Bounds on Ultralight Bosons from the Event Horizon Telescope observation of Sagittarius A*

Based on arXiv : 2208.03530

Abhishek Dubey*, Akash Kumar Saha, Priyank Parashari, Tarak Nath Maity, Subhadip Bouri, Ranjan Laha
Centre for High Energy Physics, IISc, Bangalore
*Email: abhishekd1@iisc.ac.in

Introduction to Black Hole Superradiance

- Objects scattering off a rotating cylinder can gain energy and angular momentum if this following kinematic condition is met
  $v_c > v_0$
  Here, v_c is velocity at surface of cylinder and v_0 is initial velocity of the object.

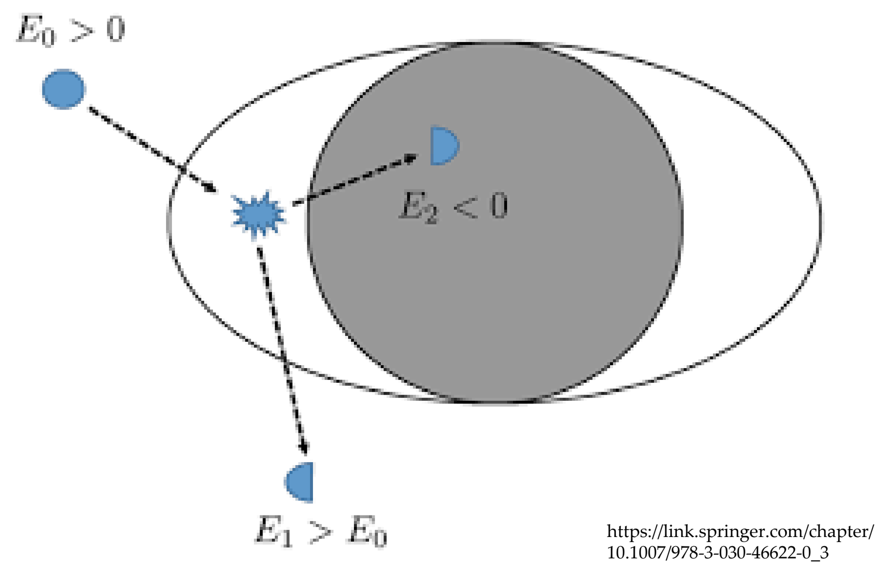

Fig:1 Classical analogue of Black Hole Superradiance

- Black Hole (BH) Superradiance is a phenomenon of a rotating BH losing its angular momentum and energy due to the existence of a massive bosonic particle. Following condition needs to satisfy for this process to happen.

$$\Omega_H > \omega/m$$

Superradiance condition

m is azimuthal angular momentum quantum number, Ω_H is angular velocity of BH event horizon and ω is angular velocity of the incoming wave.

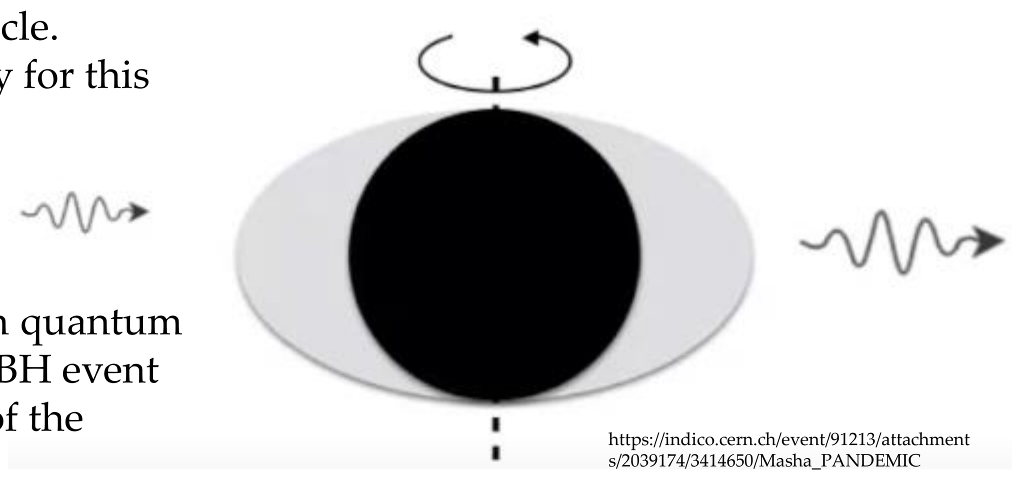

Fig:2 Black Hole Superradiance

- For high superradiance rates, Compton wavelength of the particle should be comparable to black hole radius

