A Computational and Experimental Study of the Hanbury Brown and Twiss Effect

Matthew Belzer, Eric Jones, and Harold Metcalf
Department of Physics and Astronomy, Stony Brook University
Laser Teaching Center

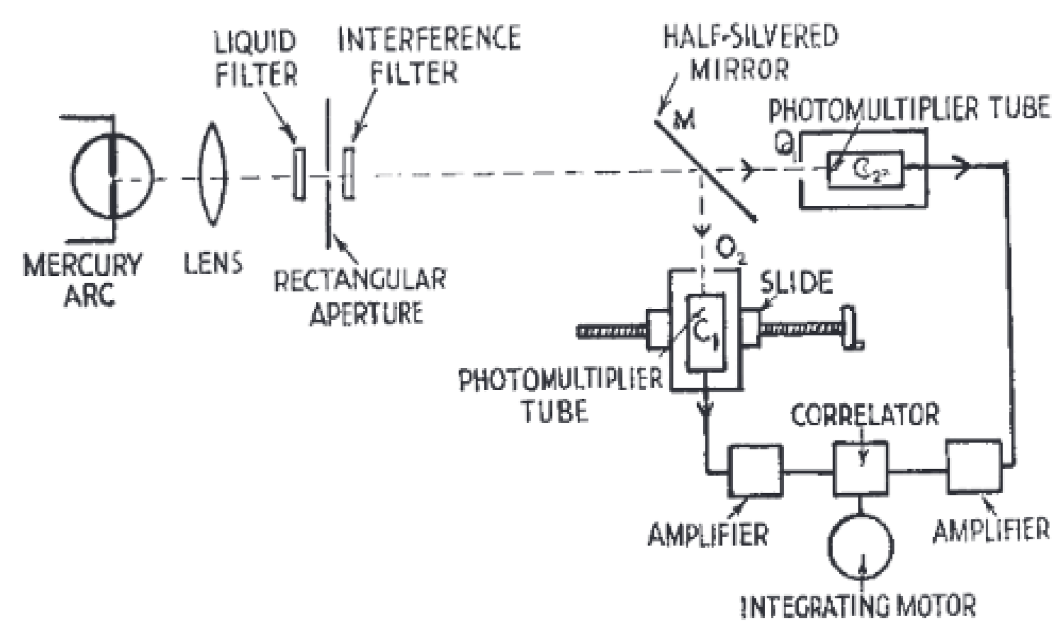
Abstract

We have successfully simulated starlight using two detectors with a variable distance between them as shown by Hanbury Brown and Twiss (HBT) in 1956. We are also working on building a tabletop experiment that will use pulse counting to find the intensity correlation of visible light from an incoherent source. So far, the photomultiplier tubes (PMTs) have been wired and equipment has been gathered.

Introduction

- In 1956, HBT correlated the intensities of visible light from a mercury arc lamp using photocurrents emitted from PMTs [1].

Figure 1: The original HBT experimental design [1].



- They used this technique to find the angular diameter of Sirius [2].
- The second order correlation, $g^{(2)}$, of Source A using Detectors 1 & 2 where Detector 2 has a variable time delay τ, is [3]

$$g^{(2)}(l_{A1}, r_2, \tau) = \langle I(l_{A1}, t) I(l_{A2}, t+\tau)\rangle / \langle I(l_{A1}, t)\rangle \langle I(l_{A2}, t+\tau)\rangle \quad (1)$$

