Title: From Bose-Einstein statistics to photon statistics: the statistical style of scientific reasoning in the genesis of quantum optics.

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Collection/Series: 100 Years of Quantum: Perspectives on its Past, Present, and Future

Subject: Quantum Foundations

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Abstract:

My research investigates the role of Bose-Einstein statistics in the genesis of quantum optics. It explores key developments following the emergence of quantum statistics in the late 1920s, which eventually led to the classification of elementary entities as bosons and fermions in 1945. Additionally, it examines whether the concept of an evolving statistical style of reasoning in physics provides a useful analytical framework for understanding the debate on the Hanbury Brown and Twiss (HBT) effect, the early investigations of photon correlations in the late 1950s, and the emergence of photon statistics in the early 1960s.

100 YEARS OF QUANTUM:

PERSPECTIVES ON ITS PAST, PRESENT, AND FUTURE

OCTOBER 20 - 24, 2025

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FROM BOSE-EINSTEIN STATISTICS TO PHOTON STATISTICS

THE STATISTICAL STYLE OF REASONING IN THE GENESIS OF QUANTUM OPTICS

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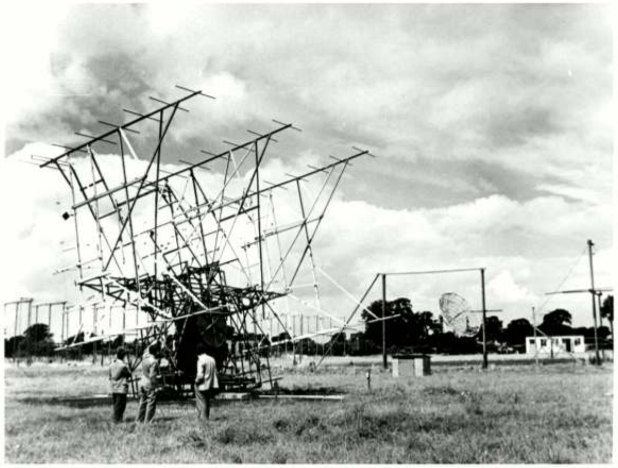
ST&S Department

science | YORK U

WHAT ROLE DID BOSE-EINSTEIN STATISTICS PLAY IN THE GENESIS OF QUANTUM OPTICS?



The Searchlight aerial, built from army surplus at Jodrell Bank Experimental Station in 1947.

- 1924, invention of Bose-Einstein statistics (BES)
- "Quantum optics was largely inspired by the inventions of the laser and the intensity interferometer, in the early 1960s and mid 1950s, respectively."*
- 1950-1956, Intensity interferometer and Hanbury Brown-Twiss (HBT) effect

* Joan Bromberg, "Device Physics vis-à-vis Fundamental Physics", *Isis 97,* 2006, 238, note 4.

OUTLINE

➢ Part 1

- Ian Hacking's styles of scientific reasoning and Hacking-type revolutions
- The statistical style in physics and the quantum revolution

