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Report on the Thesis Manuscript of Paul Barrère

Paul Barrère's thesis, titled ??Modelling Magnetar Formation," presents a comprehensive study of the state-of-the-art of the problem of magnetic field generation in newly born neutron stars. The manuscript, divided into nine chapters, addresses the problem from theoretical, numerical, and observational points of view. It also includes an appendix that reproduces two published papers where Barrère is the first author and two submitted publications where he is the second author.

First part of the Thesis

The introductory section, encompassing chapters 1 through 4, provides a detailed yet concise overview of various facets of magnetar research. Specifically, these chapters cover:

- Chapter 1: Observational Properties of Magnetars

  This chapter reviews the observed characteristics and phenomena associated with magnetars, such as bursts, outbursts, hypernovae, and superluminous supernovae. It concludes with a summary of the key observational facts, establishing a solid motivation for the thesis.

- Chapter 2: Magnetar Formation Scenarios

  This chapter delves into the long-standing and unresolved question of how magnetars form. It reviews various dynamo-like mechanisms based on hydrodynamic and magnetohydrodynamic (MHD) processes, providing a comprehensive analysis. However, as a minor drawback, the chapter does not address alternative –microphysical origin– mechanisms, which might have added historical completeness. The discussion concludes with the introduction of a new scenario central to this thesis: the Tayler-Spruit dynamo.

- Chapter 3: Basics of MHD Theory

  This chapter focuses on MHD theory, which is crucial for understanding dynamo theories, particularly the Tayler-Spruit dynamo. The author explains the fundamental principles of MHD, emphasizing their relevance to his research.

- Chapter 4: Numerical Modelling with MagIC Code

  This chapter describes the numerical code MagIC, which has been extensively used by his research group over the past decade. The chapter explains the code's functionality and its application in modelling astrophysical sources.

These initial chapters provide a self-contained overview, demonstrating a deep understanding of the research context and fundamental concepts necessary for his investigation.

Additional Chapters and Overall Contributions

Chapter 5 stands as perhaps the pivotal chapter of the thesis, introducing a novel scenario for Tayler-Spruit dynamos within the context of a rapidly rotating photo-neutron star (PNS). This scenario focuses on a specific case where a rapidly rotating PNS experiences a substantial increase in angular momentum due to fallback accretion, resulting in strong differential rotation. Following a detailed exposition of the mathematical framework and governing equations, the chapter argues for the amplification of the magnetic field, potentially leading to the formation of a magnetar. This chapter, along with the subsequent one, which further extends into the relevance of the differential rotation, constitutes the original contributions of this research. Additionally, Chapter 7 examines the impact of stable stratification on this dynamo process. These three chapters collectively encompass the content of two published articles and another submitted one, highlighting the innovative nature of this thesis research.

Chapter 8 concentrates on the dynamics of the dynamo itself, rather than the magnetic field strength, which was the focal point of the previous chapters that were specifically applied to the context of magnetar formation. The insights presented here aim at deciphering the underlying mechanisms driving the dynamo process. This part is apparently being prepared for submission to Physical Review Fluids, adding more potentially original content to the Thesis.

Finally, the concluding chapter 9 bridges the short-term evolution of the PNS with its long-term development over thousands to millions of years. This section is the product of a collaboration with the Leeds group. It is perhaps the weakest part of the thesis, being brief and underdeveloped. A more detailed and thorough effort to connect these findings with observations would have been desirable. Additionally, the microphysical ingredients (the absolute key ingredient in this part) are not well described. Although the results align with previous works on similar scenarios, the chapter's excessive conciseness and partial lack of originality give the impression of an incomplete work, possibly still in progress.

Overall, the work presented in this thesis is consistent, rigorous, and methodical. It paves the way for (yet another) promising explanation of magnetic field amplification in a proto-neutron star. Paul Barrére has demonstrated his ability to understand, analyze, and interpret the data from his simulations, making them more intelligible by elucidating the underlying physical mechanisms. The conclusion of the thesis synthesizes the research findings, highlighting their significance and potential impact on the field. The inclusion of published and submitted papers in the appendix showcases the author's contributions to the field but also provides additional validation of his research. In summary, Paul's thesis represents a significant contribution to the study of magnetar formation, combining theoretical insight, numerical expertise, and some observational analysis. His work offers a pedagogical understanding of the complex processes underlying magnetar formation, positioning him as a rising researcher in the field.

He fully deserves to present this thesis in pursuit of a PhD degree.

Sincerely,

Prof. José A. Pons
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University of Alicante