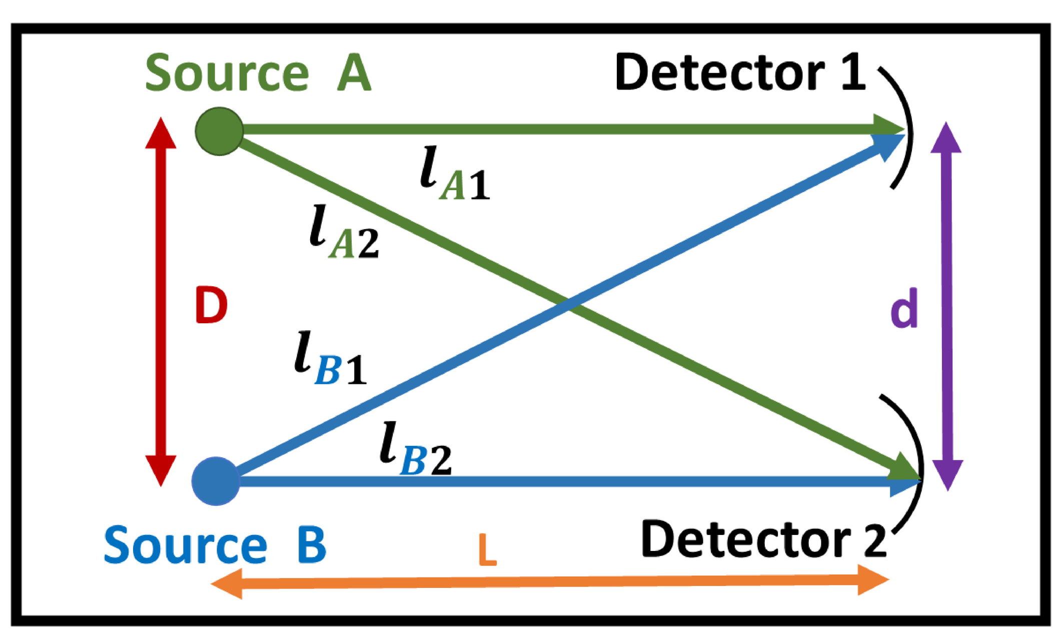


Figure 2: Diagram of a simple system of two source points and two detection points.

- $g^{(2)}$ of N incoherent sources and two detectors is

$$g^{(2)} = 1 + \sum_{i<j}^{N} \sum_{i}^{N} 2\langle |E_0|^2\rangle^2 \cos\big(k(l_{i1} - l_{i2} - l_{j1} + l_{j2})\big) / (N\langle |E_0|^2\rangle)^2 \quad (2)$$

- HBT also derived the second order correlation for a star [4].

$$g^{(2)} = (2J_1(\pi\theta_{UD} d/\lambda)/(\pi\theta_{UD} d/\lambda))^2 \ (3)$$

Star Simulation

- I stimulated source points on a semi-sphere using two methods.

