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# A proposal for introducing quantum physics in the footsteps of Einstein

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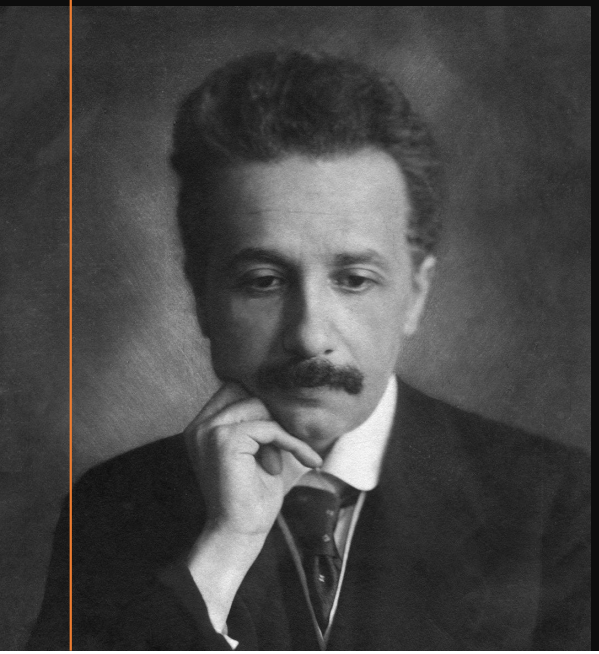
*Work done in collaboration with* Adele Naddeo *and* Salvatore Esposito



# Motivation

- Teaching quantum physics in high school in an effective and engaging way is a great challenge to teachers and researchers.
- Teachers sometimes lack a proper training in quantum physics, therefore they need dedicated training programs.
- It is desirable to choose simple, yet profound and engaging topics in order to make teachers develop an intuition about the subject. Such topics can also be presented to advanced high school students.
- History has often proved useful in teaching in multiple ways. The reading of the masters as a *supplement* to textbooks can be particularly useful for teachers to deeply grasp a subject.
- Einstein's papers stand out as models of clarity, depth, and philosophical thinking. Some of the main characteristic concepts of quantum physics were first introduced and commented there, in a way that may be useful also today.

$$\frac{N_j}{N} = \frac{e^{-\varepsilon_j/KT}}{\sum_i e^{-\varepsilon_i/KT}}$$

Probability and unpredictability

Über die Entwicklung unserer Anschauungen
über das Wesen und die Konstitution der Strahlung

Von *Albert Einstein*, Zürich

1909

Wave-particle duality

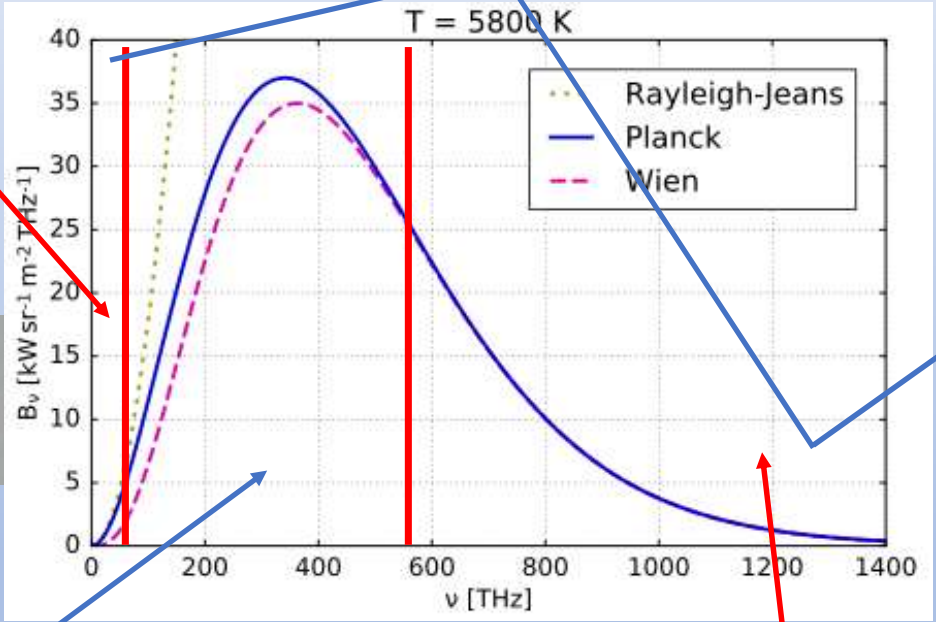
$$(\Delta E)^2 = \left[h\nu u + \frac{c^3}{8\pi}\frac{u^2}{\nu^2}\right] V\,\delta\nu$$

