# LJ18697 Review

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## 1 Summary

This manuscript proposes the new idea of detecting ultralight dark photons using polarimetric data from observations of the M87* and Sgr A* black holes at the Event Horizon Telescope (EHT). In particular, superradiance predicts the presence of a macroscopic cloud of dark photons in a coherent state, known as a gravitational atom. The dark photons in this gravitational atom then generate an electromagnetic field that the authors argue would produce Faraday rotation (FR) and Faraday conversion (FC) in the light observed from around the black holes. The authors then search for the FR and FC in the EHT data and report leading constraints on dark photons over the mass range that they consider.

If the results in this paper are correct, dark photon polarimetry would be a novel way to search for dark photons over potentially unexplored mass ranges. This is an interesting and creative idea that would set strong limits on dark photons using a signal that has not been previously studied. However, there are several key questions that are left unanswered, which we summarize below. Overall, major revisions addressing the comments and questions below are necessary before we can recommend publication.

## 2 Comments and Questions

1. As far as we can tell, the authors only modified the magnetic field used in the simulation, and reran the rest of the code as is. Did the authors simulate the time dependence of the field in IPOLE? In any case, the authors should clarify the exact modification they made.

2. Do the observed photons experience additional Faraday rotation and conversion along their path from the black hole to the observer? For example, is the FR and FC in the Milky Way important for this work?

3. Were in-medium effects for the dark photon mixing considered? Specifically, the discussion between Eq. (1) and Eq. (4) is true for dark photons in a vacuum, but in-medium effects may affect the picture substantially. For example, in Ref. [1], the authors argue that the dark photon and standard model photon decouple as $\mu/\omega_p \to 0$, where $\omega_p \propto n_e$ is the plasma mass [1]. Since $n_e$ is extremely large near the black hole, this argument suggests that that the magnetic field due to dark photons should be suppressed by a

factor of $(\mu/\omega_p)^2$, but the authors do not appear to discuss the plasma frequency near the black hole in this manuscript. Is this the case here?

4. The EM current that is sourced by $A'^{\mu}$ oscillates with a frequency of $\omega \sim \mu$. For M87$^*$ this corresponds to a period of about 30 hours and for Sgr A$^*$ about 1 minute. Are the observations for Sgr A$^*$ made with such frequency that they could detect this rate of oscillation? If not, the rapid oscillations would average out any FR, leaving a signal unobservable.

5. More generally, we are confused about what time-domain information is available in each dataset. For example, the notation of $\langle \ldots \rangle$ suggests that there is time-domain information in each image, but this is confusing given the later statements that imply that there are only 4 images total. Is each of these four "images" actually a series of images over the 6 hour observation period? This is especially confusing in the integral in Eq. (10) because it is unclear what exactly is a function of time. Clarification in the notation of $\langle \phi_{PA}^{\rm IW}(\tilde{\phi}, t)\rangle_i^a$ would also be helpful.

6. What are the relative contributions to the magnetic field around the plasma from standard effects compared to new dark photon effects? An estimate for the typical magnetic field due to $A$ as a function of $\epsilon, m_{A'}$, and black hole mass might be useful to state. Other than the transfer coefficients being obtained assuming $\nu \gg \nu_B$, should we be worried about anything else, given the presumably large magnetic fields produced by the $A$ for values of $\epsilon$ much larger than the obtained limit? For example, the expression in Eq. (7) for the electron number density comes from the radiatively inefficient accretion flow model. According to Ref. [50], this is a phenomenological model from black hole simulations. Does this model still apply when dark photon effects are considered?

7. In the discussion of the plasma emissivity and and absorption coefficients after Eq. (6), it is suggested that the absorption coefficients are exponentially suppressed by the factor of $f_\nu^{-1}$. However, the frequencies considered here are in the radio regime and the temperature of the black hole is $\sim 10^{11}$ K. Therefore, we think that $f_\nu \sim T/\omega$, with the coefficients being only linearly suppressed. Did we miss an exponential suppression from some other effect here?

8. The abstract references the applicability of dark photon polarimetry to laboratory experiments but almost nothing specific is discussed in the manuscript. We suggest either elaborating on how DP polarimetry can be realized in the lab, or removing this point from the abstract.

9. In Fig. 1, limits on dark photon dark matter from SuperMAG are shown. We suggest removing the SuperMAG limits, since they apply only to dark photon dark matter, while the authors do not rely on such an assumption at all.

## References

[1] Andrea Caputo, Samuel J. Witte, Diego Blas, and Paolo Pani. Electromagnetic signatures of dark photon superradiance. *Phys. Rev. D*, 104(4):043006, 2021.