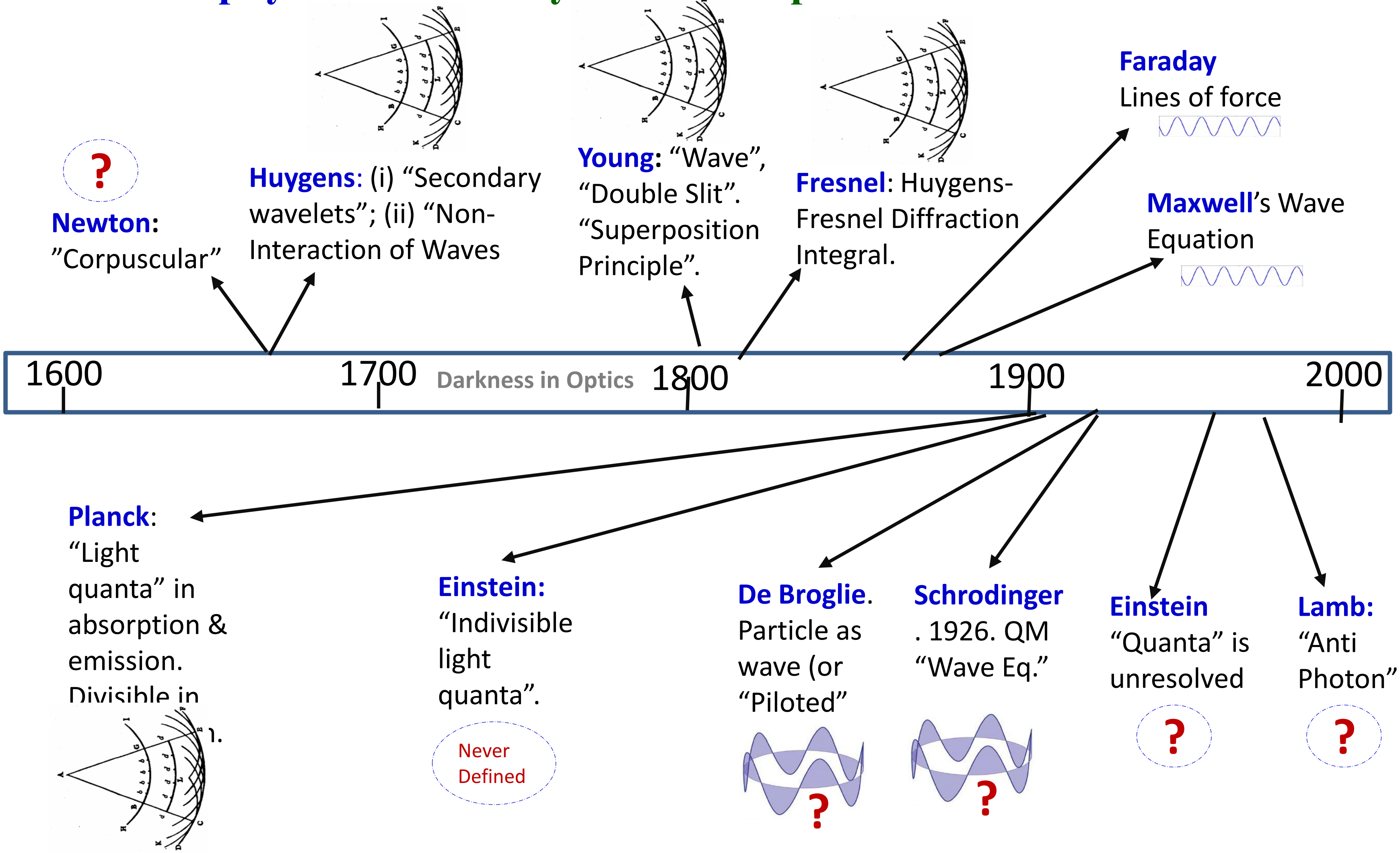
- The continuing "Wave-Particle Duality" (WPD) represents our ignorance about the deeper structures of light and particles. We should not accept WPD as a confirmed limit of finding any more newer or better knowledge.
- The WPD debate started during the third quarter of 1600 between Newton ("corpuscular") and Huygens (expanding spherical wavelets). Newton articulated that they could not resolve the WPD-debate because of the prevailing limited knowledge about light. Physics has advanced significantly since 1600; however, even today we cannot unambiguously describe what a "photon" is. Even Einstein recanted his model of "indivisible light quanta" model by early 1950's.
- We have become very comfortable using the word "photon", however, QM has not given us better mathematical alternatives to either the Huygens-Fresnel Diffraction Integral (HF-DI) of 1817, or the set of Maxwell's wave equation of 1876, which together have been leading the persistent advancements in classical optical science and engineering, the latest fields being Nanophotonics, Plasmonic Photonics and Meta Materials.

Model

The Model of light: Light emitted by atoms/molecules are classical *exponential pulse* of energy "hν", with the QM predicted carrier frequency "ν" and perpetually propagating out following Maxwell's wave equation, while diffracting as demanded by the HF-DI. Natural linewidth of all spontaneous emissions are Lorentzian, which is the Fourier transform of an exponential pulse, happen to be the time integrated response of classical spectrometers.

In emission, this proposition unifies Newton's postulate of "corpuscular" light and fold that in under Planck's "light quantum" along with Schrodinger's Quantum Mechanics of discrete level transition. ***In propagation***, it automatically obeys Maxwell's wave equation (velocity "c"; not derived by QM), while perpetually diffracting by obeying HF-DI, framed using the Huygens' model of "secondary spherical wavelet". These two equations also tell us that, in the linear domain, and in the absence of frequency-responsive interacting materials, light waves do not interact with each other. We call this ***Non-Interaction of Waves***, or NIW.

