The Kirkwood-Dirac Distribution and its Utility in Quantum Metrology

David ARVIDSSON SHUKUR

Hitachi Cambridge Laboratory, Hitachi Cambridge Laboratory
`drma2@cam.ac.uk`

In this talk, I will give a brief introduction to the Kirkwood-Dirac (KD) distribution. Then, I will show how collaborators and I have used the KD distribution as a tool to develop quantum metrology. The Wigner function has played a pivotal role in the development of continuous-variable quantum systems with clear analogues to position and momentum. However, it is ill-suited for modern quantum-information research, which mostly concerns finite-dimensional systems and general observables. Instead, recent years has seen the KD distribution [5, 3] come to the forefront as a powerful tool to analyse quantum mechanics. The KD distribution allows tools from statistics and probability theory to be applied to problems in quantum-information processing [1]. In many ways, the KD distribution behaves as a joint probability distribution, but it can take negative and nonreal values. One field advanced by the KD distribution is quantum metrology. Quantum metrology is the field of using quantum states to measure and estimate things. In metrology, one can improve signal-to-noise ratios by preparing and measuring an increasing number of probes. However, quantum measurement devices saturate if the probe intensity exceeds some threshold. By placing a filter before a detector, it is possible to mitigate the effect of detector saturation by compressing the metrological information from a high-intensity probe beam into a low-intensity one [2, 7]. But how does one design the best filters? Collaborators and I expressed quantum-metrology experiments in terms of a KD distribution [2, 4]. Doing so allowed us to connect negative values in the KD distribution with a filter's ability to compress information. Moreover, by mapping out how one could increase the magnitude of the negative values, we understood how to design optimal filters for quantum metrology. In the absence of noise, our filter allows unbounded and lossless information compression. In a recent experiment to measure polarization rotations, we used our filter to mitigate detector saturation and improved the signal-to-noise ratio by a factor of 200 [6].

References

[1] D. R. M. Arvidsson-Shukur, J. Chevalier Drori, and N. Y. Halpern. Conditions tighter than noncommutation needed for nonclassicality. *Journal of Physics A: Mathematical and Theoretical*, 54(28):284001, jun 2021.

[2] D. R. M. Arvidsson-Shukur, N. Y. Halpern, H. V. Lepage, A. A. Lasek, C. H. W. Barnes, and S. Lloyd. Quantum advantage in postselected metrology. *Nature Communications*, 11:3775, 2020.

[3] P. A. M. Dirac. On the analogy between classical and quantum mechanics. *Rev. Mod. Phys.*, 17:195–199, Apr 1945.

[4] J. H. Jenne and D. R. M. Arvidsson-Shukur. Unbounded and lossless compression of multiparameter quantum information. *Phys. Rev. A*, 106:042404, Oct 2022.

[5] J. G. Kirkwood. Quantum statistics of almost classical assemblies. *Phys. Rev.*, 44:31–37, Jul 1933.

[6] N. Lupu-Gladstein, Y. B. Yilmaz, D. R. M. Arvidsson-Shukur, A. Brodutch, A. O. T. Pang, A. M. Steinberg, and N. Y. Halpern. Negative quasiprobabilities enhance phase estimation in quantum-optics experiment. *Phys. Rev. Lett.*, 128:220504, Jun 2022.

[7] F. Salvati, W. Salmon, C. H. W. Barnes, and D. R. M. Arvidsson-Shukur. Compression of metrological quantum information in the presence of noise, 2023.