Part 2

- Intensity interferometry and the Hanbury Brown-Twiss effect

Part 3

- Working hypotheses and research questions

STYLES OF SCIENTIFIC REASONING AND HACKING-TYPE REVOLUTIONS

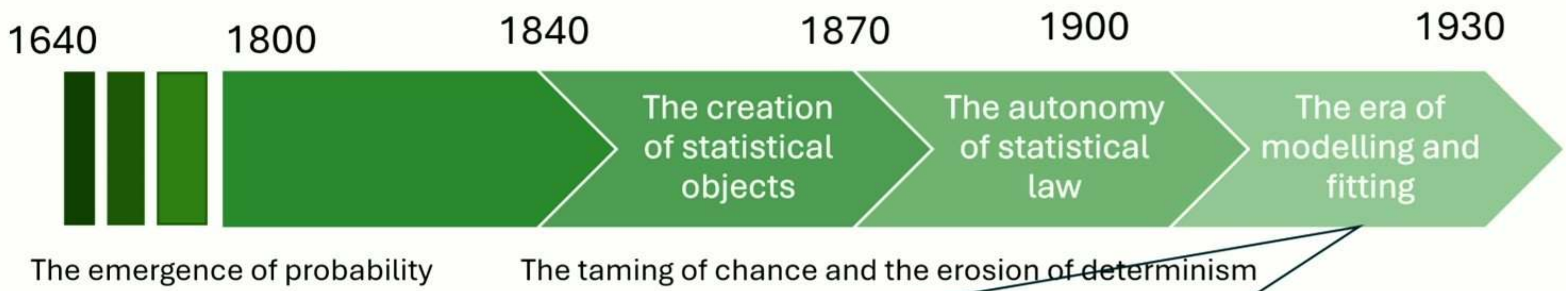
- Hacking-type revolution: genesis and evolution of a new style of scientific reasoning
  - Emplacement, not replacement
  - *longue durée* time scale, multiple stages
  - new types of true-or-false questions, evidence, objects, laws, explanations

Ian Hacking (1936-2023)

Sam Schweber (1928-2017)

  - mixing pure and applied concerns, spanning a wide range of scientific practices, multidisciplinary
  - associated with social change and new institutions
  - producing new ways of doing things and a new feel to the world

THE STATISTICAL STYLE OF REASONING AND THE STATISTICAL REVOLUTION



"First came statistical mechanics, with a new kind of population—a population of molecules in the first instance—subject to a new kind of law. The triumph was the indeterminism introduced by Planck and cemented in 1926–1927. We came to live in, as Peirce put it, a Universe of Chance."

(Hacking, "Probable Reasoning and Its Novelties" 2012, 190)

THE STATISTICAL STYLE IN PHYSICS AND THE QUANTUM REVOLUTION

1900

1930

Maxwell-Boltzmann statistics (MBS)
fields and particles
population → ideal gas analogy

Generalization of MBS
field-particle dualism
ideal gas → radiation analogy
quantum theory
light quanta and wave-particle dilemma for light

1924 Bose-Einstein statistics (BES)
radiation → ideal gas analogy
wave-particle duality
birth of QFT

autonomy of statistical law

erosion of determinism

1927, "photons"
1929, "indistinguishable particles"
1945, "bosons" and "fermions"
1950, "elementary particles" = "the amalgamation of particles and waves"

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ASTRONOMICAL INTERFEROMETRY

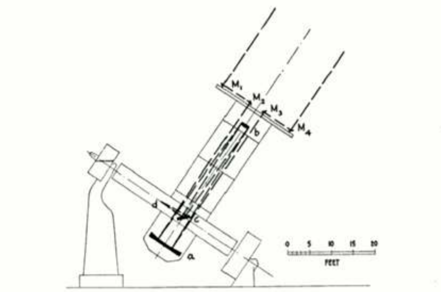


FIG. 1.—Diagram of optical path of interferometer pencils. M_1, M_2, M_3, M_4, mirrors; *a*, 100-inch paraboloid; *b*, convex mirror; *c*, coudé flat; *d*, focus.

Michelson's stellar interferometer
Michelson and Pease, *Astrophysical Journal*, 53 (1921), 249-259, 250.

- Michelson's stellar interferometer (amplitude interferometer) for measuring the angular diameter of stars
- Long baselines required for small sources
- Blurring by atmospheric turbulence ("twinkling")

"Quite simply, I thought of the idea late one night in 1949. [...] I imagined a simple detector which demodulated waves from the source and displayed them as the usual noise which one sees on a cathode-ray oscilloscope. If one could take simultaneous photographs of the noise at two stations, would the two pictures look the same? This question led directly to the idea of the correlation of intensity fluctuations and to the principle of intensity interferometry." (Hanbury Brown, *The Intensity Interferometer*, 1974, 2-3)

Robert Hanbury Brown
(1916-2002)

THE "INTENSITY INTERFEROMETER" (1)

Richard Q. Twiss (1920-2005) and Robert Hanbury Brown, date unknown.