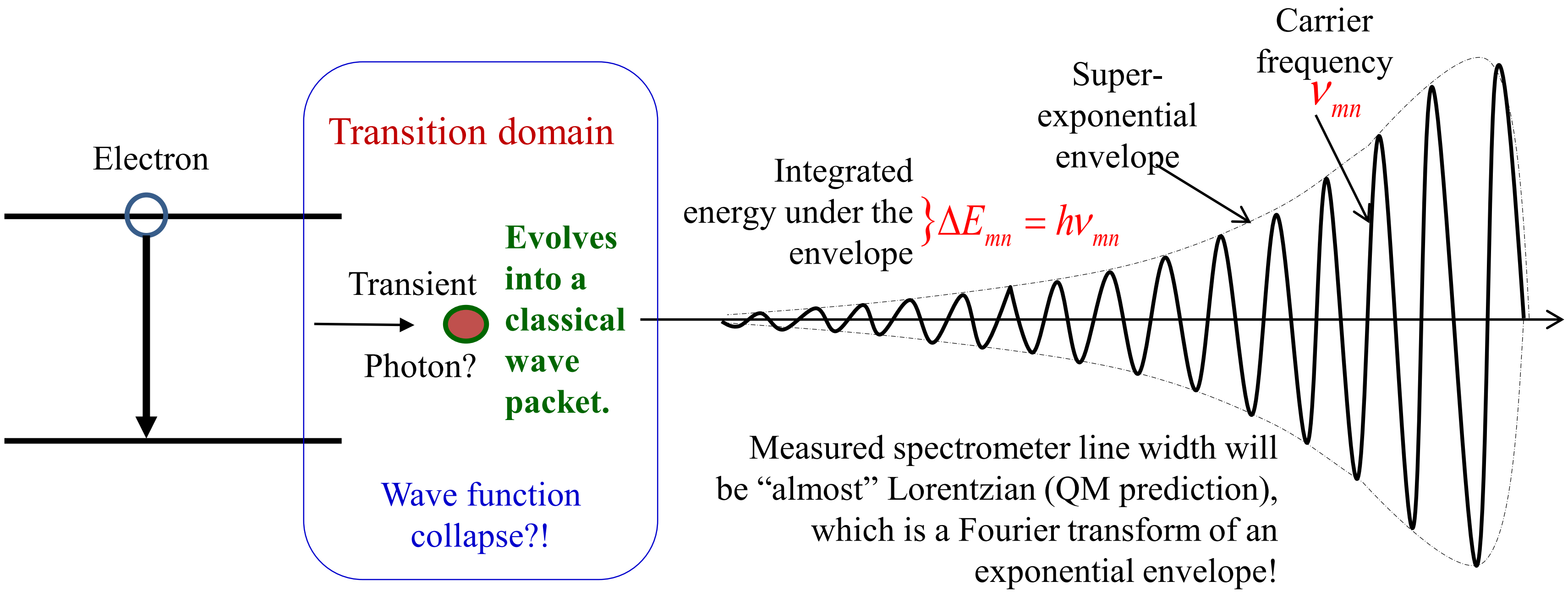
While Wave-Particle Duality is continuing, all the working equations in physics are directly waves or represent harmonic oscillations



K. Hentschel, [Photons: The History and Mental Models of Light Quanta}. Springer, 2018.
C. Roychoudhuri, "Cosmic Ether, Possessing Electric-Tension & Magnetic-Resistance, Is the Unified Field for Physics", J. Mod. Phys, 2021, 12, 671-699. https://www.scirp.org/journal/paperinformation.aspx?paperid=108837

The Hybrid Photon:

Harmonically unifies the basic postulates of Newton, Huygens, Maxwell, Planck, Lorentz and Schrödinger.



All lights emitted by atoms and molecules are Newtonian pulses, but propagate as Huygens "secondary wavelets" while remaining as independent pulses following his postulate of Non-Interaction of Waves (NIW).

1. C. Roychoudhuri and N. Tirfessa, Proc. SPIE Vol.6372-29 (2006), "Do we count indivisible photons or discrete quantum events experienced by detectors?"
2. C. Roychoudhuri, See Ch.5 for theory of pulsed light spectrometry in "Causal Physics: Photon Modell by Non-Interaction of Waves; CRC, 20014.

Both the Maxwell's EM wave & the Schrödinger's 'quantum-particle' equations are linear differential equations. Their solutions are "oscillating amplitudes", which obey the Superposition Principle.

Maxwell
$$\frac{\partial^2 E(x,t)}{\partial t^2} = \frac{1}{\varepsilon\mu}\frac{\partial^2 E(x,t)}{\partial x^2} \equiv c^2 \frac{\partial^2 E(x,t)}{\partial x^2}$$

Schrodinger
$$\frac{\partial \psi(x,t)}{\partial t} = \frac{i\hbar}{2m}\frac{\partial^2 \psi(x,t)}{\partial x^2} + \frac{1}{i\hbar}V(x,t)\psi(x,t)$$

Energy exchange via "Bullet photon" is not allowed by these two most successful equations of physics!

Pay attention the two-step stimulation processes.

EM waves move perpetually leveraging the built-in electric and magnetic tensions $\varepsilon \,\&\, \mu$. However, Schrodinger's particles can move only under the influence of a separate potential gradient, V(x).

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Interaction Process Mapping Thinking (IPM-T)

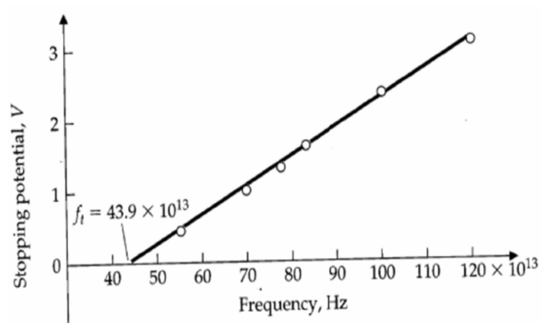
However, the measurable physical transformation, or the Superposition Effect (SE), can materialize only after the energy exchanging square-modulus operation is executed by the amplitude-stimulated dipole.