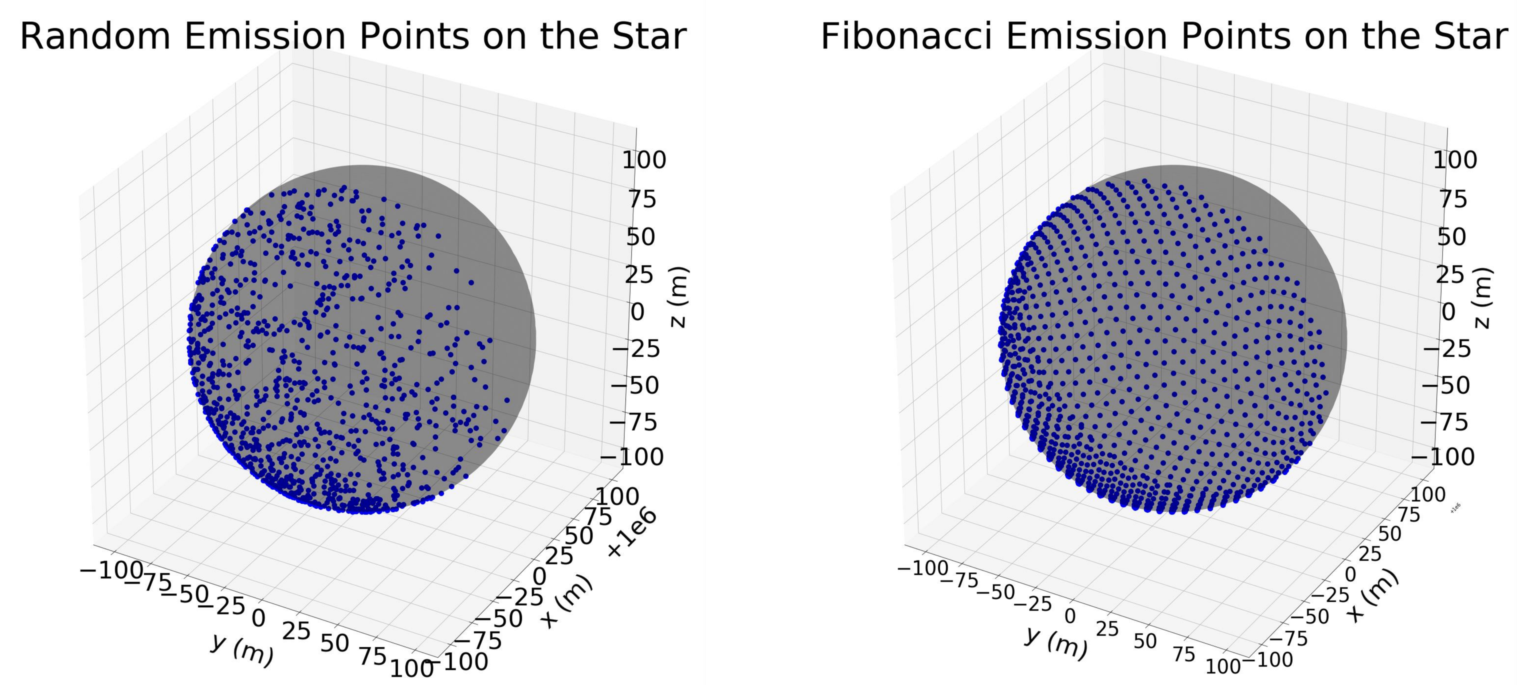


Figure 3: Emissions points on a star where L = 1000 km with a radius of 100m using a random method (left) and the Fibonacci method (right).

- The amplitude of light with a random phase emitted from all the source points was calculated at two detection points a variable distance apart.
- The random phase was made many times to represent phase averaging.