Source: S. G. Lukishova and W. J. Tango, "First Observation of Photon Correlations (Bunching) with Beamsplitter and Photomultipliers", in Boyd, R., Lukishova, S., Zadkov, V. (eds) *Quantum Photonics: Pioneering Advances and Emerging Applications* (Springer 2019), https://doi.org/10.1007/978-3-319-98402-5_19

- 1950-54, Hanbury Brown-Twiss collaboration, theory of the instrument
- 1952, Hanbury Brown, Jennison, Das Gupta's measurement of two major radio sources: "We had used sledge-hammer to crack a nut" (Hanbury Brown 1974, 4)
- Insensitivity to twinkling and decision to adapt the instrument for optical sources

THE "INTENSITY INTERFEROMETER" (2)

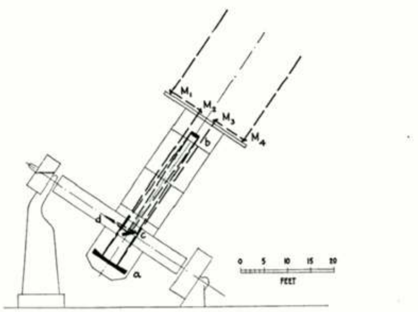


FIG. 1.—Diagram of optical path of interferometer pencils. M_1, M_2, M_3, M_4, mirrors; *a*, 100-inch paraboloid; *b*, convex mirror; *c*, coudé flat; *d*, focus.

Michelson's stellar interferometer

Michelson and Pease, "Measurement of the Diameter of α Orionis with the Interferometer", *Astrophysical Journal*, 53 (1921), 249-259, 250.

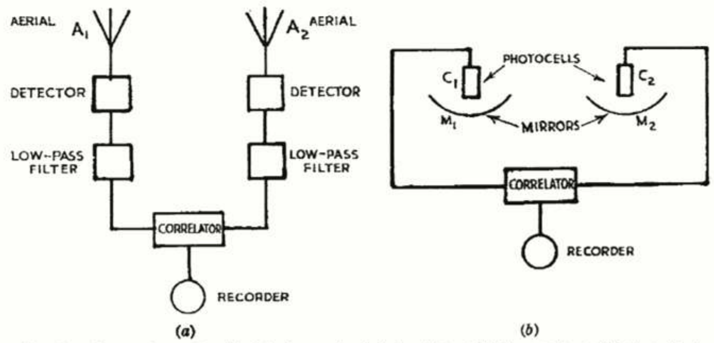


Fig. 1. A new type of radio interferometer (*a*), together with its analogue (*b*) at optical wave-lengths

Hanbury Brown's "intensity interferometer" for radio sources (a) and for optical sources (b).

Hanbury Brown and Twiss, "Correlation between Photons in Two Coherent Beams of Light", *Nature*, 4497 (1956), 27-29, 27.

"What we now realised was that an intensity interferometer working with visible light would overcome both these difficulties; we decided to carry on where Michelson had left off." (Hanbury Brown 1994, 40)

THE HBT THEORY OF THE INSTRUMENT

- "Radio engineers, before the advent of masers, thought of radio waves as waves and not as a shower of photons." (Hanbury Brown 1974, 4.)
- HBT semi-classical model of photoelectric emission:
  - light is a classical wave
  - quantization introduced by discrete energy levels in the detector
  - probability of photoelectron emission proportional to the square of the electric field component of the incident light
- "In principle, the theory is the same for all wavelengths [...] With renewed enthusiasm we returned to establish the detailed theory of an optical interferometer, and immediately ran into a barrage of criticism." (Hanbury Brown 1974, 4-5)

