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To Whom It May Concern,

I am quite happy to act as a member of Mr. Lorenzo Gavassino's PhD committee and provide a review of his PhD thesis. Let me say right away that I find the research accomplished by Mr. Gavassino to be outstanding. The thesis starts with a brief (but nicely written) introduction where Mr. Gavassino introduces the main topics of his research: thermodynamics of relativistic systems, stability under small deviations from equilibrium, and causality. The rest of the thesis is formed by six published papers (one per chapter) about those topics. I will discuss in more detail in this report only a few of these papers/ chapters, which will illustrate why I think the PhD work done by Mr. Gavassino is at the highest level.

In fact, it is very obvious from the publications that Mr. Gavassino has become a specialist in relativistic hydrodynamics and its extension to the general relativity regime, which is very relevant to neutron star mergers. Mr. Gavassino has a number of single-authored papers, which is extremely rare for a graduate student. These numbers are, of course, impressive but what really strikes me when it comes to Mr. Gavassino is the quality, novelty, and the depth of his work. I am a specialist in relativistic hydrodynamics and I can safely say that I am very impressed by his achievements so far.

Mr. Gavassino relies on his knowledge of statistical mechanics and the intuition derived from it to make contributions to the foundations of relativistic fluid dynamics. In a paper published in 2020 in Phys. Rev. D (chapter 6 of the thesis), Mr. Gavassino and collaborators clarified a number of outstanding questions concerning the role played by the 2nd law of thermodynamics in the determination of the stability properties of relativistic fluids. This very well written paper explained in a very clear way why the fluid dynamic formulations devised by Eckart and Landau and Lifshitz are indeed inconsistent with relativity, even though they formally satisfy the 2nd law of thermodynamics. In fact, they showed that their issues with stability and causality stem from the fact that such theories are constructed to always exactly satisfy the 2nd law, even when applied way beyond their regime of validity. This was a very important conceptual result, which again illustrates the type of problems Mr. Gavassino is interested in.

In one of his single-authored published papers (chapter 7), Mr. Gavassino created a quick systematic technique to construct a quadratic Lyapunov-like functional that can be used to investigate the stability properties of relativistic viscous fluid dynamic theories with an entropy current that exactly satisfies the 2nd law of thermodynamics. Before his work, published in Classical and Quantum Gravity Letters, an explicit expression for such a functional was often found by trial and error, without a general physical argument that could guide its elaboration. Mr. Gavassino's paper fixed this issue by providing for the first time both a systematic method for constructing such a functional and also the physics reasoning behind it. The two papers mentioned above would already constitute the core of an excellent PhD thesis in my opinion, but it is important to note that Mr. Gavassino also published a number of other high-quality papers during his PhD thesis (as one can see from the other chapters).

To illustrate the degree of originality of Mr. Gavassino's work, let me also mention another of one of his many published papers, which he published with his collaborators in Phys. Rev. Lett. in 2022. Unfortunately, this paper is not part of the thesis. In this paper, Mr. Gavassino and collaborators showed that relativistic fluids, which possess a well-defined entropy current that is maximized in equilibrium according to the 2nd law of thermodynamics, cannot possess superluminal perturbations that would violate relativistic causality. One may also understand this result as the statement that fluid dynamic formulations that display acausal propagation must be thermodynamically unstable. This important result, which is stated and proven as general theorem in their paper, involves a very clever use of the domain of the dependence property present in hyperbolic PDEs, which I found to be novel and simply put, beautiful.

In fact, it gives a very natural and physical way to understand the result I had previously proven with my collaborators, without the need of all the mathematical complexity we employed. Furthermore, they were able to provide a new connection between causality and information theory, in the context of fluid dynamics, which I believe can be extremely promising. After publishing this paper, Mr. Gavassino wrote another single-authored paper about this topic that significantly extended the results mentioned above.

The body of work Mr. Gavassino published during his PhD (only part of his papers are in the thesis) clearly demonstrate the originality of his work and his interest in the foundational aspects of fluid dynamics. Given that relativistic fluid dynamics is a key tool in astrophysics (neutron star mergers) and also in high energy nuclear physics (heavy-ion collisions), the scientific contributions made by Mr. Gavassino are expected to be broad and multi-disciplinary. I believe that the extremely high quality of work accomplished by Mr. Gavassino is at the level of the best PhD theses one can find at the top institutions in the US and Europe.

Summing up, I consider the doctoral thesis of Mr. Lorenzo Gavassino to be a very valuable contribution and to meet the criteria prescribed by the law for a doctoral dissertation. Therefore, I request that this dissertation be admitted to a public defense.

Sincerely,

Jorge Noronha

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