

Lopes, Ilídio; Panotopoulos, Grigoris

Radial oscillations of boson stars made of ultralight repulsive dark matter. (English)

Zbl 1475.85009

Nucl. Phys., B 961, Article ID 115266, 13 p. (2020).

Summary: We compute the lowest frequency radial oscillation modes of boson stars. It is assumed that the object is made of pseudo-Goldstone bosons subjected to a scalar potential that leads to a repulsive self-interaction force, and which is characterized by two unknown mass scales m (mass of the particle) and F (decay constant). First we integrate the Tolman-Oppenheimer-Volkoff equations for the hydrostatic equilibrium of the star, and then we solve the Sturm-Liouville boundary value problem for the perturbations using the shooting method. The effective potential that enters into the Schrödinger-like equation as well as several associated eigenfunctions are shown as well. Moreover, we found that the large frequency separation, i.e. the difference between consecutive modes, is proportional to the square root of the mass of the star and the cube of the mass scale defined by $\Lambda \equiv \sqrt{mF}$.

MSC:

- 85A15 Galactic and stellar structure
- 81V25 Other elementary particle theory in quantum theory
- 81V73 Bosonic systems in quantum theory
- 83C56 Dark matter and dark energy
- 81T12 Effective quantum field theories
- 76E20 Stability and instability of geophysical and astrophysical flows

Full Text: [DOI](#) [arXiv](#)

References:

- [1] Zwicky, F., *Helv. Phys. Acta*, **41**, 207 (2009)
- [2] Rubin, V. C.; Ford, W. K., *Astrophys. J.*, **159**, 379 (1970)
- [3] Turner, M., *Rev. Mod. Phys.*, **75**, 1433 (2003)
- [4] Olive, K. A., TASI lectures on dark matter
- [5] Munoz, C., *Int. J. Mod. Phys. A*, **19**, 3093 (2004)
- [6] Gascon, J., *EPJ Web Conf.*, **95**, 02004 (2015)
- [7] Gaskins, J. M., *Contemp. Phys.*, **57**, 4, 496 (2016)
- [8] Kahlhoefer, F., *Int. J. Mod. Phys. A*, **32**, 13, Article 1730006 pp. (2017)
- [9] Tulin, S.; Yu, H.-B. (2017), arXiv e-prints
- [10] Spergel, D. N.; Steinhardt, P. J., *Phys. Rev. Lett.*, **84**, 3760 (2000)
- [11] Dave, R.; Spergel, D. N.; Steinhardt, P. J.; Wandelt, B. D., *Astrophys. J.*, **547**, 574 (2001)
- [12] Tkachev, I. I., *Sov. Astron. Lett.*, **12**, 305 (1986)
- [13] Goodman, J., *New Astron.*, **5**, 103 (2000)
- [14] Peebles, P. J.E., *Astrophys. J.*, **534**, L127 (2000)
- [15] Weinberg, S., *Phys. Rev. Lett.*, **40**, 223 (1978)
- [16] Wilczek, F., *Phys. Rev. Lett.*, **40**, 279 (1978)
- [17] Peccei, R. D.; Quinn, H. R., *Phys. Rev. Lett.*, **38**, 1440 (1977)
- [18] Peccei, R. D.; Quinn, H. R., *Phys. Rev. D*, **16**, 1791 (1977)
- [19] Marsh, D. J.E., *Phys. Rep.*, **643**, 1-79 (2016)
- [20] Taoso, M.; Bertone, G.; Masiero, A., *J. Cosmol. Astropart. Phys.*, **0803**, Article 022 pp. (2008)
- [21] Green, M. B.; Schwarz, J. H.; Witten, E., *Superstring Theory*, vols. 1 & 2, Cambridge Monographs on Mathematical Physics (2012), Cambridge University Press: Cambridge University Press Cambridge, England
- [22] Polchinski, J., *String Theory*, vols. 1 & 2, Cambridge Monographs on Mathematical Physics (2005), Cambridge University Press: Cambridge University Press Cambridge, England