132

6. *Über einen die Erzeugung und Verwandlung des Lichtes betreffenden heuristischen Gesichtspunkt; von A. Einstein.*

1905

Classical region



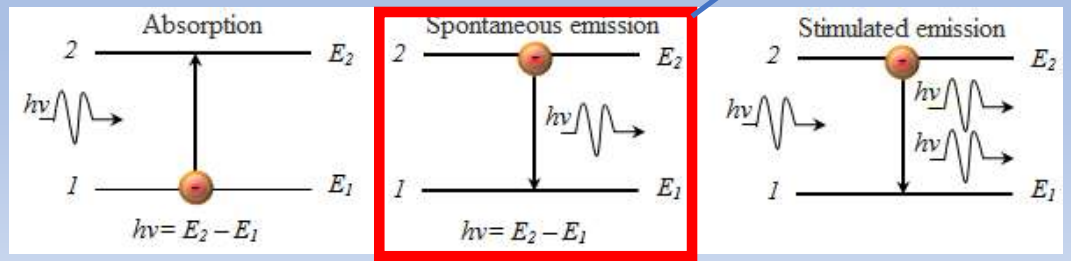

$$S(V) - S(V_0) = k \ln\left(\frac{V}{V_0}\right)^{\frac{E}{h\nu}}$$

Ideal «gas» of light quanta

Zur Quantentheorie der Strahlung.

Von A. Einstein[1]).

1917

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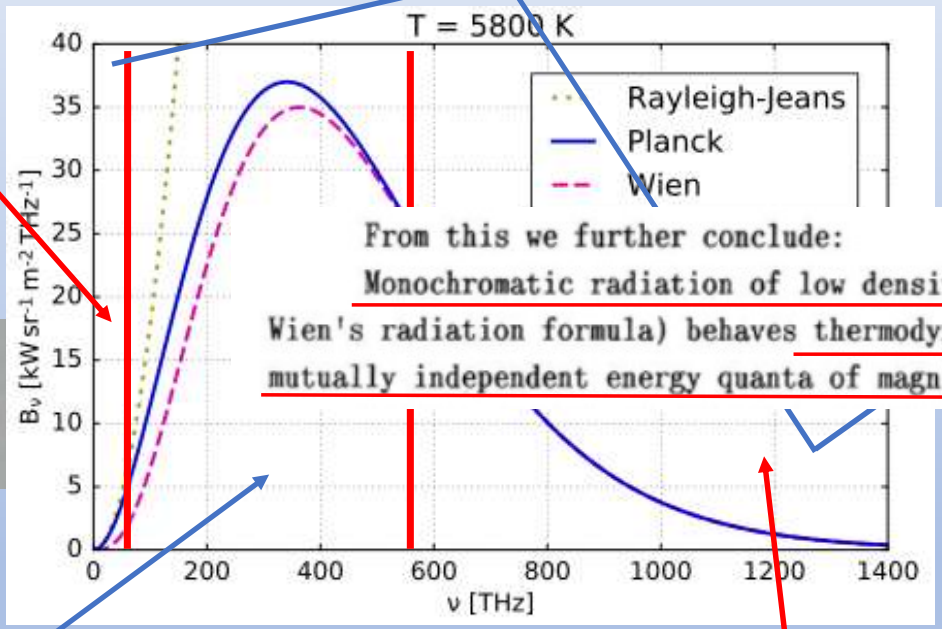


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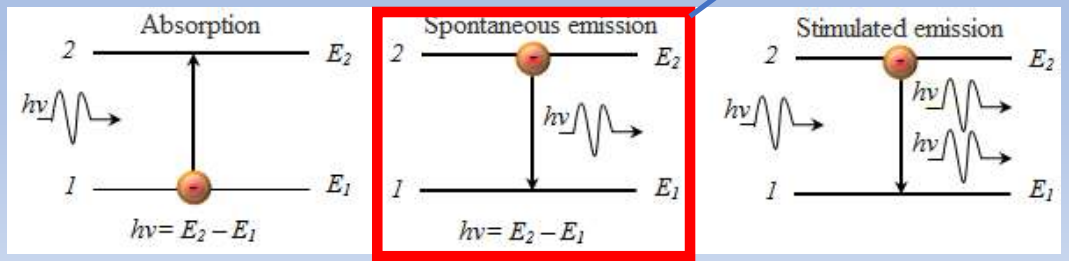
From this we further conclude:
Monochromatic radiation of low density (within the range of validity of Wien's radiation formula) behaves thermodynamically as if it consisted of mutually independent energy quanta of magnitude $R\beta\nu/N$.