THE HBT CONTROVERSY

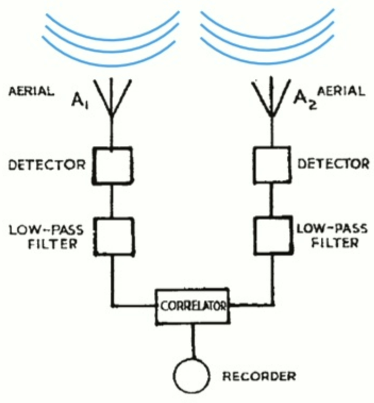
- “It was at this point that we ran into trouble. [...]
- So far the principle of our new instrument had been accepted without question, in those days radio engineers didn’t worry about photons; but when we decided to apply it to light, physicists became interested and did worry about photons.
- Indeed they were very unhappy about what we proposed to do. [...]
- Every time I stuck my nose inside Manchester University, I was waylaid by a physicist brandishing some sacred text, Heitler or Dirac, showing that the behaviour of photons could never be correlated. They told me this in person, in letters and in print.” (Hanbury Brown 1994, 40-41)

FIG. 3 R. Hanbury Brown leads blackboard discussion at the first Coherence.

Source: Emil Wolf, “Early days of coherence theory and the first Rochester conference on coherence”, *Journal of the European Optical Society – Rapid Publications* 5, 10044s (2010)

OBJECTIONS TO THE HBT PROPOSAL

- "To most physicists our ideas were laughable. Their simplest argument, among many more highbrow ones, was that because photons are generated at random times and travel with the velocity of light, they must therefore arrive at random times.



- [...] to arrive hand in hand they would have to hang about waiting for each other! Obviously our proposal would not work." (Hanbury Brown 1994, 41)

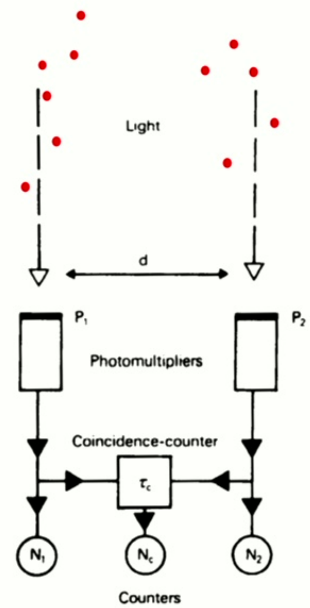


Figure 1. A coincidence-counting intensity interferometer.