- [23] Svrcek, P.; Witten, E., *J. High Energy Phys.*, 0606, Article 051 pp. (2006)
- [24] Arvanitaki, A.; Dimopoulos, S.; Dubovsky, S.; Kaloper, N.; March-Russell, J., *Phys. Rev. D*, 81, Article 123530 pp. (2010)
- [25] Kim, J. E.; Marsh, D. J.E., *Phys. Rev. D*, 93, 2, Article 025027 pp. (2016)
- [26] Freese, K.; Frieman, J. A.; Olinto, A. V., *Phys. Rev. Lett.*, 65, 3233 (1990)
- [27] Adams, F. C.; Bond, J. R.; Freese, K.; Frieman, J. A.; Olinto, A. V., *Phys. Rev. D*, 47, 426 (1993)
- [28] Savage, C.; Freese, K.; Kinney, W. H., *Phys. Rev. D*, 74, Article 123511 pp. (2006)
- [29] Freese, K.; Kinney, W. H., *J. Cosmol. Astropart. Phys.*, 1503, Article 044 pp. (2015)
- [30] Kim, J. E.; Nilles, H. P., *J. Cosmol. Astropart. Phys.*, 0905, Article 010 pp. (2009)
- [31] Dimopoulos, K.; Cormack, S., *Astropart. Phys.*, 85, 35 (2016)
- [32] Tkachev, I. I., *Phys. Lett. B*, 261, 289 (1991)
- [33] Barranco, J.; Bernal, A., *Phys. Rev. D*, 83, Article 043525 pp. (2011)
- [34] Eby, J.; Suranyi, P.; Vaz, C.; Wijewardhana, L. C.R., *J. High Energy Phys.*, *J. High Energy Phys.*, 1611, Article 134 pp. (2016), (Erratum)
- [35] Guth, A. H.; Hertzberg, M. P.; Prescod-Weinstein, C., *Phys. Rev. D*, 92, 10, Article 103513 pp. (2015)
- [36] Braaten, E.; Mohapatra, A.; Zhang, H., *Phys. Rev. Lett.*, 117, 12, Article 121801 pp. (2016)
- [37] Chavanis, P. H.
- [38] Visinelli, L.; Baum, S.; Redondo, J.; Freese, K.; Wilczek, F., *Phys. Lett. B*, 777, 64 (2018)
- [39] Kaup, D. J., *Phys. Rev.*, 172, 1331 (1968)
- [40] Ruffini, R.; Bonazzola, S., *Phys. Rev.*, 187, 1767 (1969)
- [41] Colpi, M.; Shapiro, S. L.; Wasserman, I., *Phys. Rev. Lett.*, 57, 2485 (1986)
- [42] Kusmartsev, F. V.; Mielke, E. W.; Schunck, F. E., *Phys. Rev. D*, 43, 3895 (1991)
- [43] Boehmer, C. G.; Harko, T., *J. Cosmol. Astropart. Phys.*, 0706, Article 025 pp. (2007)
- [44] Schunck, F. E.; Mielke, E. W., *Class. Quantum Gravity*, 20, R301 (2003)
- [45] Pires, M. O.C.; Souza, J. C.C., *J. Cosmol. Astropart. Phys.*, *J. Cosmol. Astropart. Phys.*, *J. Cosmol. Astropart. Phys.*, 1311, E01 (2013), (Erratum)
- [46] Souza, J. C.C.; Ujevic, M., *Gen. Relativ. Gravit.*, 47, 9, 100 (2015)
- [47] Eby, J.; Kouvaris, C.; Nielsen, N. G.; Wijewardhana, L. C.R., *J. High Energy Phys.*, 1602, Article 028 pp. (2016)
- [48] Croon, D.; Fan, J.; Sun, C.
- [49] Chavanis, P. H., *Phys. Rev. D*, 84, Article 043531 pp. (2011)
- [50] Chavanis, P. H.; Delfini, L., *Phys. Rev. D*, 84, Article 043532 pp. (2011)
- [51] Turck-Chièze, S.; Lopes, I., *Res. Astron. Astrophys.*, 12, 1107-1138 (2012)
- [52] Kelley, K.; Quinn, P. J., *Astrophys. J.*, 845, L4 (2017)
- [53] Cox, J. P., *Annu. Rev. Astron. Astrophys.*, 14, 247 (1976)
- [54] Frandsen, S., *Astron. Astrophys.*, 394, L5 (2002)
- [55] De Ridder, J.; Molenberghs, G.; Aerts, C., *Appl. Stat.*, 65, 1 (2005)
- [56] Hekker, S., *Astrophys. J.*, 713, L187 (2010)
- [57] Våth, H. M.; Chamugan, G., *Astron. Astrophys.*, 260, 250-254 (1992)
- [58] Kokkotas, K. D.; Ruoff, J., *Astron. Astrophys.*, 366, 565 (2001)
- [59] Brillante, A.; Mishustin, I. N., *Europhys. Lett.*, 105, 3, Article 39001 pp. (2014)
- [60] Gupta, V. K.; Tuli, V.; Goyal, A., *Astrophys. J.*, 579, 374 (2002)
- [61] Panotopoulos, G.; Lopes, I., *Phys. Rev. D*, 96, 8, Article 083013 pp. (2017)
- [62] Guth, A. H., *Phys. Rev. D*, 23, 347 (1981)
- [63] Fan, J., *Phys. Dark Universe*, 14, 84 (2016)
- [64] Dalfovo, F.; Giorgini, S.; Pitaevskii, L. P.; Stringari, S., *Rev. Mod. Phys.*, 71, 463 (1999)
- [65] Leggett, A. J., *Rev. Mod. Phys.*, *Rev. Mod. Phys.*, *Rev. Mod. Phys.*, 75, 1083 (2003), (Erratum)
- [66] Pethick, C. J.; Smith, H., *Bose-Einstein Condensation in Dilute Gases* (2008), Cambridge University Press: Cambridge University Press Cambridge
- [67] Oppenheimer, J. R.; Volkoff, G. M., *Phys. Rev.*, 55, 374 (1939)
- [68] Tolman, R. C., *Phys. Rev.*, 55, 364 (1939)
- [69] Mielke, E. W.; Schunck, F. E.
- [70] Li, X. Y.; Harko, T.; Cheng, K. S., *J. Cosmol. Astropart. Phys.*, 1206, Article 001 pp. (2012)
- [71] Li, X.; Wang, F.; Cheng, K. S., *J. Cosmol. Astropart. Phys.*, 1210, Article 031 pp. (2012)

