Answer to second referee report

November 5, 2018

Referee's comment: There is an assumption that the bath operators are in a thermal distribution at specific temperature [(59), (60)]. However, as they consist of Bogoliubov modes, the impurity dynamics must modify the bath oscillators, presumably included in (58) at some level of approximation. What condition does this assumption place on evolution times? This consideration is relevant to discussion after (15)

Our reply: A key assumption in our studies, is that the bath is considered to be large, such that the effects of the impurity on the bath are assumed to be negligible. However, that is not to say that there is no backflow of energy between the impurities and the bath. In fact this is studied in more detail in [1]. That the bath oscillators are modified by the impurity dynamics, can be seen in Eq. (21). Nevertheless, in Eqs. (59) and (60), we indeed make this assumption that the bath is large enough such that at any time is in its thermal equilibrium state, which is what allowed us to obtain these equations. This assumption also turns into a condition onto the coupling between bath an impurity, which cannot be too strong (see [1] for the conditions on the coupling strength under which our Hamiltonian is valid).

An amendment was introduced in the text before Eq. (5), in pg. 11.

Requested minor changes:

1. page 4 and equations (2*) contain a lot of different uses of the symbol V , including as trapping potential, interaction potential, and system volume. Please disambiguate. **FIXED**
2. Make (4) consistent with (2b), (2c) containing $\int$ddx for volume integral. **FIXED**
3. At present it is not entirely clear whether xj, pj are classical or quantum variables until later in the article. To clarify equations (2*), it would help the reader for commutators to be supplied. **FIXED**
4. In the development of (8), the authors should state that, as usual, the diagonal form is only valid up to quadratic order in the bath operators.**FIXED**
5. The exponents in (12), (14), (16)-(19), etc, should be formatted as a dot product. **FIXED**
6. Equation (20e) is an empty line. **FIXED**
7. In the unnumbered solutions (number these) after (20e), the first term should read bk(t0)e−iωk(t−t0), etc, to be consistent with the initial condition. Presumably t0 should appear in (22), (23) also. **FIXED**
8. Eq. (27) as written is unclear since BT and W have different dimension, and can't strictly be subtracted. **FIXED**
9. After (36), "In the following sections we solve Eqs (27) and (32) for the cases under study". At this point it would be help the reader (in a long article such as this) to clarify how they are solved. **FIXED**
10. Eq (37) - where does this come from? Presumably the frequencies are found by unpacking (36)? **FIXED**
11. Eq (39) and (40) have different arguments of Θ(), please make consistent. **FIXED**
12. Just before (49): "This can be achieved by introducing an ultraviolet cutoff given by Λ such that only the part of the spectrum where $\omega \ll \Lambda$ remains." is not consistent with the way the cutoff is implemented. It should read $\omega < \Lambda$. [I do not refer to whether the physics is dominated by $\omega \ll \Lambda$, a separate issue, as clarified after (51)]. Both implementations (50) and (51) retain $\omega < \Lambda$. **FIXED**
13. ELN introduced in (73) is different from the y-axis label used in the figures. Please make these consistent, and provide a reference from the caption of figure 1 to (73), so that the more casual reader may identify the definition without combing the text. **FIXED**
14. Appendix B: the imaginary part is italic but real is roman. Please make consistent. **FIXED**
15. Appendix B: before (96) a definition of the incomplete gamma function is given, however there is an upper and a lower, and this appears to be an unusual definition. Please specify. **FIXED**

16. Provide a summary of validity conditions for assumptions, and parameters satisfying them at the end of the formalism, or start of results section. **We expanded and clarified a list with the contraints at pg. 17, start of results section.**

References

[1] A. Lampo, S. H. Lim, M. A. Garcia-March and M. Lewenstein , "Bose polaron as an instance of quantum Brownian motion" , Quantum 1 , 30 (2017)