

USING A BLACK HOLE TO WEIGH LIGHT: CAN THE EVENT HORIZON TELESCOPE YIELD NEW INFORMATION ABOUT THE PHOTON REST MASS?

Robert P. Cameron¹

¹*SUPA and Department of Physics, University of Strathclyde, Glasgow G4 0NG, U.K.*

It is an exciting time for the study of black holes. The Event Horizon Telescope is due to release the first image of an event horizon, namely that of the black hole Sgr A* at the centre of our galaxy (Balick & Brown (1974); Brown (1982)). This comes hot on the heels of the first direct detection of a binary black hole merger, using gravitational waves (Abbott et al. (2016)).

In this research note we point out that data collected by the Event Horizon Telescope or a similar project (Issaoun et al. (2019)) might yield new information about the photon rest mass m_γ .

Surprisingly, it is not yet known with certainty how much light weighs: it is usually assumed that m_γ is *exactly* zero, however this has never actually been confirmed. The most precise laboratory tests of Coulomb's law have only succeeded in establishing that $0 \leq m_\gamma \lesssim 10^{-50}$ kg (Williams et al. (1971)) and the strongest empirical claim made to date, on the basis of astronomical observations, is that $0 \leq m_\gamma \lesssim 10^{-63}$ kg (Chibisov (1976)) (the reliability of the assumptions underlying this claim has been disputed (Adelberger et al. (2007))). The possibility remains that $m_\gamma \neq 0$.

The question of whether or not m_γ is indeed exactly zero is of fundamental importance. If it were discovered that m_γ has a non-zero value (no matter how small), Maxwell's equations would have to be replaced in principle by the Proca equations (Proca (1936); Goldhaber & Nieto (1971); Jackson (2001)). This would dramatically alter our basic understanding of light: according to the Proca equations, the potential A^μ is uniquely defined and thus directly observable; light has three possible polarisation states, not two; light does not propagate at the universal speed limit c but instead with phase and group speeds that differ from each other and vary with frequency, even in vacuum (Goldhaber & Nieto (1971); Jackson (2001)). A non-zero value for m_γ would also imply the existence of a new elementary scalar field or fields to produce the mass (Stueckelberg (1938)).

A remarkable prediction was made by Bekenstein in 1971: a static black hole with electric charge has a Coulombic electric field outside the event horizon if $m_\gamma = 0$ but *no* electric field outside the event horizon if $m_\gamma \neq 0$, regardless of how small m_γ is; a corollary of the no-hair theorem (Bekenstein (1972); Dolgov & Pelliccia (2007)). Further static calculations revealed that the electric charge of matter outside the event horizon is, in effect, *screened* by the hole if $m_\gamma \neq 0$, with no such screening if $m_\gamma = 0$ (Vilenkin (1978); Leaute & Linet (1985); Dolgov & Pelliccia (2007)). Finally, dynamic calculations revealed that this screening is realised after a time $\tau \sim 1/\mu_\gamma c = \hbar/m_\gamma c^2$ (Paul (2004); Dolgov & Pelliccia (2007)), where $\mu_\gamma = m_\gamma c/\hbar$ is the Compton wavenumber of the photon. Thus, electromagnetic radiation produced by matter just outside the event horizon of a black hole should differ dramatically depending on whether $m_\gamma = 0$ or $m_\gamma \neq 0$, assuming that this matter has been in the vicinity of the hole long enough for the screening to be realised if $m_\gamma \neq 0$. The possibility of exploiting this phenomenon to extract information about m_γ does not appear to have been pointed out explicitly before, perhaps because of the extreme difficulty of the necessary observations.

We propose that data collected by the Event Horizon Telescope or a similar project (Issaoun et al. (2019)) be analysed with the above in mind. There are two distinct possibilities. If the electromagnetic radiation produced by matter just outside the event horizon of a black hole reveals that screening *does* occur, it can be concluded that $m_\gamma \neq 0$ and, furthermore, that $m_\gamma \gtrsim \hbar/\tau c^2$, where τ is the duration for which the matter has been in the vicinity of the hole. As indicated above, the discovery that $m_\gamma \neq 0$ would be revolutionary. If, instead, the electromagnetic radiation produced by matter just outside the event horizon does *not* reveal any sign of screening, it can be concluded that $0 \leq m_\gamma \lesssim \hbar/\tau c^2$. For Sgr A*, τ could conceivably be as large as the age of the Milky Way, in which case $\hbar/\tau c^2 = 10^{-69}$ kg. Thus, there is scope to improve on the best upper bound on m_γ obtained via laboratory tests

of Coulomb's law (10^{-50} kg (Williams et al. (1971))) by up to nineteen orders of magnitude and even the strictest empirical upper bound on m_γ yet claimed (10^{-63} kg (Chibisov (1976))); disputed in (Adelberger et al. (2007))) might be beaten, by up to six orders of magnitude.

This work was supported by The Leverhulme Trust (RPG-2017-048).

REFERENCES

- Abbott, B. P., et al. 2011, *PhRvL*, 116, 061102
- Adelberger, E., Dvali, G., & Gruzinov, A. 2007, *PhRvL*, 98, 010402
- Balick, B., & Brown, R. L. 1974, *ApJ*, 194, 265
- Bekenstein, J. D. 1972, *PhRvD*, 5, 1239
- Brown, R. L. 1982, *ApJ*, 262, 110
- Chibisov, G. V. 1976, *SvPhU*, 19, 624
- Dolgov, A., & Pelliccia, D. N. 2007, *PhLB*, 650, 97
- Goldhaber, A. S., & Nieto, M. M. 1971, *RvMP*, 43, 277
- Issaoun, S., et al. 2019, *ApJ*, 871, 30
- Jackson, J. D. 2001, *Classical Electrodynamics* (John Wiley & Sons)
- Leaute, B., & Linet, B. 1985, *GReGr*, 17, 783
- Paul, A. 2004, *PhRvD*, 70, 124005
- Proca, A. 1936, *LeRad*, 7, 347
- Stueckelberg, E. C. G. 1938, *AcHPh*, 11, 225, 299, & 312
- Vilenkin, A. 1978, *PhRvD*, 20, 373
- Williams, E. R., Faller, J. E., & Hill, H. A. 1971, *PhRvL*, 26, 721