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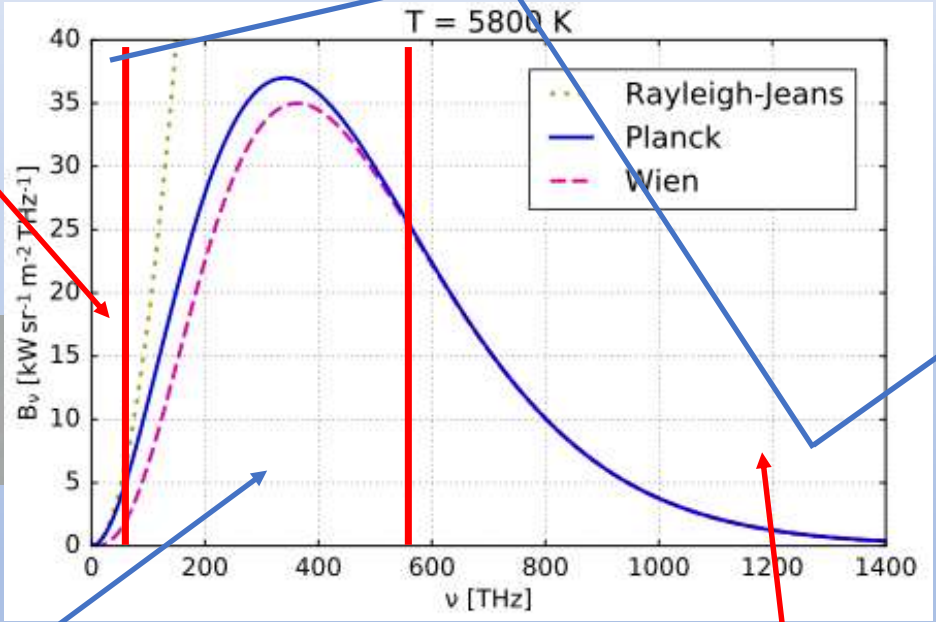


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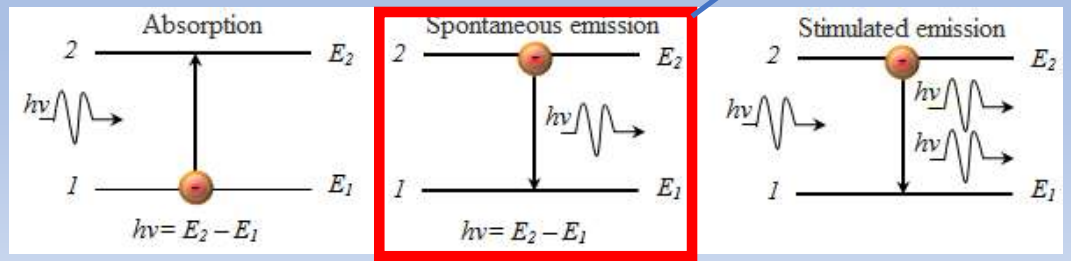


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*"I already attempted earlier to show that our current foundations of the radiation theory have to be abandoned . . . it is my opinion that the next phase in the development of theoretical physics will bring us a theory of light which can be interpreted as a kind of fusion of the wave and the emission theory . . . [the] wave structure and [the] quantum structure . . . are not to be considered as mutually incompatible . . . it seems to follow from the Jeans law [Eq. 16] that we will have to modify our current theories, not to abandon them completely."*

(Quoted in A. Pais, RMP, 1979)

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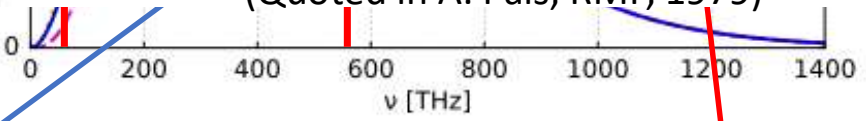


