Critical Assessment and Referee Report on "Is it Gaussian? Testing bosonic quantum states"

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SUMMARY

The manuscript studies the problem of testing whether an unknown bosonic quantum state is Gaussian, proposing operational criteria and sample complexity bounds based on invariance under orthogonal transformations. The technical analysis is carefully executed and mathematically consistent within the stated assumptions.

However, despite its technical sophistication, the manuscript suffers from a fundamental conceptual flaw: Gaussianity is implicitly treated as a physically privileged or structurally meaningful property, without being derived from any variational, dynamical, or stability principle. As a consequence, the proposed tests characterize representational symmetry rather than physical necessity.

For this reason, the present assessment cannot recommend publication in its current form.

MAJOR CONCEPTUAL ISSUE

The manuscript assumes throughout that Gaussian states constitute a physically distinguished class of bosonic quantum states. This assumption is never justified beyond historical usage and operational convenience.

In particular:

- Gaussianity is not derived from an action or variational principle.
- Gaussianity is not shown to be dynamically stable under generic interactions.
- Gaussianity is not demonstrated to be necessary for physical realizability.

The criteria developed in the paper therefore test membership in a convenient representation class, not in a class selected by physical necessity.

INVARIANCE DOES NOT IMPLY PHYSICAL PRIVILEGE

The central results rely on invariance under orthogonal transformations acting on mode space. While such invariance may characterize Gaussian states within a restricted mathematical setting, it does not imply that Gaussianity is a structurally fundamental property of bosonic quantum systems.

Symmetry under a transformation group identifies representational simplicity, not physical closure. Many physically admissible non-Gaussian states fail the proposed tests while remaining dynamically stable and experimentally relevant.

Thus, the logical implication

$$\text{invariance} \Rightarrow \text{physical relevance}$$

is not established.

FAILURE FOR MIXED STATES

The manuscript explicitly acknowledges that testing Gaussianity for mixed states is exponentially hard. This admission has severe physical implications.

Any criterion that ceases to be operationally meaningful in the presence of noise cannot serve as a fundamental physical diagnostic. Realistic quantum systems are mixed, open, and noisy; a physically meaningful property must remain well-defined under these conditions.

The exponential overhead therefore indicates that Gaussianity is not a robust physical invariant, but a fragile idealization.

ABSENCE OF DYNAMICAL CLOSURE

At no point does the manuscript demonstrate that Gaussian states form a closed class under realistic bosonic dynamics. Without closure, Gaussianity cannot be treated as a physically stable category.

Testing whether a state is Gaussian at a fixed time provides no information about its persistence, relevance, or role in the long-term dynamics of the system.

PHYSICAL INTERPRETATION

The results quantify the cost of identifying Gaussianity, but they do not explain why Gaussianity should matter physically. The work therefore answers a methodological question while implicitly promoting an unproven physical premise.

In its present form, the manuscript risks conflating mathematical convenience with physical principle.

RECOMMENDATION

I recommend **rejection**.

To become suitable for publication in a Physical Review journal, the manuscript would need to:

- Provide a physical or variational principle selecting Gaussian states.
- Demonstrate dynamical stability or closure of Gaussianity.
- Clarify the physical meaning of Gaussianity beyond operational testability.

Without addressing these foundational issues, the results remain mathematically correct but physically unmotivated.