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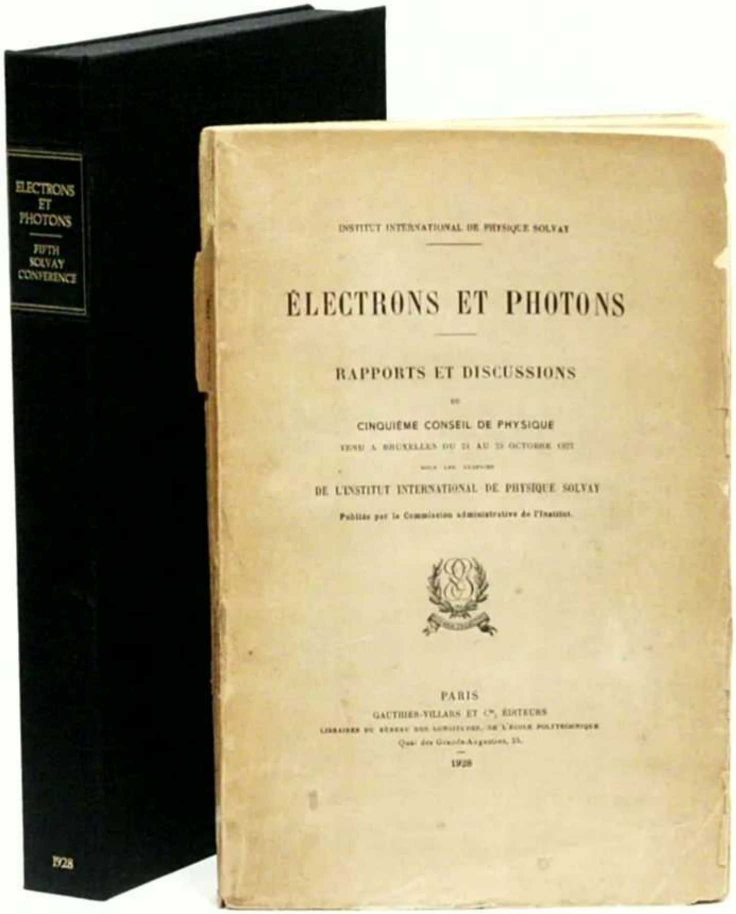
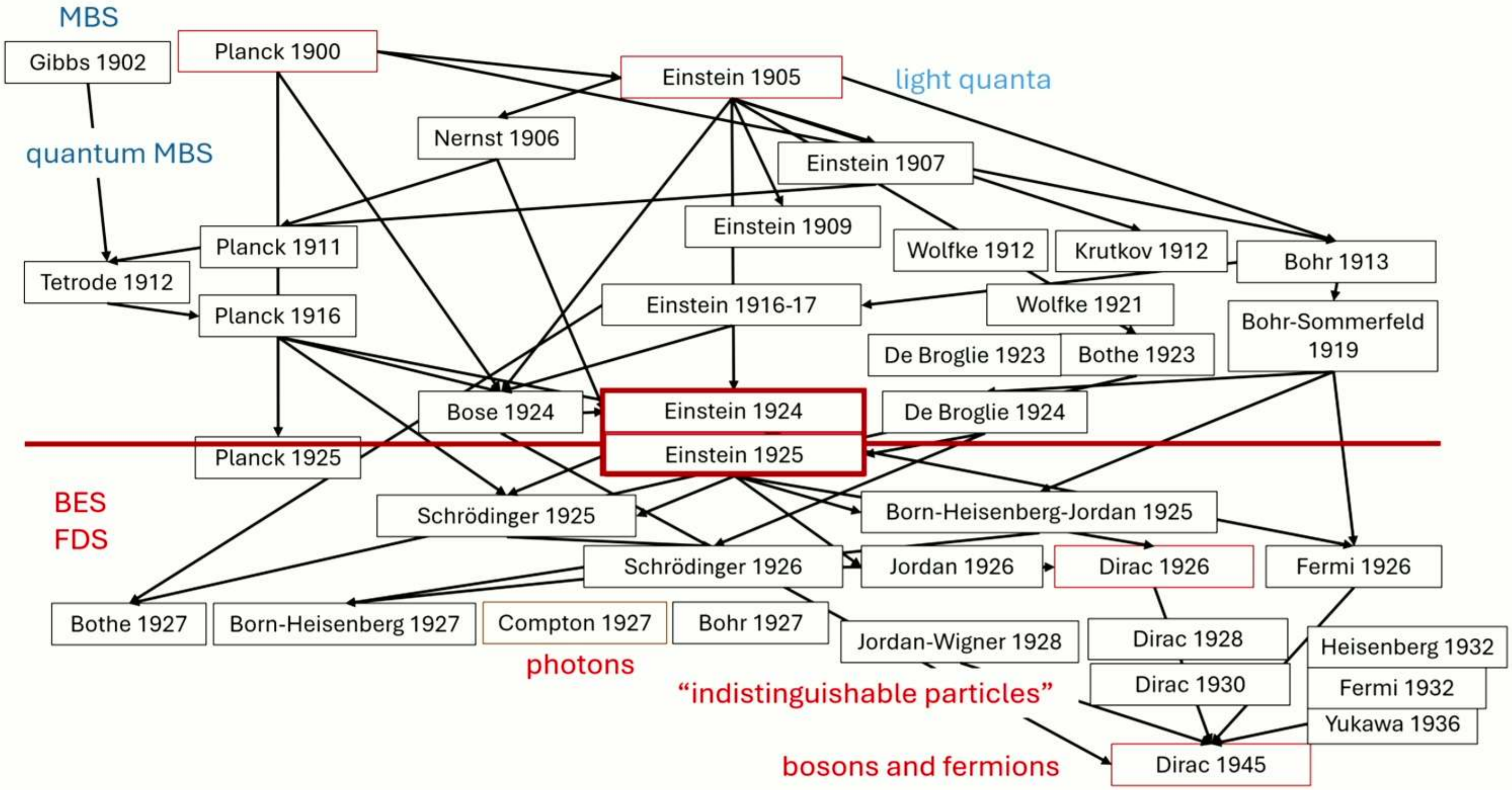


