Directed searches for gravitational waves from ultralight boson clouds around stellar mass black holes

Maximiliano Isi,[1,2] Ling Sun,[2,3,4] Richard Brito,[5,6] and Andrew Melatos[3,4]

[1] *LIGO Laboratory, Massachusetts Institute of Technology, Cambridge, Massachusetts 02139, USA*
[2] *LIGO Laboratory, California Institute of Technology, Pasadena, California 91125, USA*
[3] *School of Physics, University of Melbourne, Parkville, Victoria 3010, Australia*
[4] *Australian Research Council Centre of Excellence for Gravitational Wave Discovery (OzGrav)*
[5] *Max Planck Institute for Gravitational Physics (Albert Einstein Institute), Am Mühlenberg 1, Potsdam-Golm, 14476, Germany*
[6] *Dipartimento di Fisica, "Sapienza" Università di Roma & Sezione INFN Roma1, Piazzale Aldo Moro 5, 00185, Roma, Italy*

Gravitational-wave (GW) detectors can be used to search for yet-undiscovered ultralight bosons, including those conjectured to solve problems in particle physics, high-energy theory and cosmology. In particular, ground-based instruments could probe ultralight bosons with masses $\sim 10^{-15}$–10^{-11} eV, which are largely inaccessible to other experiments. The number of ultralight boson particles around a rapidly rotating black hole (BH) can grow exponentially due to the phenomenon of superradiance, forming a macroscopic cloud and generating continuous quasi-monochromatic GW signals. We explore the prospect of searching for such signals generated by boson clouds around known BHs [1–8]. We model the signal waveforms using the latest-available numerical results, and demonstrate the suitability of a specific search algorithm based on a hidden Markov model to efficiently search for such signals, even when the source parameters are not perfectly known and allowing for some uncertainty in theoretical predictions [9–12]. There are two types of promising sources for directed searches: (1) remnants from compact binary coalescences (CBCs), and (2) known BHs in X-ray binaries [3, 13, 14]. For CBC remnants, due to their typically relatively large distance, prospects only become good with future detectors (LIGO Voyager, Cosmic Explorer, and Einstein Telescope). The X-ray binaries have the advantages of being much closer and better measured location, and hence might be within the sensitive range of existing detectors. However, the impact from the active astrophysical environment surrounding these BHs is not well understood, and there are technical challenges in searching for sources in binaries. Advantages and limitations of interesting candidate sources are discussed, along with preliminary results from analyzing Advanced LIGO observational data.

---

[1] A. Arvanitaki and S. Dubovsky, Physical Review D **83**, 044026 (2011).
[2] H. Yoshino and H. Kodama, Progress of Theoretical and Experimental Physics **2014**, 43E02 (2014).
[3] H. Yoshino and H. Kodama, Progress of Theoretical and Experimental Physics **2015** (2015).
[4] A. Arvanitaki, M. Baryakhtar, and X. Huang, Physical Review D **91**, 084011 (2015).
[5] A. Arvanitaki, M. Baryakhtar, S. Dimopoulos, S. Dubovsky, and R. Lasenby, Physical Review D **95**, 043001 (2017).
[6] R. Brito, S. Ghosh, E. Barausse, E. Berti, V. Cardoso, I. Dvorkin, A. Klein, and P. Pani, Physical Review Letters **119**, 131101 (2017).
[7] R. Brito, S. Ghosh, E. Barausse, E. Berti, V. Cardoso, I. Dvorkin, A. Klein, and P. Pani, Physical Review D **96**, 064050 (2017).
[8] M. Baryakhtar, R. Lasenby, and M. Teo, Phys. Rev. D **96**, 035019 (2017), ISSN 2470-0010.
[9] S. Suvorova, L. Sun, A. Melatos, W. Moran, and R. J. Evans, Physical Review D **93**, 123009 (2016).
[10] B. P. Abbott et al., Phys. Rev. D **95**, 122003 (2017).
[11] L. Sun, A. Melatos, S. Suvorova, W. Moran, and R. J. Evans, Phys. Rev. D **97**, 043013 (2018).
[12] M. Isi, L. Sun, R. Brito, and A. Melatos (2018), 1810.03812.
[13] R. A. Remillard and J. E. McClintock, Ann. Rev. Astron. Astrophys. **44**, 49 (2006).
[14] M. Middleton, in *Astrophysics of Black Holes: From Fundamental Aspects to Latest Developments*, edited by C. Bambi (2016), vol. 440 of *Astrophysics and Space Science Library*, p. 99.