$$r_g \lessapprox \mu^{-1}$$

where μ is the mass of the boson.

The Spectra of Gravitational atom

- Massive boson particles, e.g. axion, can get trapped due to gravitational potential barrier $V(r) = -\frac{G_N M_{BH}\mu}{r}$ around black hole. This eventually, forms gravitational bound states analogous to Hydrogen atom.

- Energy levels or quasi-normal mode frequencies of these states are,

$$E \simeq \mu\left(1 - \frac{\alpha^2}{2n^2}\right) + i\Gamma_{sr}$$

← Superradiant instability growth rate

"Fine-structure constant"

$$\alpha \equiv G_N M_{BH}\mu = r_g\mu = 0.1\left(\frac{r_g}{3\,\text{km}}\right)\left(\frac{\mu}{7\times10^{-12}\,\text{eV}}\right)$$

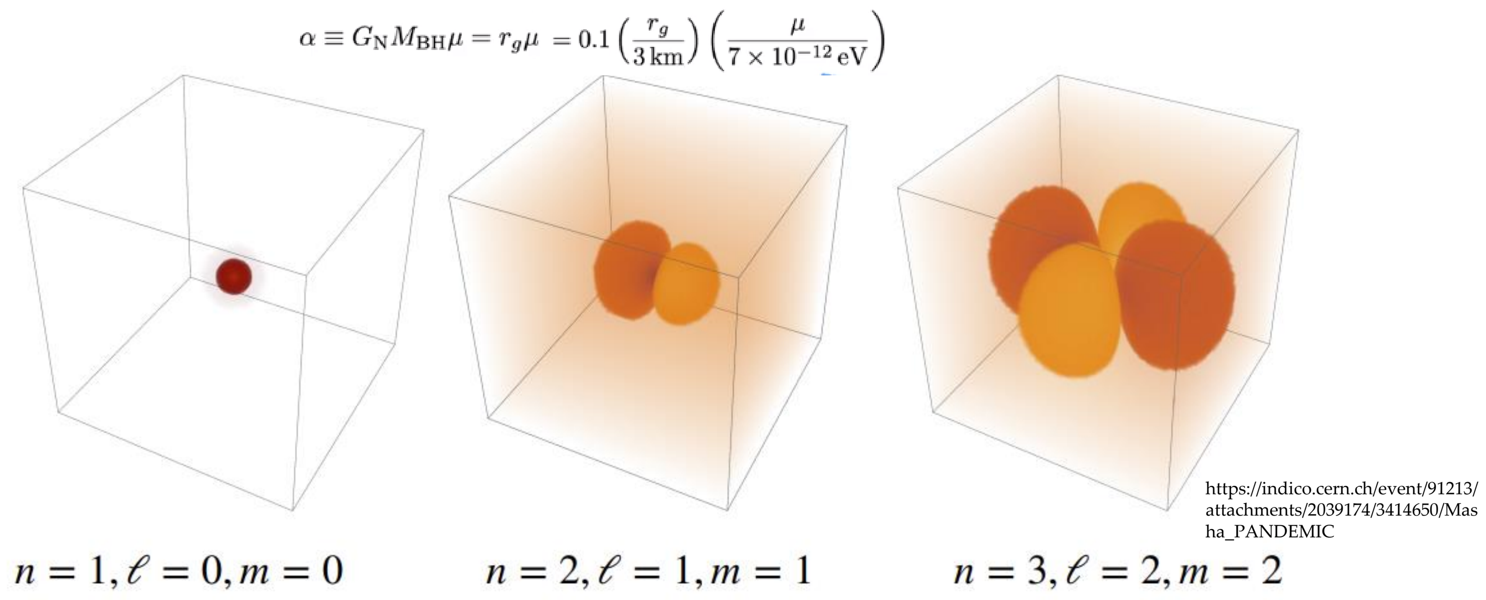

Fig:3 Hydrogen atom like bound state of Massive Bosons around Black Hole due to Superradiance