WHAT

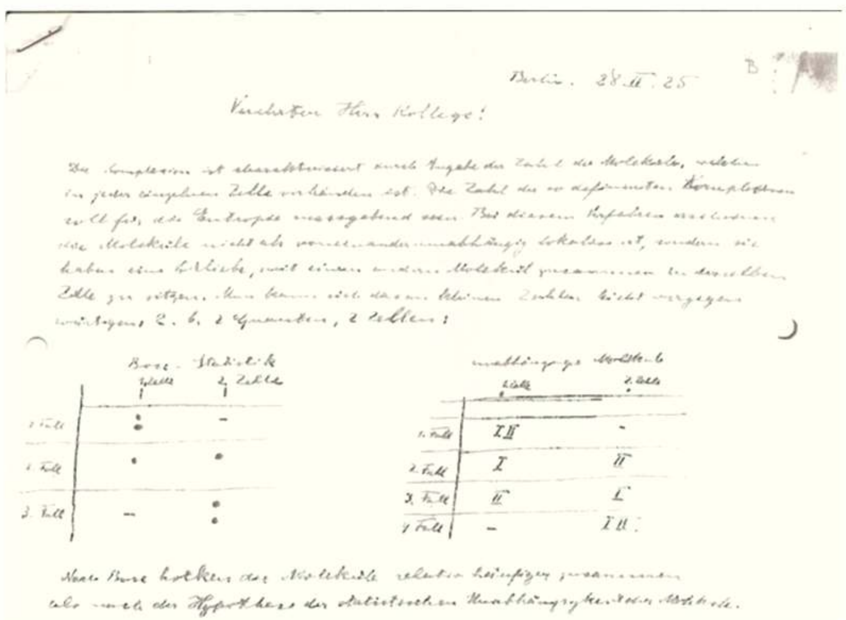
HAD HAPPENED
TO THE CONCEPT OF A
PHOTON
SINCE 1927

?

A CONDENSED AND SCHEMATIC HISTORY OF "BOSONS AND FERMIONS"

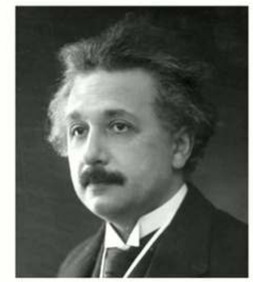


THE STATISTICS OF LIGHT QUANTA


Berlin. 28.II.25

Verehrter Herr Kollege!

Bose-Statistik



“According to Bose, the molecules sit together relatively more frequently than according to the hypothesis of the molecules being statistically independent.” (Einstein to Schrödinger, 28 Feb 1925)

CLOSING REMARKS/RESEARCH QUESTIONS

- No continuous storyline from BES to the HBT effect
- Drawn-out and uneven process of revision and transformation
- No abandonment of the classical wave and particle concepts
- Different paths in different research environments, interdependence of thinking and doing within local context
- Interpretive flexibility and interdependence of material tools and paper tools
- Autonomy of BES-based explanations?
- From formalism-driven to device-driven developments?

THANK YOU!