Suggested EHT modeling to include black hole leakage

Stephen L. Adler*

Institute for Advanced Study, Einstein Drive, Princeton, NJ 08540, USA

(Memo for the Talks+Memos section of my home page: https://www.ias.edu/sns/adler)

- In the standard FLRW homogeneous cosmology, with $g_{00}(x) \equiv 1$, the following two dark energy actions are indistinguishable [1]:

  Usual dark energy action – four space generally covariant

$$S_{\rm dark\ energy} = -\frac{\Lambda}{8\pi G}\int d^4x({}^{(4)}g)^{1/2} \quad , \tag{1}$$

  Novel dark energy action – three space generally covariant, frame dependent, but Weyl scaling invariant

$$S_{\rm dark\ energy} = -\frac{\Lambda}{8\pi G}\int d^4x({}^{(4)}g)^{1/2}(g_{00})^{-2} \quad , \tag{2}$$

- In geometrized units $G = c = 1$, the cosmological constant is $\Lambda \sim 10^{-52}{\rm m}^{-2}$. For Sg A*, mass is $M \sim 10^{10}$m. Dimensionless parameter

$$\delta \equiv \Lambda M^2 \sim 10^{-32} \tag{3}$$

  gives fractional deviations of photon sphere, black hole shadow radii from standard values, for both dark energy actions above [2]. So both agree with EHT measurements.

- A second quantity, with dimension of length,

$$\ell \equiv \Lambda^{1/2} M^2 \sim 10^{-6}{\rm m} \tag{4}$$

  sets scale for changes in horizon structure for the novel dark energy action. For $r - 2M < \ell$, the horizon structure is substantially modified: *no* event horizon [3], *no* apparent horizon and trapped surfaces [4]. So "black" hole corresponding to the novel dark energy action could leak particles. Other types of models of compact objects with no true event horizon are reviewed by Cardoso and Pani [5]; although their focus is on gravitational radiation signatures, there could also be particle leakage in these models.

*Electronic address: `adler@ias.edu`

- Two ways to test this: (1) "bottom-up" - try to calculate leakage rate in novel model by solving the modified Tolman-Oppenheimer-Volkoff equations. I am working on this. (2) "top-down" – include a parameterized leakage in various astrophysical modeling.

- From the EHT writeup [6]: "The failure of nearly all fiducial models to match the light-curve variability is interesting. It may signal the presence of extended, slowly varying structure...".

- **Suggests model extension as follows:** Take inner boundary *outside* the nominal horizon, at $r - 2M >> \ell \sim 10^{-6}$m. Say $r - 2M$ is taken as 1 meter, 10 meters, etc. To keep things simple, assume leakage is a radial geodesic, with a flux parameter F and an energy parameter $E = (1/2)v^2 - M/r$, with $E \geq 0$. (This is the general relativistic formula, which agrees with the Newtonian one.) At the horizon $r = 2M$, taking $E = 0$ corresponds to $v = 1$. So with an inner boundary just outside the horizon the emerging leakage particles would be nearly relativistic for E close to 0.

- **Heuristic** Matter falling into the hole can carry large and random angular momentum, whereas leakage particles out of the hole would have zero or small angular momentum, which if they collide with the infalling matter could reduce the variability.

- **Question: Does this model extension improve agreement with the imposed constraints?**

---

[1] Review article: S. L. Adler, "Is 'Dark Energy' a Quantum Vacuum Energy?", Modern Physics Letters A **36**, 2130027 (2021), arXiv:2111.12576.

[2] S. L. Adler and K. S. Virbhadra, "Cosmological constant corrections to the photon sphere and black hole shadow radii", arXiv:2205.04628(2022).

[3] S. L. Adler and F. M. Ramazanoğlu, Int. J. Mod. Phys. D **24**, 1550011 (2015), arXiv:1308.1448.

[4] S. L. Adler, "Are Black Holes Leaky?", arXiv:2107.11816, International Journal of Modern Physics D (in press).

[5] V. Cardoso and P. Pani, Living Rev. Relativ **22**, 4 (2019), arXiv:1904.05363.

[6] EHT Collaboration, ApJ Lett. 930:L16 (2022).