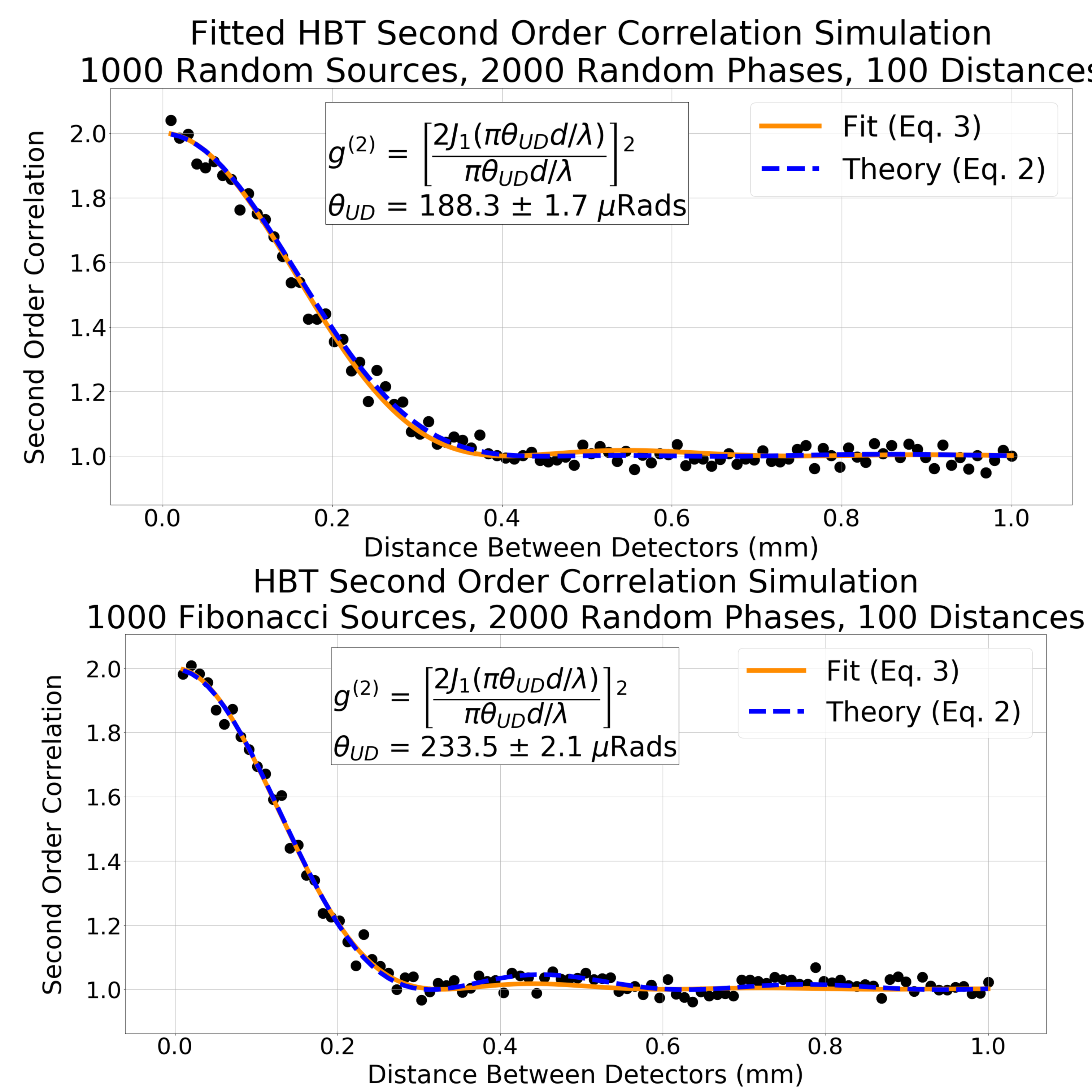


Figure 4: The random source plot (Top) and the Fibonacci source plot (Bottom) are in agreement with the expected angular diameter of 200 μrad.

- We observed that as the number of random phases increased, the chi-squared value decreased, so the data points should converge to theory

Tabletop Experiment

- Instead of photocurrents, we will count photons using PMT pulses.
- A heavily filtered mercury arc lamp will emit incoherent light to two PMTs, which will create voltage pulses.

