Black holes in alternative theories and the structure of accretion disc

Indrani Banerjee, Sumanta Chakraborty* and Soumitra SenGupta

Department of Theoretical Physics, Indian Association for the Cultivation of Science Kolkata 700032, India.
**Email:sumantac.physics@gmail.com*

Continuum spectrum from black hole accretion disc holds enormous information regarding the strong gravity regime around the black hole and hence about the nature of gravitational interaction in extreme situations. To explore them I will discuss effects of these alternative theories on the black hole continuum spectrum in an explicit manner. In the scenarios under consideration we have shown that there can be signatures sculptured on the black hole continuum spectrum, distinct from the standard general relativistic scenario. Interestingly, all these models exhibit black hole solutions with tidal charge parameter which can become negative, in sharp contrast with the situation in general relativity. Using the observational data of optical luminosity for eighty Palomer Green quasars we have illustrated that the difference between the theoretical estimates and the observational results gets minimized for negative values of the tidal charge parameter, signaling the possibility of higher dimensions or, scalar hair at play in those high gravity regimes.

Keywords: Accretion process; Extra dimensions

In this talk our main aim was to understand the distinctive signature of alternative gravity theories in the context of black hole continuum spectrum. In particular we were mainly interested in possible effects on the electromagnetic emission from accretion disc around black holes due to presence of higher dimensions, higher curvature as well as scalar hairs in the theory. We have discussed three such possible scenarios — (i) Higher dimensions manifested by modification of lower dimensional gravitational field equations, (ii) Einstein-Gauss-Bonnet gravity in higher spacetime dimensions modifying black hole solutions in four-dimensions and finally (iii) scalar hairs in black hole spacetime, inherited by Horndeski (or, generalised Horndeski) models. Interestingly in all the three scenarios, black hole solutions inherit tidal charge parameters which can be negative, in contrast with the Reissner-Nordstr´omscenario. Thus if the sign of tidal charge parameter can be estimated by some means it will provide an interesting window to look for possible signatures of these alternative gravity models.

For this purpose, we have used the continuum spectrum emanating from accretion disc around supermassive black holes for this purpose, where the effect of gravity theory beyond Einstein is most prominent and the imprint of tidal charge parameter on the continuum spectrum can be estimated. Keeping this in mind, we have studied 80 quasars harboring supermassive black holes and have provided a qualitative estimate of the difference between theoretical and observational results, showing a minimization of error for negative values of the tidal charge parameter. We have made this statement more quantitative by discussing several estimators of errors — (a) reduced χ^2, (b) Nash-Sutcliffe Efficiency, (c) index of agreement and modified versions of the last two respectively. Most interestingly, all of them points towards a negative value for the tidal charge parameter, minimizing deviation from observations. This may indicate emergence of alternative gravity models harbouring black holes beyond Schwarzschild. The models with extra dimensions as well as scalar hairs are seemingly two such natural choices.

The above analysis opens up new observational avenues to explore, such as, measurement of strong gravitational lensing using VLBI, or understanding the gravitational waveform emanating from collision of two black holes with higher precision (e.g., using Advanced Laser Interferometer Gravitational-wave Observatory or Laser Interferometer Space Antenna) and their implications on these alternative gravity theories. It may also be worthwhile to explore the robustness of our result in more detail, e.g., whether the conclusion is affected if one considers some other sample of supermassive black holes or, how much dependent the results are on the statistics. Further, one can search for other alternative gravity theories, such as, gravity with torsion, pure Lovelock theories and $f(R)$ theories, in a similar context. We are currently pursuing some of these aspects and will possibly report elsewhere.

References

1. T. Clifton, P. G. Ferreira, A. Padilla, and C. Skordis, "Modified Gravity and Cosmology," *Phys. Rept.* **513** (2012) 1–189, `arXiv:1106.2476 [astro-ph.CO]`.
2. S. Capozziello and M. De Laurentis, "Extended Theories of Gravity," *Phys. Rept.* **509** (2011) 167–321, `arXiv:1108.6266`

[gr-qc].
3. S. Nojiri, S. D. Odintsov, and V. K. Oikonomou, "Modified Gravity Theories on a Nutshell: Inflation, Bounce and Late-time Evolution," arXiv:1705.11098 [gr-qc].
4. C. M. Will, "The Confrontation between General Relativity and Experiment," *Living Rev. Rel.* **17** (2014) 4, arXiv:1403.7377 [gr-qc].
5. C. Lanczos, "Electricity as a natural property of Riemannian geometry," *Rev. Mod. Phys.* **39** (1932) 716–736.
6. D. Lovelock, "The Einstein tensor and its generalizations," *J. Math. Phys.* **12** (1971) 498–501.
7. T.Padmanabhan, *Gravitation: Foundations and Frontiers.* Cambridge University Press, Cambridge, UK, 2010.
8. T. Padmanabhan and D. Kothawala, "Lanczos-Lovelock models of gravity," *Phys.Rept.* **531** (2013) 115–171, arXiv:1302.2151 [gr-qc].
9. N. Dadhich, "Characterization of the Lovelock gravity by Bianchi derivative," *Pramana* **74** (2010) 875–882, arXiv:0802.3034 [gr-qc].
10. S. Nojiri and S. D. Odintsov, "Modified f(R) gravity consistent with realistic cosmology: From matter dominated epoch to dark energy universe," *Phys. Rev.* **D74** (2006) 086005, arXiv:hep-th/0608008 [hep-th].
11. S. Capozziello, S. Nojiri, S. D. Odintsov, and A. Troisi, "Cosmological viability of f(R)-gravity as an ideal fluid and its compatibility with a matter dominated phase," *Phys. Lett.* **B639** (2006) 135–143, arXiv:astro-ph/0604431 [astro-ph].
12. S. Bahamonde, S. D. Odintsov, V. K. Oikonomou, and M. Wright, "Correspondence of $F(R)$ Gravity Singularities in Jordan and Einstein Frames," arXiv:1603.05113 [gr-qc].
13. S. Chakraborty and S. SenGupta, "Solving higher curvature gravity theories," *Eur. Phys. J.* **C76** no. 10, (2016) 552, arXiv:1604.05301 [gr-qc].
14. T. Shiromizu, K.-i. Maeda, and M. Sasaki, "The Einstein equation on the 3-brane world," *Phys.Rev.* **D62** (2000) 024012, arXiv:gr-qc/9910076 [gr-qc].
15. N. Dadhich, R. Maartens, P. Papadopoulos, and V. Rezania, "Black holes on the brane," *Phys.Lett.* **B487** (2000) 1–6, arXiv:hep-th/0003061 [hep-th].