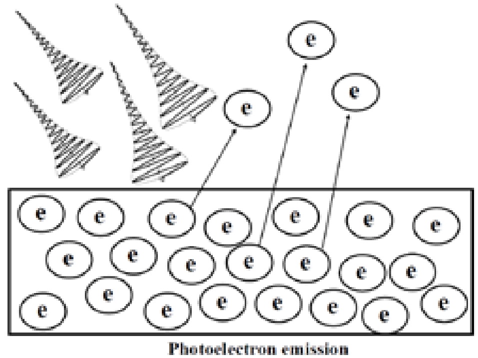
$$|\psi_{res.}(t)|^2 = \left|\sum_q \chi(\nu_q) E(\nu_q, t)\right|^2$$

Light-matter amplitude-amplitude stimulation must precede before the square-mod. energy transfer can take place.

Light-matter quantum interaction is a two-step process: (i) Frequency-compatible amplitude-amplitude stimulation, followed by (ii) the quadratic step of energy exchange. These two successful theories clearly dictate that light as "energy bullets" cannot facilitate energy exchange!

Einstein's energy-balancing photoelectric equation requires semi-classical re-modeling to accommodate amplitude and phase fluctuations of wave packets of light





$$h\nu = \phi_{work\ fn.} + (1/2)mv_{el.}^2$$

It only models the measured CLASSICAL kinetic energy of electrons released in the free space. The threshold frequency relates to quantum mechanically bound electron inside the material.

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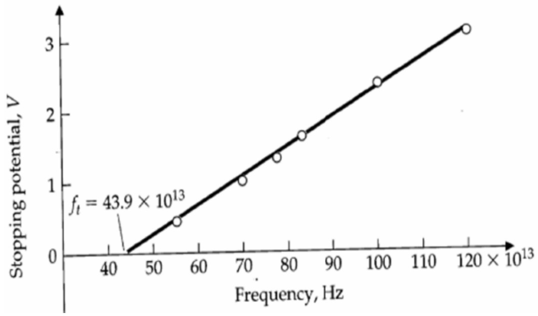

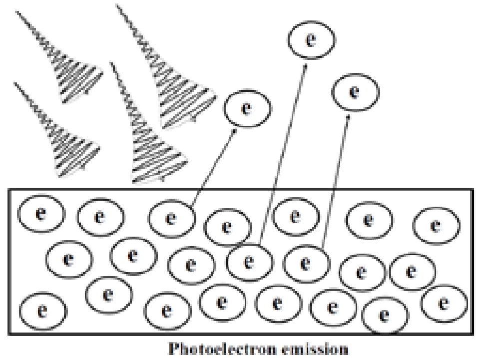

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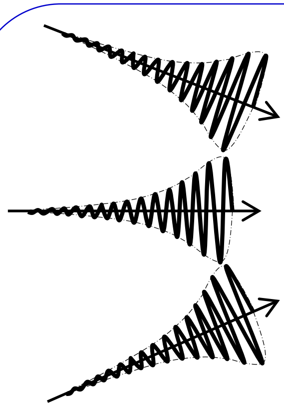
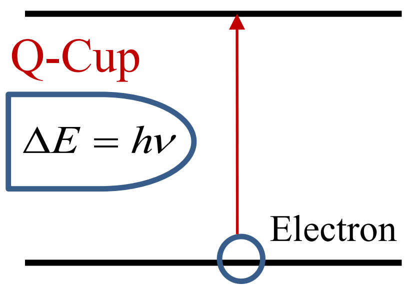
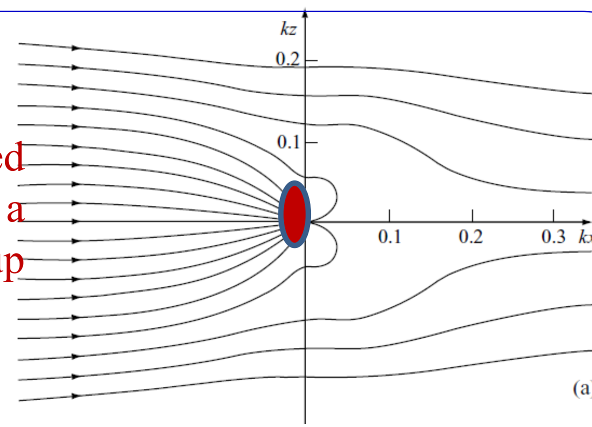




Diffractively spreading multiple wave packets fill up the Quantum Cup to help the upward transition.

Stimulated dipole as a Q-Cup

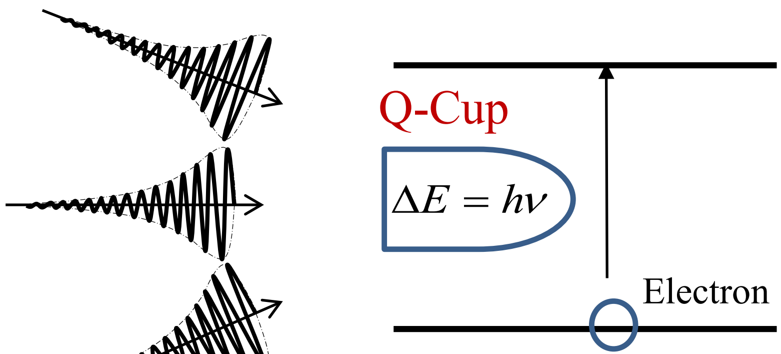


See p.53 in *Introduction to Quantum Optics*, *by* H. Paul, Cambridge U. Press, 2004..

$$\left\langle \left|\psi_{res.}(t)\right|^2 \right\rangle = \left\langle \left| \sum_q \chi(\nu_q) E(\nu_q, t) \right|^2 \right\rangle \Rightarrow \left\langle h\nu_q \right\rangle = \left\langle \phi_{work\ fn.} + (1/2)mv_{el.}^2 \right\rangle$$

There are many rigorous treatments of semi-classical photoelectric effect, starting with Lamb and Scully.

