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Report on the doctoral thesis of Mehraveh Nikjoo
entitled *The Gravitating Universe*

The doctoral dissertation *The Gravitating Universe*, submitted by Mehraveh Nikjoo, addresses several contemporary topics in gravitational physics and cosmology. It combines developments in the mathematical foundations of gravitational theory with phenomenological studies of inflationary cosmology and analyses of modern observational probes, including weak gravitational lensing and the stochastic gravitational-wave background. Such breadth is uncommon in a doctoral dissertation and demonstrates the candidate's ability to work successfully across the theoretical, computational, and observational aspects of modern gravitational physics.

The dissertation comprises five substantive chapters, preceded by an introduction and followed by four technical appendices. Although the individual research projects are largely independent, they are united by the overarching aim of understanding gravitation, from its fundamental formulation to its observational consequences. The candidate's publication record includes three papers published in *Physical Review D* and *Classical and Quantum Gravity*, as well as a recent arXiv preprint awaiting publication. Three of these works are directly related to the contents of the dissertation. Taken together, they constitute a body of research that meets the usual expectations for a PhD candidate in the field.

Chapter 1 reviews the theoretical foundations required in the remainder of the dissertation. Beginning with the representation theory of the Lorentz group and its complexification, the author develops the mathematical machinery needed for gauge formulations of gravity, including spinors, differential forms, Einstein–Cartan gravity, Hamiltonian methods, and the Ashtekar formalism. The chapter is pedagogical and comprehensive and could serve as a self-contained introduction to modern formulations of gravitation.

Chapter 2 presents the first major original contribution of the dissertation. The author develops a Hamiltonian formulation of a class of gravitational theories interpreted as spontaneously broken gauge theories of the complexified Lorentz group. The analysis systematically derives the constraint structure and determines the number of propagating

degrees of freedom.

Chapter 3 provides a bridge between the mathematical formulation of gravity and its cosmological applications. It reviews the standard cosmological framework, inflationary dynamics, cosmological perturbation theory, and observational probes, including gravitational waves and weak gravitational lensing. Although primarily introductory, the material is presented clearly and provides the theoretical background needed to understand the original research discussed in the subsequent chapters.

Chapter 4 investigates an inflationary model motivated by left–right-symmetric extensions of particle physics. The author develops the cosmological background equations, derives the perturbation equations, performs extensive numerical analyses, and explores the model's viable parameter space. Particular attention is devoted to the role of the effective Barbero–Immirzi parameter. The numerical study demonstrates that, within the phenomenologically viable parameter space, this parameter has no statistically significant effect on observable inflationary quantities. In addition to developing the theoretical model, the chapter presents a substantial body of original numerical work, including parameter-space exploration, emulator development, feature-importance analysis, and the statistical interpretation of the results.

Chapter 5 focuses on two observational studies. The first concerns weak gravitational lensing by photometric density ridges using Dark Energy Survey Year 3 data. In addition to reporting a statistically significant detection of the ridge-lensing signal, the study introduces improvements to the ridge-identification methodology and uses numerical simulations to examine the signal's dependence on cosmological and algorithmic parameters. The second study analyses tomographic cross-correlations between galaxy surveys and maps of the stochastic gravitational-wave background constructed from LIGO–Virgo observations.

Overall, the dissertation is of high scientific quality. Its principal strengths are the breadth of the topics addressed, the technical sophistication of the theoretical developments, the effective combination of analytical calculations with numerical and observational methods, and the generally clear presentation. The original contributions span several distinct research directions, including Hamiltonian formulations of gauge gravity, phenomenological studies of inflationary models, methodological advances in weak-lensing analyses, and observational studies of the stochastic gravitational-wave background. This diversity demonstrates the candidate's versatility and broad expertise in gravitational physics and cosmology. Nevertheless, in my opinion, several aspects of the dissertation could be improved.

- Chapter 4 would benefit from a more detailed discussion of the model's prospects for experimental detection. In particular, the range of predicted values of the tensor-to-scalar ratio r is not entirely clear. Is its upper limit determined solely by current observational constraints? What fraction of the viable parameter space could be

probed by planned experiments?

- The phenomenological significance of the Barbero–Immirzi parameter in Chapter 4 also requires clarification. The analysis indicates that its effect on the observables considered is not statistically significant, yet the conclusions emphasize its importance. It would be helpful to explain more explicitly whether, and under what circumstances, this parameter is phenomenologically relevant.
- Chapter 5 ends somewhat abruptly. Given that no stochastic gravitational-wave background has yet been detected in the data considered, the absence of a statistically significant cross-correlation is understandable. Nevertheless, a discussion of the expected signal and the prospects for future observations would be valuable. In its present form, the reader must consult the original publication for this information.

Despite these reservations, my overall assessment of the dissertation is very positive. In conclusion, I find that the dissertation fully meets the standards expected of a PhD thesis, and I recommend that Mehraveh Nikjoo be admitted to the doctoral defence.

Conclusion in the Polish language:

Podsumowując, w mojej ocenie rozprawa doktorska w pełni spełnia wymagania stawiane pracom doktorskim i wnioskuję o dopuszczenie mgr Mehraveh Nikjoo do obrony rozprawy doktorskiej.

Signed by / Podpisano przez:

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