Draft version May 23, 2022
Typeset using LaTeX **preprint** style in AASTeX631

Note on fundamental physics tests from black hole imaging: Comment on "Hunting for extra dimensions in the shadow of Sagittarius A*"

Sunny Vagnozzi[1] and Luca Visinelli[2,3]

[1]*Kavli Institute for Cosmology, University of Cambridge, Madingley Road, Cambridge CB3 0HA, United Kingdom*
[2]*Tsung-Dao Lee Institute (TDLI), 520 Shengrong Road, 201210 Shanghai, P. R. China*
[3]*School of Physics and Astronomy, Shanghai Jiao Tong University, 800 Dongchuan Road, 200240 Shanghai, P. R. China*

ABSTRACT

Several recent works have tested fundamental physics with horizon-scale black hole (BH) images, using the size $r_{\rm sh}$ and deviation from circularity $\Delta\mathcal{C}$ of the BH shadow. For the Event Horizon Telescope image of Sgr A*, limits on $\Delta\mathcal{C}$ are not available due to the sparse interferometric coverage of the 2017 observations, alongside the short variability timescale of Sgr A* compared to M87*. We comment on the results of a recent preprint which purports to have derived new limits on extra dimensions using the deviation from circularity of Sgr A*'s shadow. The latter is quoted to be $\lesssim 10\%$ as with M87*, based on the "similarity" of the two shadows, which however is an incorrect assumption. In the immediate future, the simplest tests of fundamental physics from Sgr A*'s image will mostly have to rely on $r_{\rm sh}$.

Keywords: High energy astrophysics — Astrophysical black holes — Black hole physics

1. INTRODUCTION

Millimeter-scale Very Long Baseline Interferometry (VLBI) has provided us the first horizon-scale images of supermassive black holes (BHs): these feature a central brightness depression, related to the underlying BH shadow (Luminet 1979; Falcke et al. 2000), surrounded by a bright ring of emission. In most scenarios, the BH shadow corresponds to the apparent image of the photon region, the region of space-time where photons are forced to travel along orbits (Perlick & Tsupko 2022). Various fundamental physics scenarios leave imprints on the BH shadow: conversely, horizon-scale BH images can thus be used to test fundamental physics, provided the size of the bright ring can serve as a proxy for the shadow size $r_{\rm sh}$, with little dependence on the accretion flow details, as is the case for the radiatively inefficient accretion flows surrounding both Sagittarius A* (Sgr A*) and M87* (see Narayan et al. 2019; Bronzwaer & Falcke 2021).

sunny.vagnozzi@ast.cam.ac.uk
luca.visinelli@sjtu.edu.cn

2. BLACK HOLE SHADOW CIRCULARITY AND FUNDAMENTAL PHYSICS TESTS

Over the past years, considerable work has been devoted to tests of fundamental physics from the Event Horizon Telescope (EHT) images of M87* (Akiyama et al. 2019; Kocherlakota et al. 2021). These have been based both on the size of the bright ring of emission (as a proxy for $r_{\rm sh}$), and the deviation from circularity of the shadow $\Delta\mathcal{C}$ (Bambi et al. 2019), which quantifies the shadow's oblateness (Johannsen & Psaltis 2010). In Akiyama et al. (2019), the limit $\Delta\mathcal{C} \lesssim 10\%$ has been quoted and translated into a deviation from the Kerr quadrupole moment of order 4.

In Vagnozzi & Visinelli (2019) (VV19 hereafter), we have shown how this limit can be used to test extra dimension scenarios such as the Randall-Sundrum model (Randall & Sundrum 1999a,b), and in particular constrain the AdS_5 curvature radius ℓ (see also Banerjee et al. 2020; Neves 2020; Hou et al. 2021). We found that the limit $\Delta\mathcal{C} \lesssim 10\%$ translates to a limit of $\ell \lesssim 170\,\mathrm{AU}$.

Recently, Wu (2022) purported to have derived a new constraint on ℓ based on the new EHT image of Sgr A* (Akiyama et al. 2022a). This preprint, almost entirely based on VV19 and following a similar analysis, quotes a deviation from circularity $\Delta\mathcal{C} \lesssim 10\%$ for Sgr A*, analogously to M87*. We disagree with these findings, as the procedure used to derive the results are not correct. The author quotes the limit $\Delta\mathcal{C} \lesssim 10\%$ on the basis of "Sgr A* and M87* [being] very similar and [...] accurately described by the Kerr metric" (see Footnote 1 of Wu 2022). However, limits on $\Delta\mathcal{C}$ have not been quoted for Sgr A*'s image, as explicitly discussed by the EHT collaboration on page 19 of Akiyama et al. (2022b), due to the sparse interferometric coverage of the observations taken in 2017 when Sgr A* had been imaged (at the time of the observations the EHT network did not have enough telescopes online to robustly obtain circularity measurements). Moreover, the variability timescales $t_g \sim GM/c^3$ change considerably between Sgr A* and M87* due to the sheer difference in mass, with the short timescale of Sgr A* leading to an extensive overnight variability. Therefore, it is not yet possible to perform an analysis similar to VV19 to obtain analogous results from Sgr A*. In fact, some of the latest results based on the new image of Sgr A* do not make use of $\Delta\mathcal{C}$ (Chen et al. 2022; Jusufi et al. 2022; Chen 2022; Vagnozzi et al. 2022).