Evolution of Black Hole Spin due to Superradiance

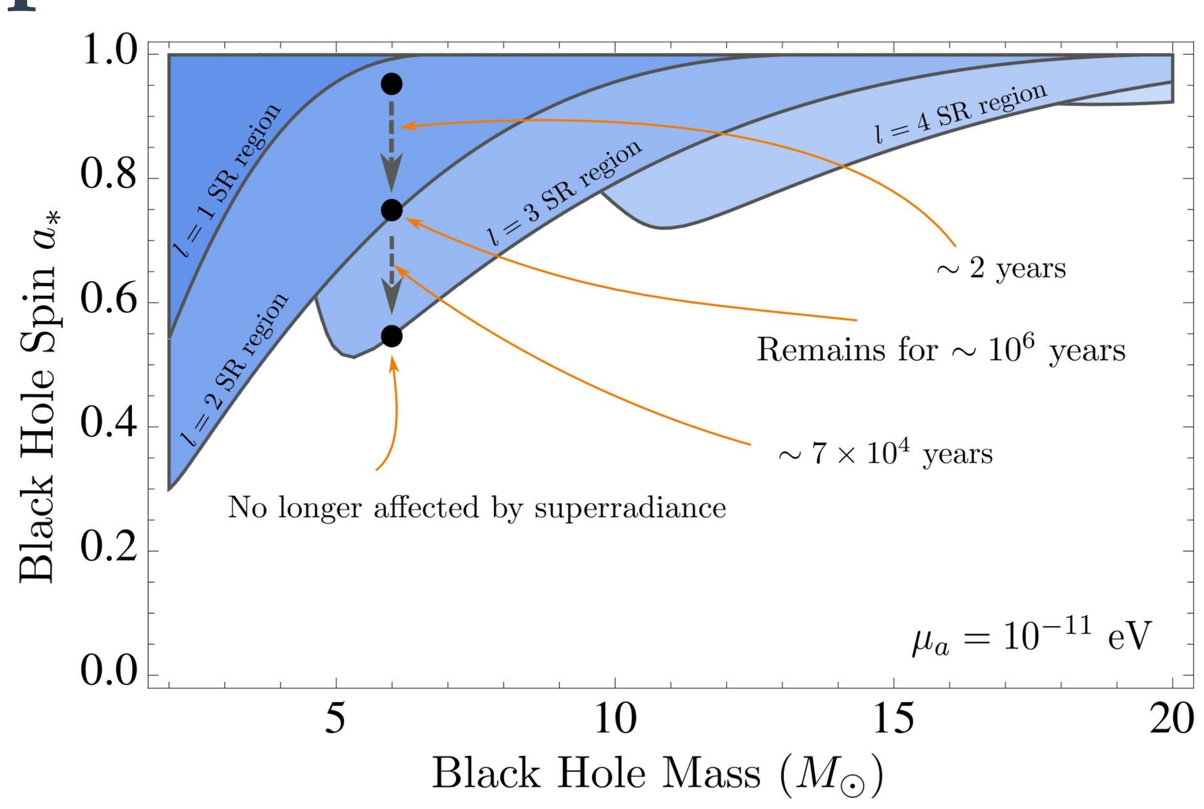

Fig: 4 Spin down of Black Hole due to Superradiance, if there exist a scalar boson of mass = 10^{-11} eV.
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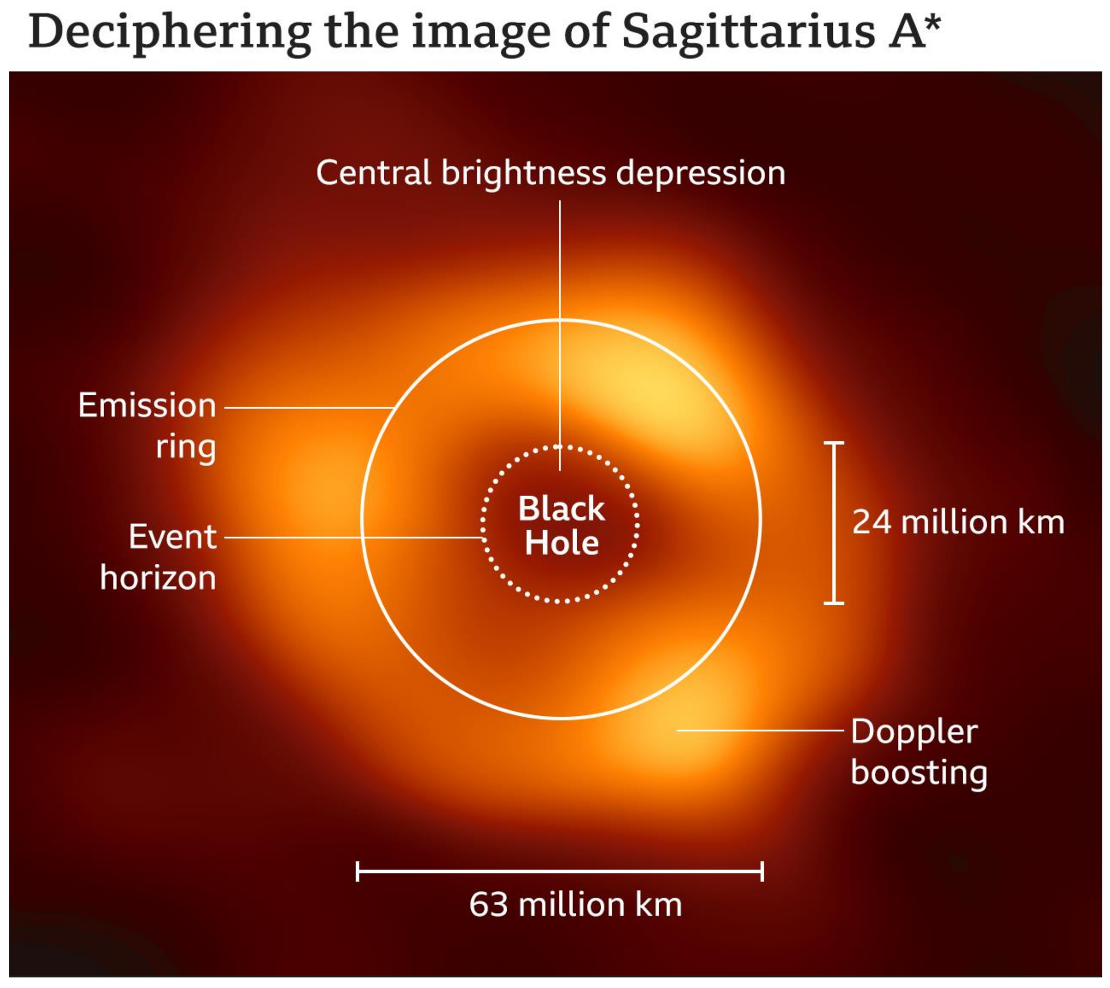
- To have significant change in black hole spin, superradiance instability growth time scale must be less than the characteristics time scale of black hole.
- In our case, i.e., for Sagittarius A*, we take a conservative choice for the characteristic timescale, $\tau_{BH} = 5\times10^9$ year, which we had calculated using Salpeter time.

Event Horizon Telescope (EHT) Observation

Deciphering the image of Sagittarius A*



EHT collaboration

- Mass of Sagittarius A* = $4\times10^6\,M_\odot$
- Sagittarius A* is a rapidly rotating black hole.
- Kerr Spin parameter a* = 0.5 and a* = 0.94 pass all EHT constraints.
- Recent observation using Outflow method also confirmed spin of Sagittarius A* = 0.90 ∓ 0.06. [arXiv:2310.12108]

What if ULBs have Self Interaction?