There is a field-dipole “Push-Pull” interaction process



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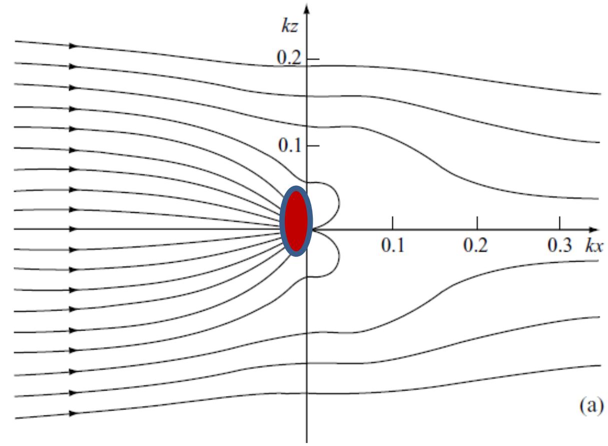
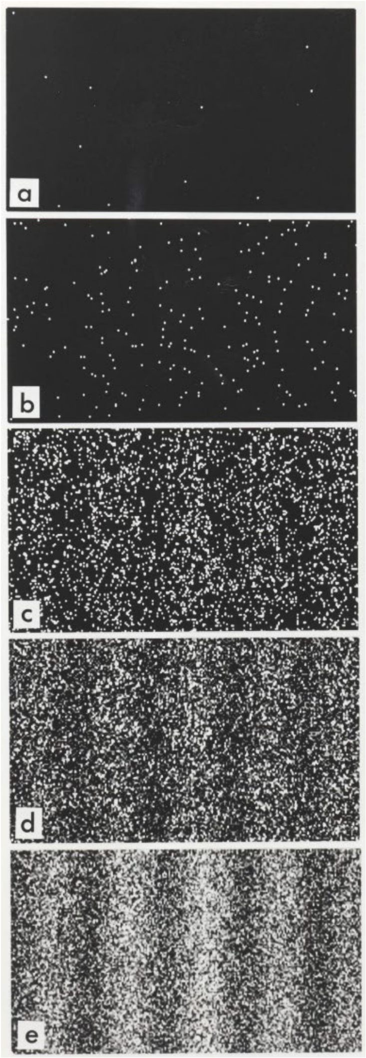


See p.53 in *Introduction to Quantum Optics, by* H. Paul, Cambridge U. Press, 2004..

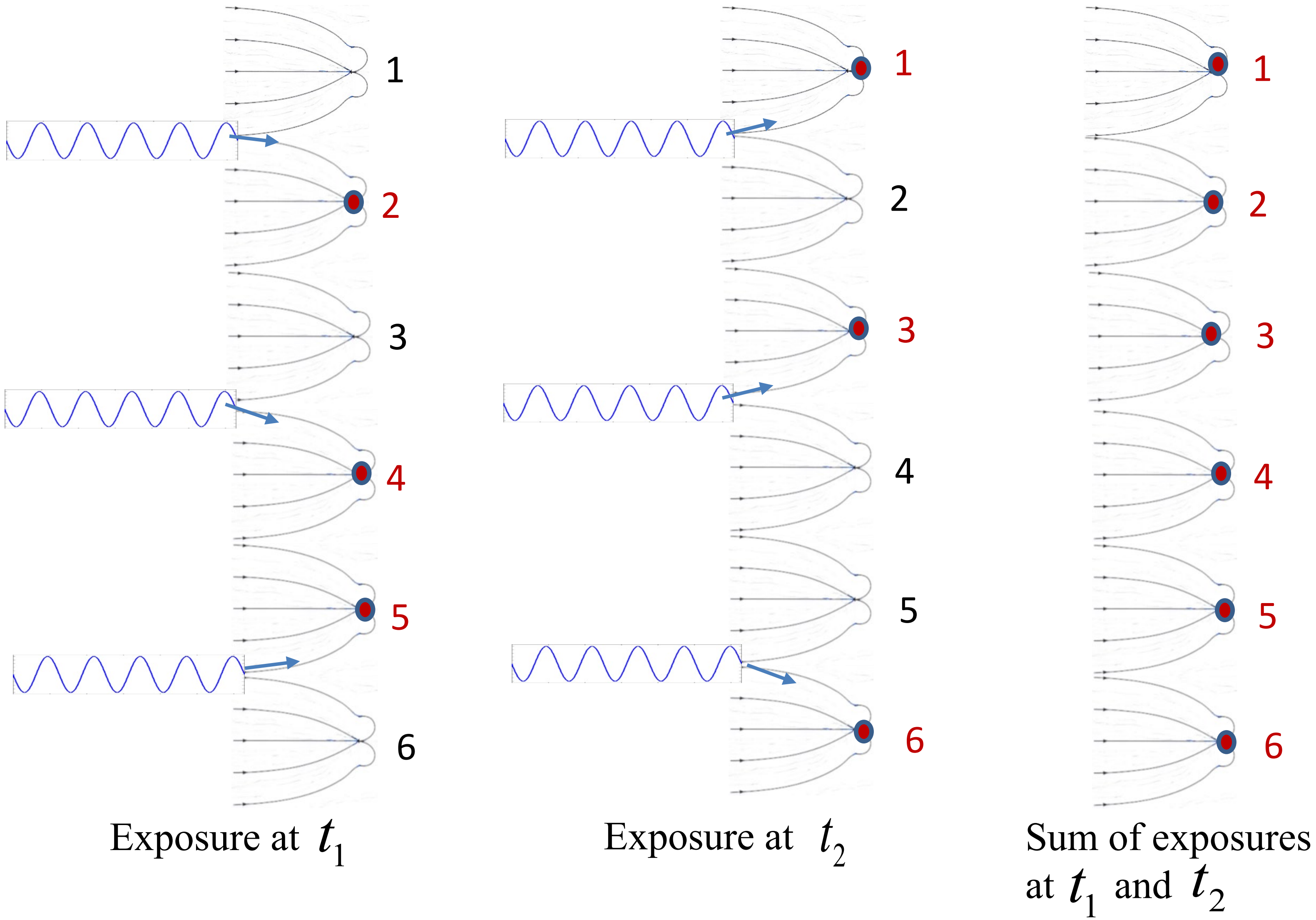
- Once stimulated by EM waves, the dipole facilitates the convergence of EM field energy. There is a **push** (by the field) and **pull** (by the dipole) during the interaction. Energy is collected out of a very large volume compared to the atomic volume of ~ one cubic Angstrom.
- A propagating electromagnetic wave packet cannot deliver all its energy instantly; or at a rate faster than its finite velocity c or c/n. The “**Push-Pull**” interaction still assures energy absorption in the Femto second domain.