16. T. Harko and M. Mak, "Vacuum solutions of the gravitational field equations in the brane world model," *Phys.Rev.* **D69** (2004) 064020, `arXiv:gr-qc/0401049 [gr-qc]`.
17. T. R. P. Carames, M. E. X. Guimaraes, and J. M. Hoff da Silva, "Effective gravitational equations for $f(R)$ braneworld models," *Phys. Rev.* **D87** no. 10, (2013) 106011, `arXiv:1205.4980 [gr-qc]`.
18. T. Kobayashi, T. Shiromizu, and N. Deruelle, "Low energy effective gravitational equations on a Gauss-Bonnet brane," *Phys. Rev.* **D74** (2006) 104031, `arXiv:hep-th/0608166 [hep-th]`.
19. T. Shiromizu and K. Koyama, "Low-energy effective theory for two brane systems: Covariant curvature formulation," *Phys. Rev.* **D67** (2003) 084022, `arXiv:hep-th/0210066 [hep-th]`.
20. Z. Haghani, H. R. Sepangi, and S. Shahidi, "Cosmological dynamics of brane f(R) gravity," *JCAP* **1202** (2012) 031, `arXiv:1201.6448 [gr-qc]`.
21. E. Babichev, C. Charmousis, and A. Lehbel, "Black holes and stars in Horndeski theory," *Class. Quant. Grav.* **33** no. 15, (2016) 154002, `arXiv:1604.06402 [gr-qc]`.
22. C. Brans and R. H. Dicke, "Mach's principle and a relativistic theory of gravitation," *Phys. Rev.* **124** (1961) 925–935.
23. C. A. R. Herdeiro and E. Radu, "Asymptotically flat black holes with scalar hair: a review," *Int. J. Mod. Phys.* **D24** no. 09, (2015) 1542014, `arXiv:1504.08209 [gr-qc]`.
24. J. Gleyzes, D. Langlois, F. Piazza, and F. Vernizzi, "Healthy theories beyond Horndeski," *Phys. Rev. Lett.* **114** no. 21, (2015) 211101, `arXiv:1404.6495 [hep-th]`.
25. D. Langlois and K. Noui, "Hamiltonian analysis of higher derivative scalar-tensor theories," *JCAP* **1607** no. 07, (2016) 016, `arXiv:1512.06820 [gr-qc]`.
26. C. Deffayet, G. Esposito-Farese, and A. Vikman, "Covariant Galileon," *Phys. Rev.* **D79** (2009) 084003, `arXiv:0901.1314 [hep-th]`.
27. K. Van Acoleyen and J. Van Doorsselaere, "Galileons from Lovelock actions," *Phys. Rev.* **D83** (2011) 084025, `arXiv:1102.0487 [gr-qc]`.
28. G. Neugebauer, R. F. Green, K. Matthews, M. Schmidt, B. T. Soifer, and J. Bennett, "Continuum energy distributions of quasars in the Palomar-Green Survey," *Astrophys. J. Suppl.* **63** (Mar., 1987) 615–644.

29. A. Baskin and A. Laor, "What controls the C IV line profile in active galactic nuclei?," *Mon. Not. Roy. Astron. Soc.* **356** (2005) 1029–1044, `arXiv:astro-ph/0409196 [astro-ph]`.
30. K. M. Dasyra, L. J. Tacconi, R. I. Davies, R. Genzel, D. Lutz, B. M. Peterson, S. Veilleux, A. J. Baker, M. Schweitzer, and E. Sturm, "Host dynamics and origin of Palomar-Green QSOs," *Astrophys. J.* **657** (2007) 102–115, `arXiv:astro-ph/0610719 [astro-ph]`.
31. M. J. Wolf and A. I. Sheinis, "Host Galaxies of Luminous Quasars: Structural Properties and the Fundamental Plane," *Astron. J.* **136** (2008) 1587, `arXiv:0808.0918 [astro-ph]`.
32. M. Polletta, D. Weedman, S. Hoenig, C. J. Lonsdale, H. E. Smith, and J. Houck, "Obscuration in extremely luminous quasars," *Astrophys. J.* **675** (2008) 960–984, `arXiv:0709.4458 [astro-ph]`.
33. R. Reyes, N. L. Zakamska, M. A. Strauss, J. Green, J. H. Krolik, Y. Shen, G. Richards, S. Anderson, and D. Schneider, "Space Density of Optically-Selected Type 2 Quasars," *Astron. J.* **136** (2008) 2373–2390, `arXiv:0801.1115 [astro-ph]`.