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November 29, 2022

Assessment of the doctoral thesis presented by Paritosh Verma

Paritosh Verma presented a doctoral dissertation entitled ``Gravitational diopole and quadrupole radiation from pulsars.'' The thesis is 103 pages long; it consists of 5 chapters and 4 appendices. Paritosh Verma's dissertation is devoted to a study of gravitational waves emitted by pulsars within the Brans-Dicke theory (and hence the dipole radiation in the title). The author discusses methods of a possible detection of such gravitational waves in current detectors of gravitational waves and performs an actual search in LIGO-Virgo O2 and O3 data.

Paritosh Verma's thesis has been written in a traditional way – as a self-contained work, but his results have already been published in international journals in the following papers:

1. Andrzej Królak, Paritosh Verma, Recent observations of gravitational waves by ligo and virgo detectors, Universe 7, 137 (2021)
2. Paritosh Verma, Probing gravitational waves from pulsars in brans–dicke theory, Universe 7, 235 (2021)
3. Paritosh Verma, A Swinging Rod in Brans-Dicke Theory, Annalen der Physik, 2100600 (2022)
4. LIGO-Virgo-KAGRA Collaborations, Searches for Gravitational Waves from Known Pulsars at Two Harmonics in the Second and Third LIGO-Virgo Observing Runs, The Astrophysical Journal 935, 1 (2022)

Paritosh Verma is also a co-author of several recent publications by the Virgo Collaboration (similar to paper 4 in the above list).

The first chapter of the thesis presents a general introduction to gravitational waves. The author discusses astrophysically relevant sources and gravitational wave detectors. The second key chapter introduces the Brans-Dicke theory, putting emphasis on the propagation of gravitational waves. In the third chapter the author considers gravitational waves emitted by a ``mountain'' on a pulsar surface. A new element is related to the differences in the expected gravitational wave signal computed within General Relativity (GR) and the Brans-Dicke theory, respectively. In the same chapter the author computes the expected detector response to the gravitational wave signal and

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introduces a suitable detection statistic. Chapter 4 reports results of Monte Carlo simulations testing the proposed data analysis method. Chapter 5 presents real-data results – a search of gravitational waves emitted from pulsars in the LIGO-Virgo O2 and O3 data. The results turn out to be negative – no statistically significant signal has been detected – but they can be interpreted as yielding an upper bound on the amplitude of gravitational waves.

The thesis is followed by 4 appendices. Appendix A is devoted to the multipole expansion and discusses a relation between the spherical-harmonic decomposition and an expansion formalism based on symmetric trace-free tensors. Appendix B recalls basic facts related to the χ^2 distribution. Many details concerning the statistical method developed in this thesis are collected in Appendix C. Appendix D gives basic formulas involving the power emitted by a pulsar in the form of gravitational waves.

In this thesis gravitational waves are described in the linear approximation, which is sufficient to capture differences between the Brans-Dicke theory and GR. The source of the gravitational radiation – the ``mountain'' on the pulsar surface – is approximated by a point mass, rotating with a given frequency. The emission of the gravitational radiation is approximated by the multipole expansion.

The main achievement of this thesis is, in my opinion, the development of a statistical method suited for a detection of gravitational waves originating from pulsars, including the possibility to detect gravitational waves signals allowed by the Brans-Dicke theory. Paritosh Verma's work is complete – his theoretical framework is checked against real LIGO-Virgo data. This last step is of course demanding, and it requires technical skills and knowledge in the actual data analysis. I believe that the method developed in this thesis can be repeated in the future with more accurate and sensitive observational data.

Paritosh Verma's dissertation is clearly written and well organized. I have no serious critical comments. The only critical remarks, which I list below, are mostly of typographical character.

1. Fig. 1.1. Plus and cross tensor polarizations are depicted with blue lines, while the text in caption of this figure refers to black ones.
2. Page 7. Chandrasekhar's limit of 1.44 solar masses is only an approximate value, which in real conditions, depends on several factors, including the chemical composition of a star, possible rotation, etc.
3. Page 27. ``Lorentz gauge'' should be spelled as ``Lorenz gauge''.
4. Page 44. The quantity T_0 is not defined around Eq. (3.79), where it appears for the first time. The definition – as an observation time – appears only two pages later.

5. Fig 4.6. Upper right panel: There is only one label at the ordinate axis, and consequently one has to guess the numbers the other ticks refer to.
6. Pages 65, 67: the same typo appears a few times: CW instead of GW.
7. Page 72, after Eq. (A.10): In general, a function needs to be of a class C^2 to ensure that the partial derivatives to commute.

None of those tiny errors, mostly unrelated to the main discussion in this thesis, diminish my very high opinion on the presented results, their originality, and the overall quality of the thesis. I believe that they constitute a valuable contribution to the gravitational wave physics.

Let me also note that the topic investigated by Paritosh Verma is timely and important. Gravitational wave physics belongs to the forefront of current research both in gravity and astrophysics.

One should also stress that at least two of Paritosh Verma's papers listed at the beginning of this report are single authored, proving that he is already a matured and independent researcher.

Summing up, I consider the doctoral thesis of Paritosh Verma to be a 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.

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