Spatial granularity lies with the micro-granular structure of the detector array with resonant quantum dipoles.

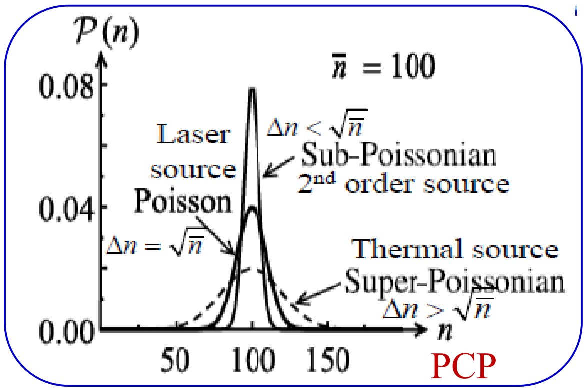


1. Both the photographic (Ag-Halide crystallites) plate and the modern CCD array have granular structure to create high resolution pictures. They are frequency sensitive quantum detectors. All sufficiently enlarged pictures will show granularity. Both of their physics of exposure process is quantum mechanical. E-vector frequency determines the exposure potential.
2. As the flux or the rate of energy flow of light gets very low, the probability of energy availability per pixel gets reduced. Consequently, a longer period of exposure is required to get higher density of pixels getting exposed. There is also "push-pull" effect from field to dipole (detector) energy transfer [Ref.1]. A resonant dipole can absorb energy out of the field of an area very much larger than its physical size, thus robbing energy from the neighboring pixels at low flux.
3. The "bullet photon" & the "single photon interference" postulates completely defy the physics of EM wave propagation, the very foundation of Optical science and engineering, without developing any alternate analytical model to replace them. Particles move under the influence of four known forces. EM waves propagate perpetually across the entire universe leveraging Maxwell's ether.

Second reason for the appearance of granularity with continued exposure.
At very low light level, the dipolar quantum cups out-compete neighbors for energy

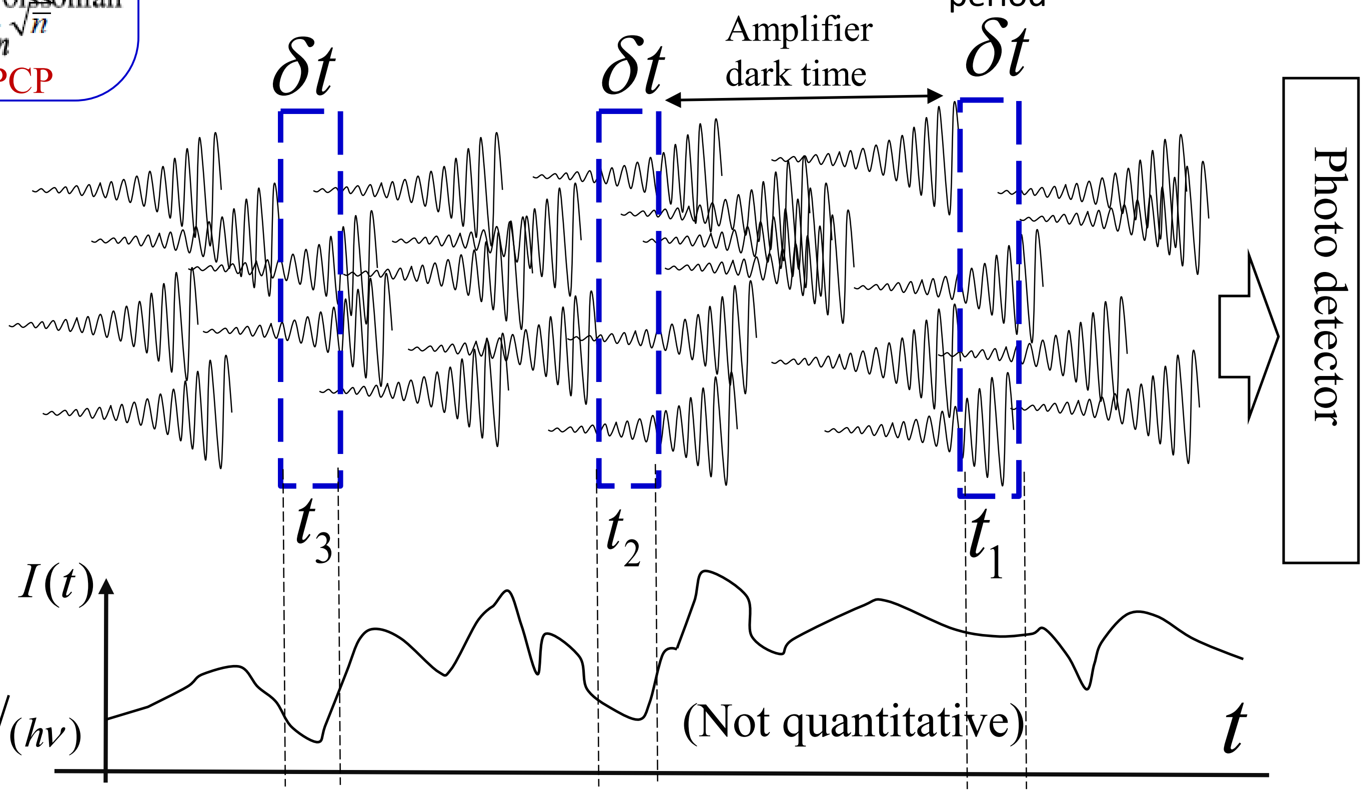


Temporal granularity in the photoelectron release lies with the pulsed nature of all light as they bring time fluctuating amplitudes and phases as they stimulate the amplitudes of the detecting dipole holding the would-be photoelectron