- Many well-motivated theories beyond the Standard Model (SM) predict ultralight scalar particles having interaction among themselves and with SM states, e.g., the QCD axion.

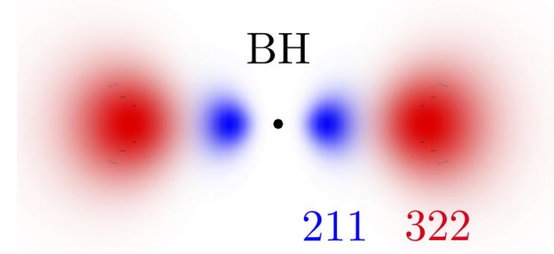


Fig: 6 Superradiance cloud around black hole

- This self coupling will cause slowing down of rate of superradiance cloud growth around black hole.

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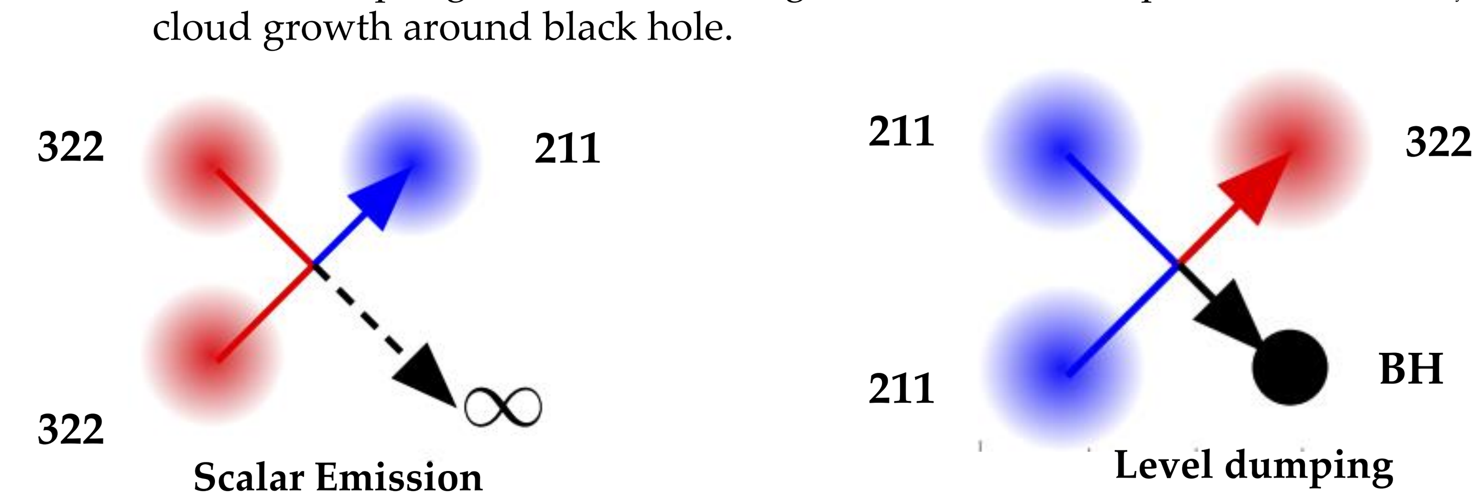

Fig: 7 Dominant modes of interaction if particles have self-coupling.