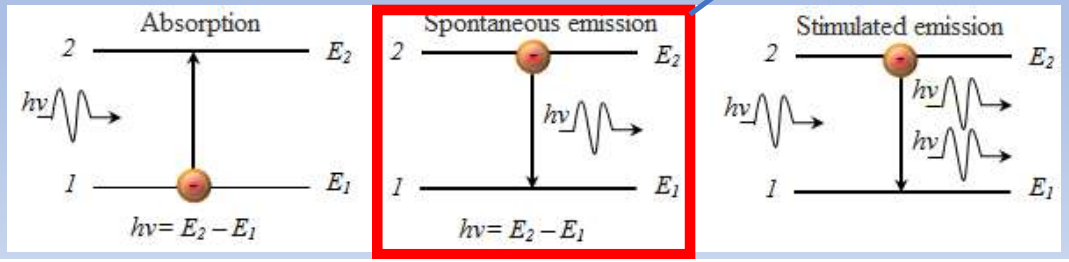


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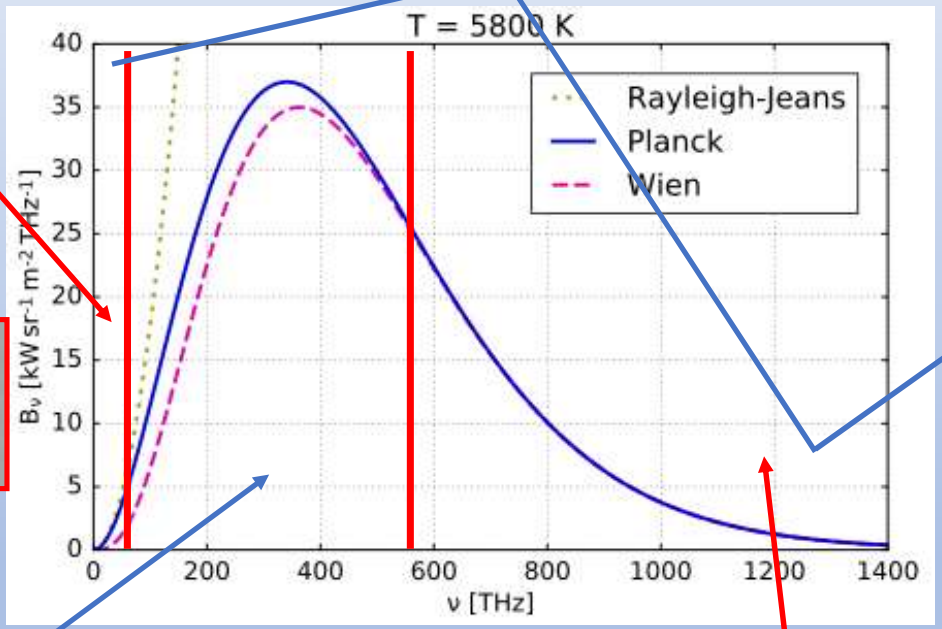


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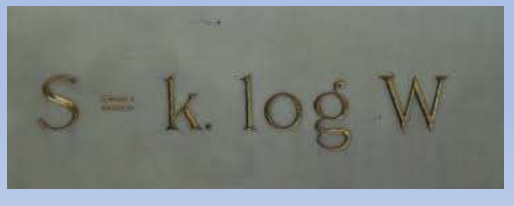