From the book by Fox

Random semi-classical collimated "photon" beam

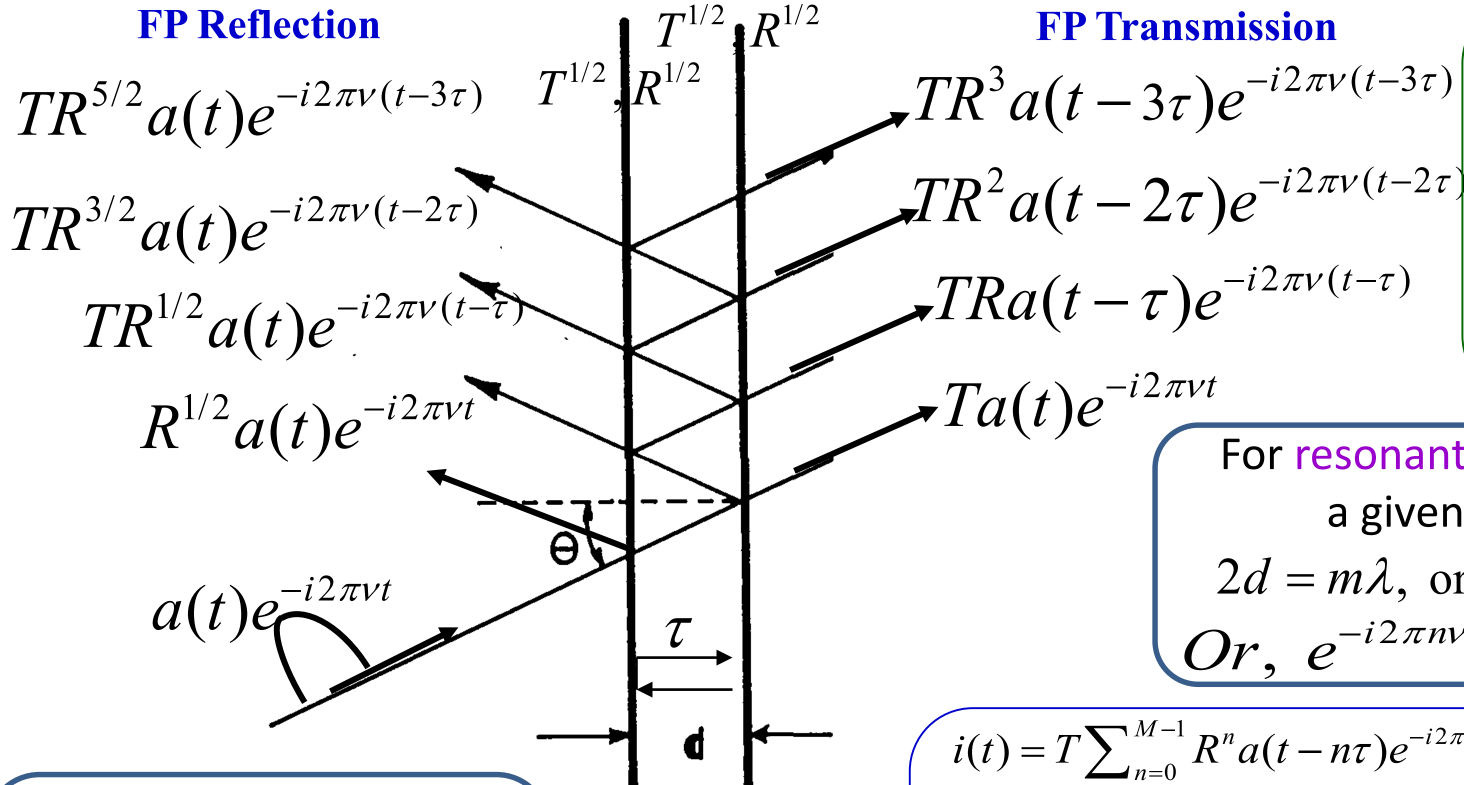


"PCP" number:

$$N \sim \int_{\delta t} I(t)dt \big/ (h\nu)$$

Managing light pulses & smoothing out the amplitude and the phase fluctuations

A pair of parallel reflectors replicates an input pulse into an infinite train of periodic pulses



When the wave Poynting vectors are exactly collinear, the boundary layers actively re-directs the energy of all the superposed amplitudes.

