Responses to Referee

immediate

March 16, 2021

Manuscript Title : QMetrology from QCosmology: Study with Entangled Two Qubit Open Quantum System in De Sitter Space
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Dear Editor,

We thank the referees for their reports and insightful comments on our work. Based on the comments, we have modified the paper as needed, corrected all the errors that they mentioned and provided clarifications where required. We request reconsidering this paper for publication in SciPost. Below are our responses to the referee's comments :

Response to Anonymous Report 1

1. **Referee's Comment :**
   The analysis appears to be erroneous. As per the statement made in the paper, the results for density matrices were obtained in the para regime $k\omega \gg 1$ subject to the constraint $\coth(\pi k\omega_0) = 0$. Now there is no real solution to the constraint, the only solution is $k\omega_0 = (n+1)i/2$ for integer n. ω_0 being real, this means k must be purely imaginary. Then it is unclear how $k\omega \gg 1$ can be fulfilled, since ω is real again. In any case, in the section on Fisher Information only real values of all the parameters have been considered and further only small values. In any case, in the section on Fisher Information only real values of all the parameters have been considered and further only small values $k\omega$ have been considered. So it appears that neither of the two conditions, under which the paper claims to have derived the expressions for density matrices, were satisfied when the same density matrices were used for the calculation of Fisher Information.

   Authors' Response :
   In this work we have not used the condition $k\omega_0 = (n+1)i/2$ for integer n, which was appearing in our previous work $\coth(\pi k\omega_0) = 0$. It is very simple since we have not used such conditions in this paper, we have not mentioned about this to include confused statement from our side. This condition was used only to simplify the form of the spectral shifts, which was used in the published paper of us as mentioned by

the referee. Since we have not used such condition in ω_0 (which is obviously not needed at all for the present discussion we have not strictly mentioned this) the objection made by the referee raised is not at all valid. We only have used $k\omega \gg 1$ which we have have clearly mentioned. I think now it is clear what we did. So in our case ω_0, ω, k all are real and clearly satisfy $k\omega \gg 1$ condition. So during working on the problem of Fisher Information we have only taken real values of the parameter which is necessarily required. In the revised version we have clearly added this note which I think now will justify our point. In the revised version of the we have added a detailed discussion regarding this issue in support of our performed analysis in this paper.

2. **Referee's Comment :**
It is not clear why the problem studied here is significant: Even if the above issues did not exist, the study here would still need to establish significance. It has not been established why the qubit system is of physical interest, or why metrological considerations are appropriate for this system, or if the calculation of QFI tells us anything non-trivial. There have been interesting applications of Fisher Information in a de Sitter background (for instance, to ask if there are fundamental limitations to measuring cosmological observables of interest), but in this case the study of QFI appears to be arbitrary.

Authors' Response :

This kind of two qubit entangled system is of prime significance as the Resonant Casimir Polder interaction (RCPI) between the two entangled qubits can be used to extract information about spacetime curvature. Hence one can extract information about gravity from Casimir physics. This kind of entangled qubits shows out-of equilibrium features. Our purpose of using fisher information was to estimate certain important parameters and validate certain assumptions used in studying the time evolution of the open quantum model. Our analysis revealed certain features like revival of non-equilibrium feature at late time scale.

3. **Referee's Comment :**
Similar studies have appeared in past: Quantum Fisher information for an Unruh-DeWitt detector coupled to a scalar field in a dS background was obtained in arXiv 1806.08922, QFI for a qubit coupled to a scalar field in a dS background was obtained in 'Protecting quantum Fisher information in curved space-time' by Zhiming Huang (EPJP, 2018). Even if significance could be established for this direction of research, the paper would have to be establish how this study is telling us something significantly different from these previous ones.

Authors' Response :
We thank the referee for pointing out the two relevant references which we have cited in our modified draft. Fisher information can be computed for various models, the model that we have chosen in our paper, is not one qubit rather two entangled qubits interacting with a scalar field in the static patch of De-Sitter space. The significance and our purpose of studying fisher information in such a two entangled qubit as an open quantum system in dS space has been discussed in the previous

response.

4. **Referee's Comment :**
   Relevant past works and similar studies have not been cited: the two papers mentioned above which also studied QFI in a very similar context have not been cited. The model of the two qubit system in de Sitter used here first appeared in arXiv 1310.7650 and the formulae given in this paper appear to closely follow the results presented there. While this paper has been cited in previous papers by some of the same authors, it was not cited here. Some other relevant references which studied Fisher information or the dynamics of similar systems in de Sitter space but have not cited: 1812.02345, 1707.09702, 1407.4930, 1605.07350, 1706.0917, 1707.08414.

   Authors' Response :
   We thank the referee for pointing out previous works in this direction. We have taken care to cite them in the modified version of the draft.

5. **Referee's Comment :**
   The paper does not always clearly distinguish what has been done previously by others and what is the original contribution of the authors: The authors did not mention where the qubit model used here originated. The fact that it had already been studied in de Sitter space (first in 1310.7650) should have been mentioned. These omissions, together with the authors' referring to the qubit model as 'our model', can be misleading for the reader. More generally, there is no discussion in the introduction about any previous work on open systems in dS (even though some of this research is cited), which can again give an incorrect impression about the originality of the paper.

   Authors' Response :
   We have modified the draft accordingly and included some discussions of open quantum systems in dS space along with relevant citations.

6. **Referee's Comment :**
   Presentation lacks clarity: Previous results that have been used as the main input in the study of this paper were not presented explicitly nor was a detailed reference given (see point 1 above). Quantities were not defined where they were introduced (for instance, L and ω_0 first appear in eqns 10 and 11 and are not defined till two pages later). There were a number of things that were not clearly explained (such as the distinction between ω and ω_0, both of which are defined as 'Fourier modes of the Wightman functions' in the paper). Lack of paragraph breaks hampered readability (the whole first column of the second page is a single block of text).

   Authors' Response :
   We thank the referee for his valuable comments. We have modified the draft according to the suggestions and have included the results and discussions that have been used in this paper in the appendix. We have also improved the presentation of the draft.

We believe that our comments in this report along with the modified version of our manuscript have addressed all the concerns raised by the referees. We, therefore, request

the Editor to reconsider our paper for publication in SciPost.