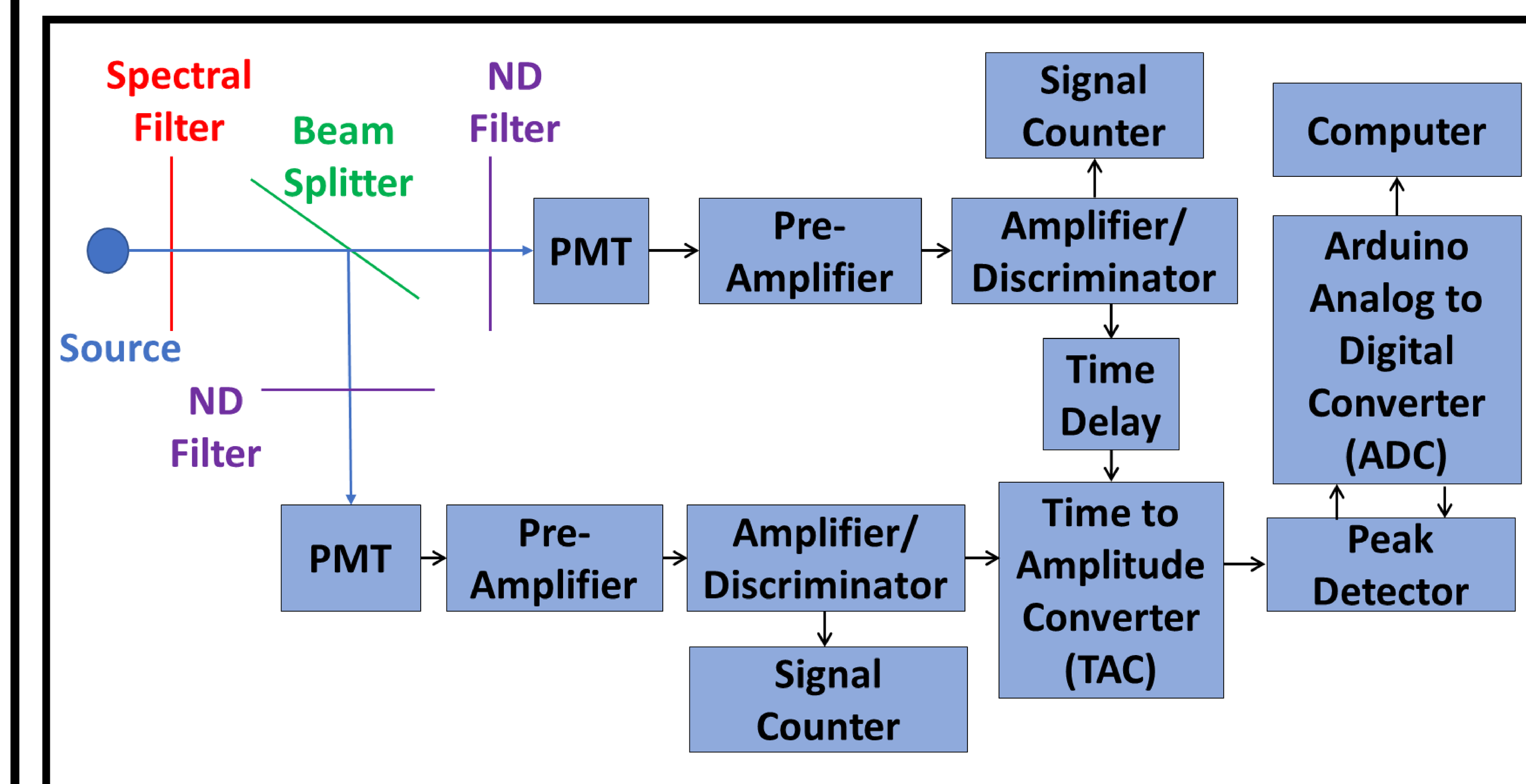


Figure 5: A diagram of the planned tabletop experiment.

- The pulses will be counted at the signal counters and an ADC.
- The peak detector will let the ADC read the voltage of the microsecond TAC pulses and will then be reset after the voltage has been read.
- So far, the PMTs have been wired and tested and we are working on the ADC and peak detector part of the experiment.

Acknowledgements

- We would like to thank Dr. Vaneet Singh, Prof. Jan Bernauer, Dr. Marty Cohen, Dr. Eric Jones, and Prof. Harold Metcalf for their help.
- This project was supported by the Laser Teaching Center.

References

1. Hanbury Brown, R. & Twiss, R. Correlation between Photons in two Coherent Beams of Light. *Nature* 177, 27–29 (1956). https://doi.org/10.1038/177027a0
2. Hanbury Brown, R. & Twiss, R. A Test of a New Type of Stellar Interferometer on Sirius. *Nature* 178, 1046–1048 (1956). https://doi.org/10.1038/1781046a0
3. Institut des Hautes Etudes Scientifiques (IHES). (2018, October 6). *Alain Aspect - Hanbury Brown - Twiss, Hong - Ou - Mandel, and other landmarks in quantum optics* [Video]. YouTube. https://www.youtube.com/watch?v=7R2Ehcvdxmg
4. Hanbury Brown, R., & Twiss, R. Q. (1958). Interferometry of the intensity fluctuations in light III. applications to astronomy. *Proceedings of the Royal Society of London. Series A. Mathematical and Physical Sciences*, *248*(1253), 199–221. https://doi.org/10.1098/rspa.1958.0239