- [72] Chanmugan, G., *Astrophys. J.*, 217, 799 (1977)
- [73] Lopes, I. P., *Mon. Not. R. Astron. Soc.*, 321, 615-624 (2001)
- [74] Shapiro, S. L.; Teukolski, S. A., *Black Holes, White Dwarfs and Neutron Stars: The Physics of Compact Objects* (1983), Wiley: Wiley New York, USA, 645 pp.
- [75] Lopes, I.; Turck-Chieze, S., *Astron. Astrophys.*, 290, 845-860 (1994)
- [76] Casanellas, J.; Lopes, I., *Mon. Not. R. Astron. Soc.*, 410, 535 (2011)
- [77] Raby, S., *Phys. Rev. D*, 94, Article 103004 pp. (2016)
- [78] Iwazaki, A., *Phys. Rev. D*, 91, 2, Article 023008 pp. (2015)
- [79] Postnikov, S.; Prakash, M.; Lattimer, J. M., *Phys. Rev. D*, 82, Article 024016 pp. (2010)
- [80] Maselli, A.; Pnigouras, P.; Nielsen, N. G.; Kouvaris, C.; Kokkotas, K. D., *Phys. Rev. D*, 96, 2, Article 023005 pp. (2017)
- [81] Cardoso, V.; Franzin, E.; Maselli, A.; Pani, P.; Raposo, G., *Phys. Rev. D*, *Phys. Rev. D*, *Phys. Rev. D*, 95, 8, Article 089901 pp. (2017), (Addendum)
- [82] Hinderer, T., *Astrophys. J.*, 677, 1216 (2008)
- [83] Kashiyaama, K.; Oguri, M.
- [84] Khmelnitsky, A.; Rubakov, V., *J. Cosmol. Astropart. Phys.*, 002, Article 019 pp. (2014)
- [85] Amaro-Seoane, P., *GW Notes*, vol. 6, 2013, pp. 4-110
- [86] Lopes, I.; Silk, J., *Astrophys. J.*, 807, 135 (2015)

This reference list is based on information provided by the publisher or from digital mathematics libraries. Its items are heuristically matched to zbMATH identifiers and may contain data conversion errors. It attempts to reflect the references listed in the original paper as accurately as possible without claiming the completeness or perfect precision of the matching.