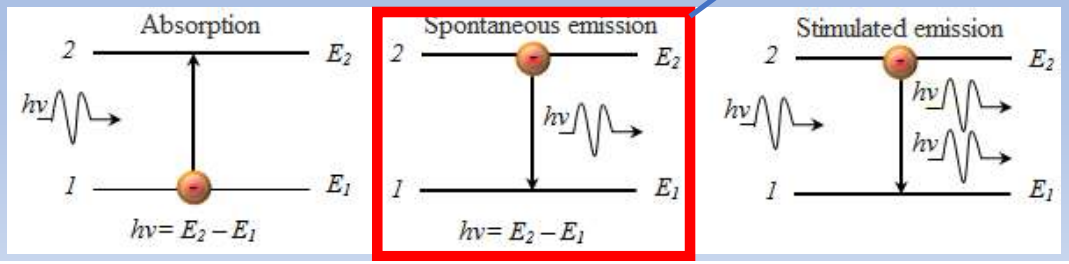


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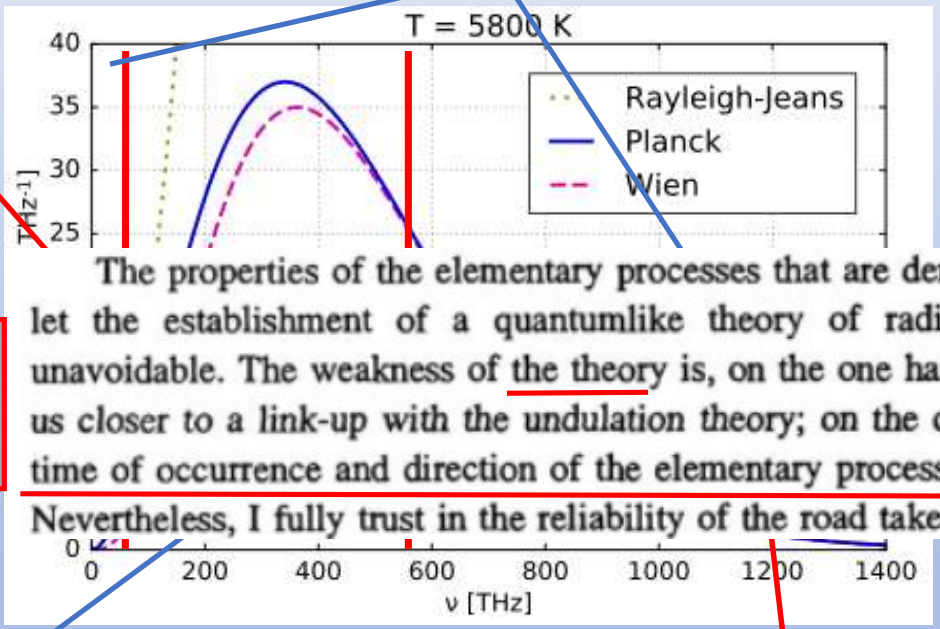


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The properties of the elementary processes that are demanded by equation (12) let the establishment of a quantumlike theory of radiation appear as almost unavoidable. The weakness of the theory is, on the one hand, that it does not bring us closer to a link-up with the undulation theory; on the other hand, it also leaves time of occurrence and direction of the elementary processes a matter of "chance." Nevertheless, I fully trust in the reliability of the road taken.

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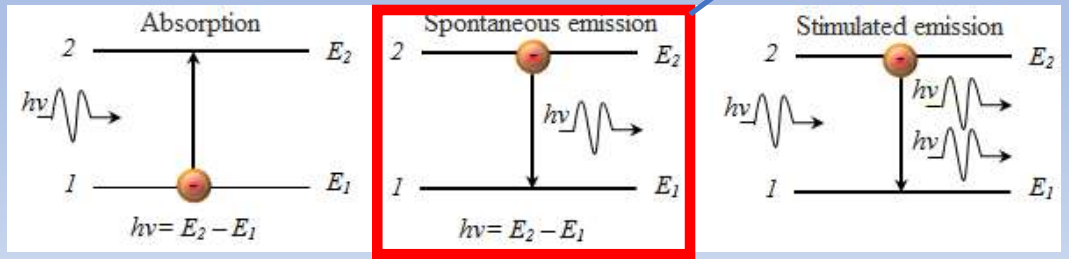