For resonant transmission for a given frequency:

$$2d = m\lambda, \text{ or, } \nu\tau = m \text{ (integer)}$$

$$Or, \; e^{-i2\pi n\nu\tau} = e^{-i2\pi n'} = 1$$

$\tau = 2d/c$
Our case:
$\theta = 0$

$T^{1/2}, R^{1/2}$
Light-matter interaction is via amplitudes. But we can only measure energy, or intensity.

$$i(t) = T\sum_{n=0}^{M-1} R^n a(t-n\tau)e^{-i2\pi\nu(t-n\tau)}$$
$$= Te^{-i2\pi\nu t}\sum_{n=0}^{M-1} R^n a(t-n\tau)$$
$$= Te^{-i2\pi\nu t}\sum_{n=0}^{M-1} R^n e^{-(t-n\tau)/t_0}$$

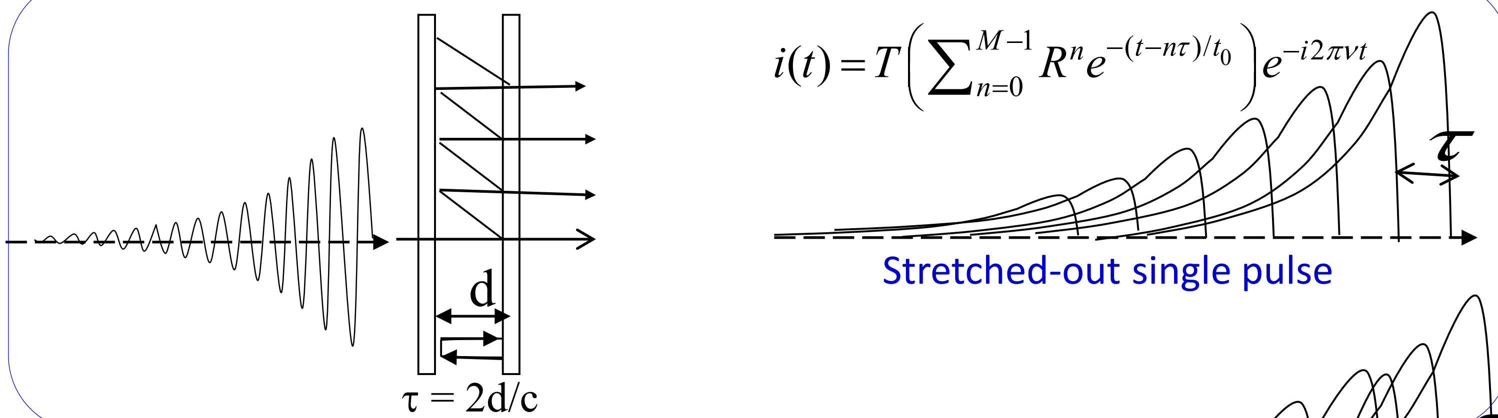
Final stretched amplitude is simply the summation of the train of the reduced-amplitude exponential pulses!

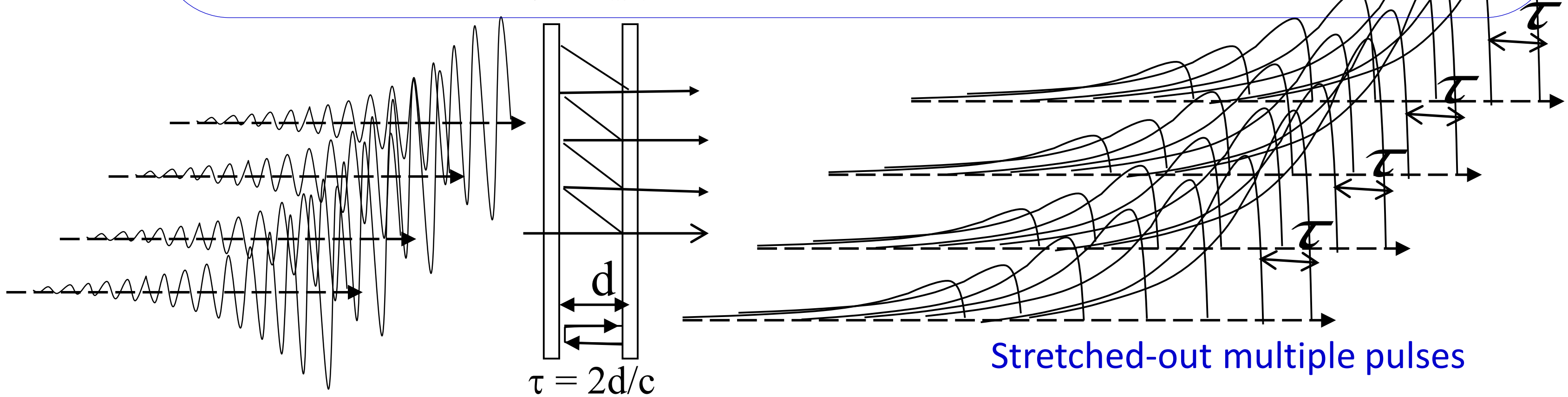
Cartoon-view of amplitude stretching and smoothing of pulsed light

The Fabry-Perot is in the resonant transmission mode for a given frequency:

$$2d = m\lambda, \text{ or } \nu\tau = m \text{ (integer)} \quad M \sim M_{Finesse} = \pi\sqrt{R}/(1-R)$$

$$i(t) = T\left(\sum_{n=0}^{M-1} R^n e^{-(t-n\tau)/t_0}\right)e^{-i2\pi\nu t} \Rightarrow I(t) = |i(t)|^2 = T^2\left(\sum_{n=0}^{M-1} R^n e^{-(t-n\tau)/t_0}\right)^2$$