3. CONCLUSIONS

Horizon-scale BH images can be used to test fundamental physics, using the BH shadow's size $r_{\rm sh}$ and deviation from circularity $\Delta\mathcal{C}$. However, while for M87* information on both $r_{\rm sh}$ and $\Delta\mathcal{C}$ is available, for the 2017 EHT observations of Sgr A* only the former one is available: therefore, in the near future, the simplest tests of fundamental physics from Sgr A*'s shadow will inevitably have to be based on its size and not its oblateness, until the EHT collaboration or its successor will explicitly constrain the latter (Raymond et al. 2021). We have commented on erroneous results obtained in Wu (2022) in the context of extra dimensions, based on incorrect premises relating the circularity of Sgr A*'s shadow. Besides $r_{\rm sh}$ and $\Delta\mathcal{C}$, complementary observables and techniques to explore new physics are being developed, including polarimetric measurements, the photon ring, and shadow drift (Chen et al. 2020; Hadar et al. 2021; Chen et al. 2022), all of which will soon be accessible to VLBI arrays.

ACKNOWLEDGEMENTS

S.V. is supported by the Isaac Newton Trust, the Kavli Foundation, the Foundation Blanceflor Boncompagni Ludovisi, and Homerton College, University of Cambridge.

REFERENCES

Akiyama, K., et al. 2019, Astrophys. J. Lett., 875, L1, doi: 10.3847/2041-8213/ab0ec7

—. 2022a, Astrophys. J. Lett., 930, L12, doi: 10.3847/2041-8213/ac6674

—. 2022b, Astrophys. J. Lett., 930, L17, doi: 10.3847/2041-8213/ac6756

Bambi, C., Freese, K., Vagnozzi, S., & Visinelli, L. 2019, Phys. Rev. D, 100, 044057, doi: 10.1103/PhysRevD.100.044057

Banerjee, I., Chakraborty, S., & SenGupta, S. 2020, Phys. Rev. D, 101, 041301, doi: 10.1103/PhysRevD.101.041301

Bronzwaer, T., & Falcke, H. 2021, Astrophys. J., 920, 155, doi: 10.3847/1538-4357/ac1738

Chen, C.-Y. 2022, arXiv e-prints, arXiv:2205.06962. https://arxiv.org/abs/2205.06962

Chen, Y., Roy, R., Vagnozzi, S., & Visinelli, L. 2022, arXiv e-prints, arXiv:2205.06238. https://arxiv.org/abs/2205.06238

Chen, Y., Shu, J., Xue, X., Yuan, Q., & Zhao, Y. 2020, Phys. Rev. Lett., 124, 061102, doi: 10.1103/PhysRevLett.124.061102

Falcke, H., Melia, F., & Agol, E. 2000, Astrophys. J. Lett., 528, L13, doi: 10.1086/312423

Hadar, S., Johnson, M. D., Lupsasca, A., & Wong, G. N. 2021, Phys. Rev. D, 103, 104038, doi: 10.1103/PhysRevD.103.104038

Hou, Y., Guo, M., & Chen, B. 2021, Phys. Rev. D, 104, 024001, doi: 10.1103/PhysRevD.104.024001

Johannsen, T., & Psaltis, D. 2010, Astrophys. J., 718, 446, doi: 10.1088/0004-637X/718/1/446

Jusufi, K., Capozziello, S., Bahamonde, S., & Jamil, M. 2022, arXiv e-prints, arXiv:2205.07629. https://arxiv.org/abs/2205.07629

Kocherlakota, P., et al. 2021, Phys. Rev. D, 103, 104047, doi: 10.1103/PhysRevD.103.104047

Luminet, J. P. 1979, Astron. Astrophys., 75, 228

Narayan, R., Johnson, M. D., & Gammie, C. F. 2019, Astrophys. J. Lett., 885, L33, doi: 10.3847/2041-8213/ab518c

Neves, J. C. S. 2020, Eur. Phys. J. C, 80, 717, doi: 10.1140/epjc/s10052-020-8321-z

Perlick, V., & Tsupko, O. Y. 2022, Phys. Rept., 947, 1, doi: 10.1016/j.physrep.2021.10.004

Randall, L., & Sundrum, R. 1999a, Phys. Rev. Lett., 83, 3370, doi: 10.1103/PhysRevLett.83.3370

—. 1999b, Phys. Rev. Lett., 83, 4690, doi: 10.1103/PhysRevLett.83.4690

Raymond, A. W., Palumbo, D., Paine, S. N., et al. 2021, Astrophys. J. Suppl., 253, 5, doi: 10.3847/1538-3881/abc3c3

Vagnozzi, S., Roy, R., Tsai, Y.-D., & Visinelli, L. 2022, arXiv e-prints, arXiv:2205.07787. https://arxiv.org/abs/2205.07787

Vagnozzi, S., & Visinelli, L. 2019, Phys. Rev. D, 100, 024020, doi: 10.1103/PhysRevD.100.024020

Wu, D. 2022, arXiv e-prints, arXiv:2205.07207. https://arxiv.org/abs/2205.07207