Our Results

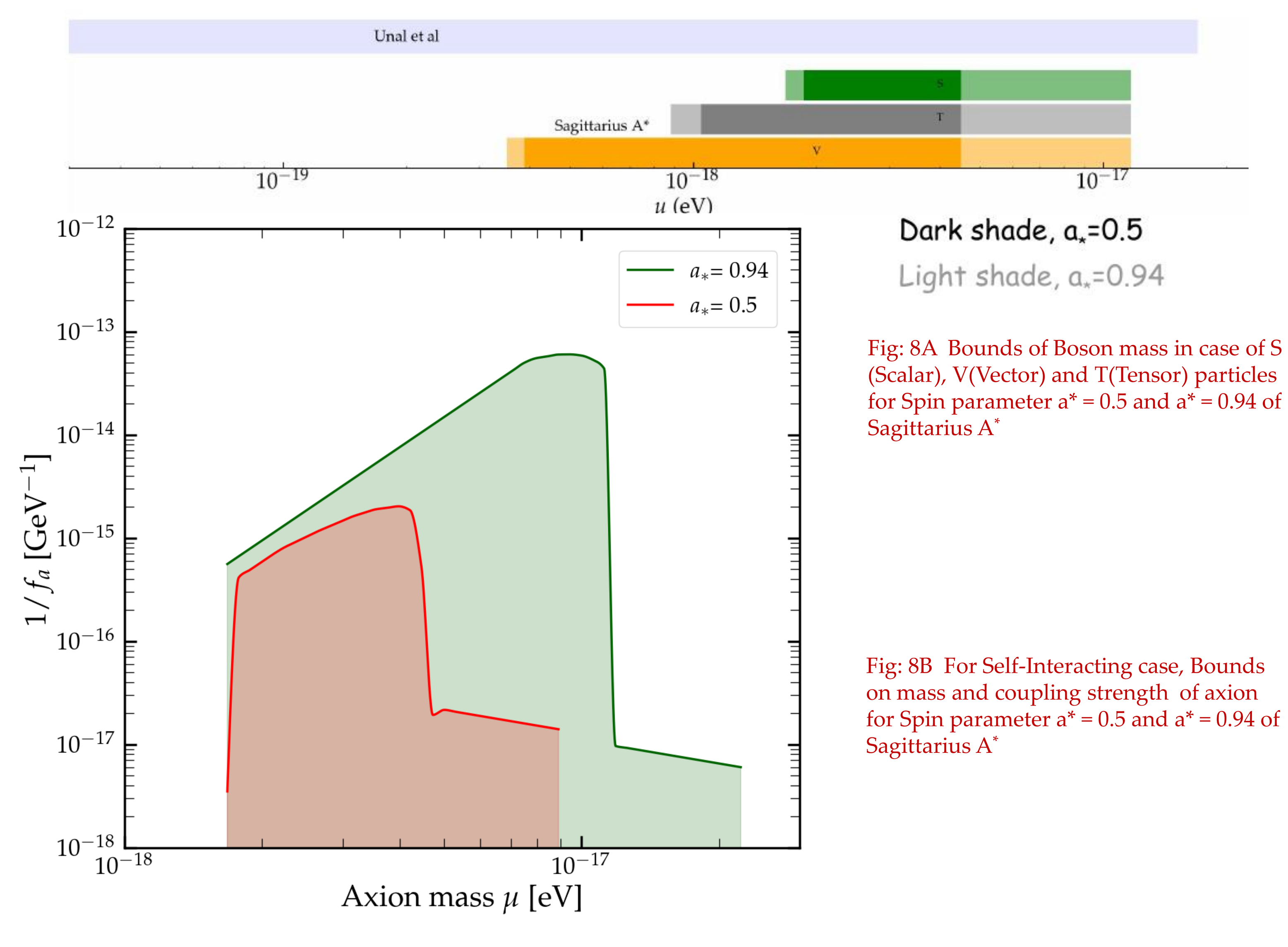

Fig: 8A Bounds of Boson mass in case of S (Scalar), V(Vector) and T(Tensor) particles for Spin parameter a* = 0.5 and a* = 0.94 of Sagittarius A*

Fig: 8B For Self-Interacting case, Bounds on mass and coupling strength of axion for Spin parameter a* = 0.5 and a* = 0.94 of Sagittarius A*

Conclusion

- In the presence of ultralight bosons, black holes spin down, converting their rotational energy to superradiance clouds.
- Using the latest observation of Sagittarius A* by EHT, we have put constraints on ultra light boson masses, for Scalar, Vector and Tensor particles cases.
- Sufficient self-interactions of axions may slow down superradiance rate, thus leading to slowing down of energy extraction from black holes.
- We probe a new region of parameter space of decay constant for ultra light scalar boson .