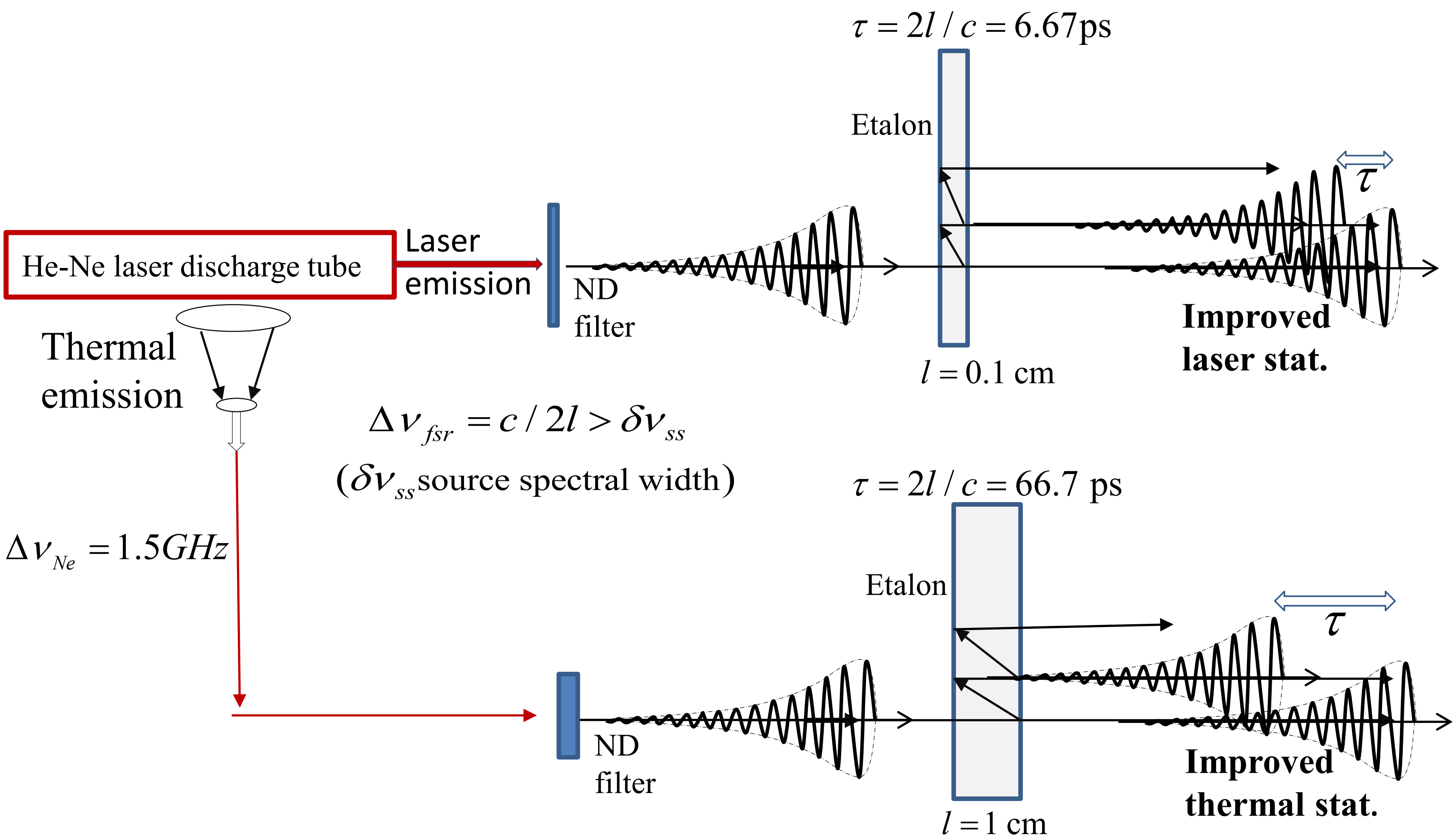


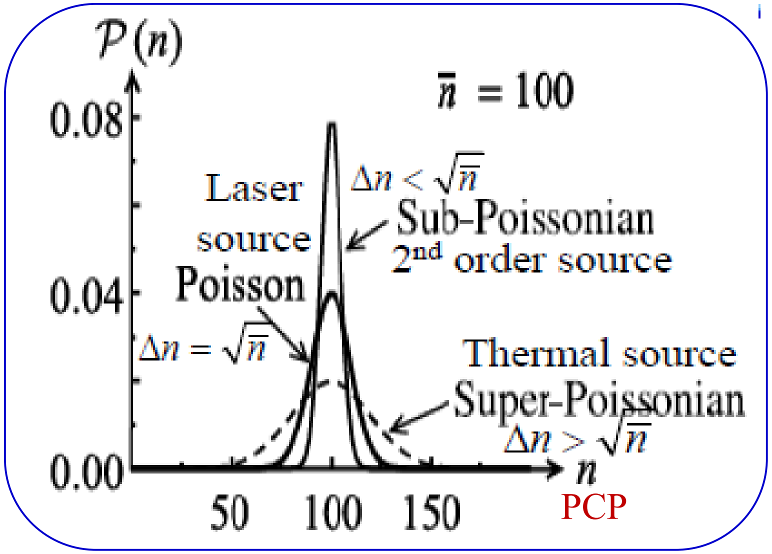


C. Roychoudhuri, "Response of Fabry-Perot interferometers to light pulses of very short duration", J. Opt. Soc. Am. V.65 (12), pp.1418-26 (1975). See also Ch.5 of R1

Validating the concept

Demonstrating the improved PCP statistics





$\mathcal{P}(n)$
$\bar{n} = 100$
0.08
0.04
0.00
Laser
source
Poisson
$\Delta n = \sqrt{\bar{n}}$
$\Delta n < \sqrt{\bar{n}}$
Sub-Poissonian
2nd order source
Thermal source
Super-Poissonian
$\Delta n > \sqrt{\bar{n}}$
n
50
100
150
PCP

Some Useful References

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Conclusions

1. We believe that we have presented a paper with several important concepts to better understand the nature of light. And use them for practical benefits.

2. We have unified the concepts of Newton, Huygens, Planck, Maxwell and Schrodinger to **resolve the wave-particle duality**, lingering on since 1670's; Newton was right that all atom- and molecule-generated light are necessarily pulsed and they remain as independent pulses due to Non-Interaction of Waves (NIW), as postulated by Huygens.

3. We have used the Interaction Process Mapping Thinking (IPM-T) to construct a more pragmatic model to understand the **origin of photoelectric current pulse (PCP) statistics** using Newton-Huygens light model.

4. The improved semi-classical photon model guides us to propose that high-finesse **Fabry-Perot etalon could smooth the amplitude and phase fluctuations** of pulsed light.

5. We have **proposed very simple experiments to validate** the concept to improve the photoelectric current pulse (PCP) statistics.