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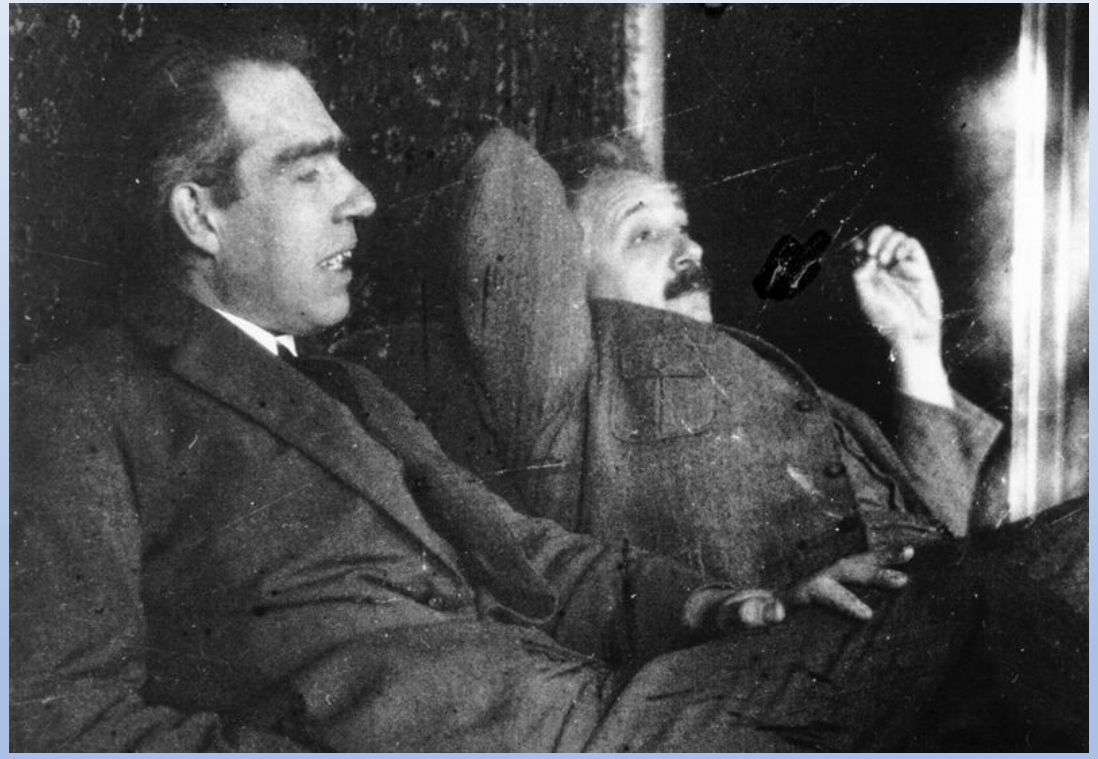
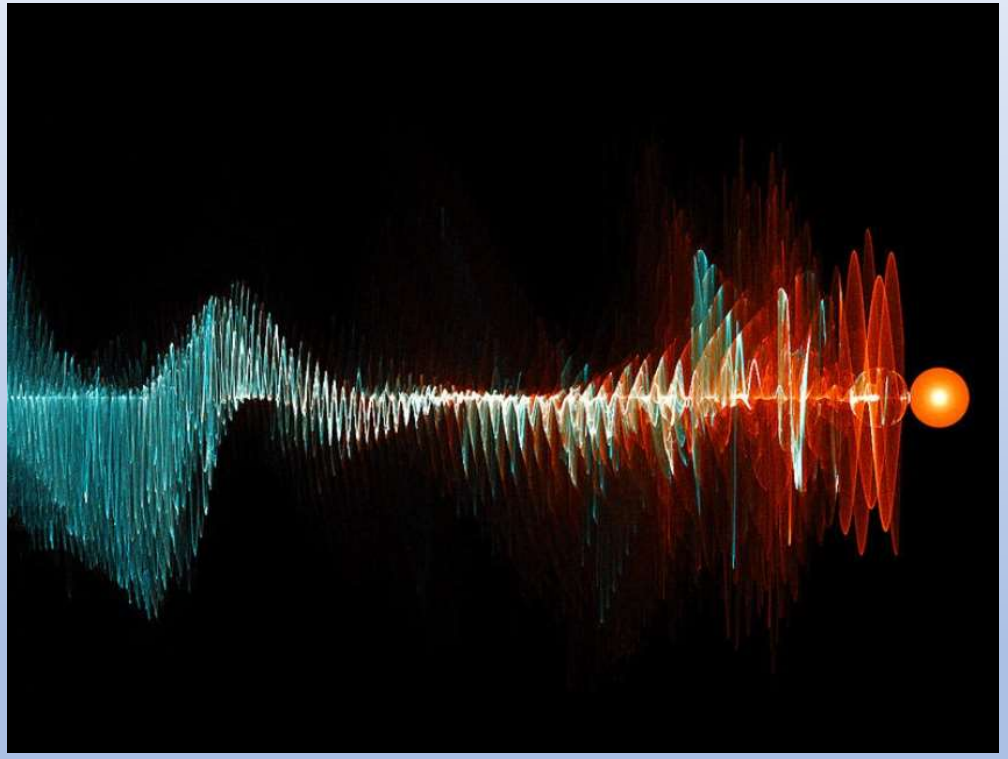
# Preliminary results (PLS 2019-20, PONs, etc.)

- Teachers were exposed to parts of the above proposal. Most of them claimed that this way of presenting the subject (mostly absent from textbooks) gave them a new point of view, they also gained an intuitive grasp of some quantum features.
- A group of selected students was exposed to the material as well, and found it intriguing (also because of the name of Einstein) and a good number of them developed some intuition about quantum phenomena.
- The didactic path can be supplemented by more modern topics (wave mechanics, tunneling, quantum 2-level systems, entanglement,…). More work is on the way!

# Thank you for your attention!





*(Particle-Wave Duality,* © D. Davoe)