Superradiant instabilities by accretion disks in scalar-tensor theories

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in collaboration with Enrico Cannizzaro and Paolo Pani
based on arXiv:2204.09335

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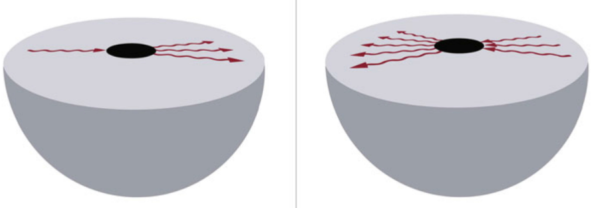
Black hole superradiant instability of confined bosons

Zel'dovich (1971); Misner (1972); Press and Teukolsky (1972-1974); Damour (1976); Zouros and Eardley (1979); Detweiler (1980); Dolan (2007); Rosa and Dolan (2012); Pani et al (2012); Baryakthar et al (2017); East (2017); Cardoso et al (2018); Frolov et al (2018); Dolan (2018); Baumann et al (2019)

$$\Phi_i \sim A_i e^{-i\omega(t+r)} e^{im\phi} S(\theta) \qquad \Phi_f \sim A_f e^{-i\omega(t-r)} e^{im\phi} S(\theta)$$

$$|\omega| < m\Omega \implies |A_f| > |A_i| \text{ (superradiance)}$$



(R.Brito, V.Cardoso, P.Pani, *"Superradiance: New Frontiers in Black Hole Physics"*, ISBN: 978-3-030-46622-0)

Scalar field effective mass in scalar-tensor theories

Jordan Frame:

$$S = \frac{1}{16\pi G}\int d^4x\sqrt{-g}[\mathcal{F}(\phi)R - Z(\phi)g^{\mu\nu}\partial_\mu\phi\partial_\nu\phi - U(\phi)] + S_m(\psi_m, g_{\mu\nu})$$

Einstein frame:

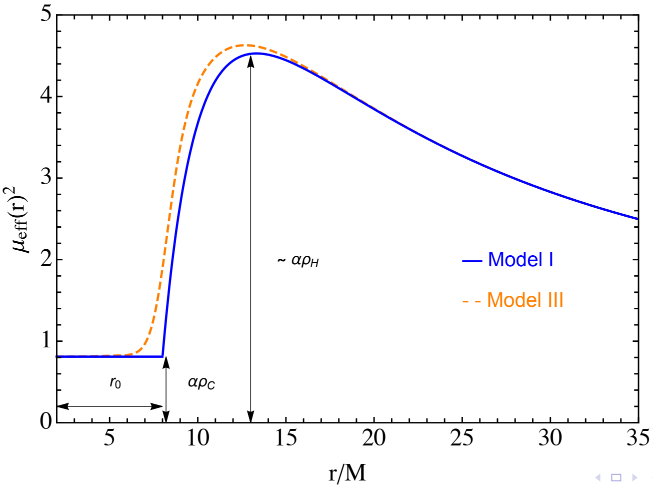
$$S = \int d^4x\sqrt{-g^E}\left(\frac{R^E}{16\pi} - \frac{1}{2}g^E_{\mu\nu}\partial^\mu\Phi\partial^\nu\Phi - \frac{V(\Phi)}{16\pi}\right) + S(\psi_m, \mathcal{A}(\Phi)^2 g^E_{\mu\nu})$$

$\implies$ non-minimal coupling $\implies$ effective mass in matter: $[\Box^E - \mu^2_{\text{eff}}(r,\theta)]\varphi = 0$

$\mathcal{A}(\Phi) = \sum_{n=0} A_n(\Phi - \Phi^{(0)})^n\ ,\quad \varphi := \Phi - \Phi^{(0)}$ Scalar-Tensor coupling: $\alpha := \frac{A_2}{A_0}$

Superradiance by effective mass from black hole accretion disk

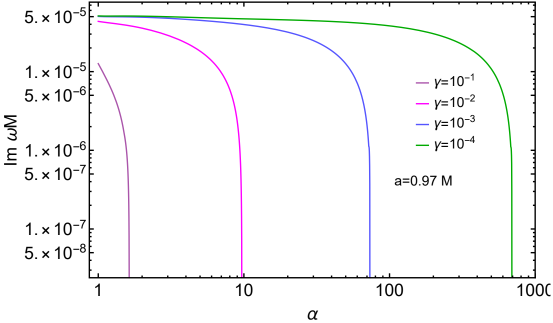
Cavity in effective mass $\implies$ superradiant instability shuts down superradiance (Dima, Baurausse 2020)

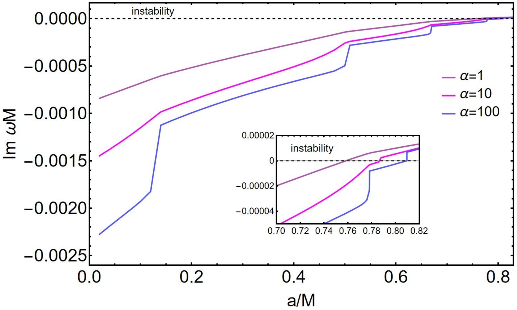


(G.L, E. Cannizzaro, P. Pani, *arXiv:2204.09335*)

Superradiance in scalar-tensor theories from BH accretion disk

In scalar tensor we can avoid shutting down superradiance by changing coupling (suppression when $\alpha\gamma \gtrsim O(10^{-1})$, γ is renormalized corona parameter)





(G.L, E. Cannizzaro, P. Pani, *arXiv:2204.09335*)

Conclusion: constraining scalar-tensor with BH superradiance

In principle we can constrain scalar-tensor through superradiance:

- We have superradiance when: $3 \times 10^6 \lesssim \alpha \left(\frac{M}{10^6 M_\odot} \right)^{13/10} \lesssim 3 \left(\frac{10^{-4}}{\gamma} \right) 10^{10}$
- Different class of BHs constrain wide range of α from $\alpha \sim O(100)$ for $M \sim 10^9 M_\odot$ to $\alpha \sim O(10^{17})$ for $M \sim 5 M_\odot$
- Put upper bound on unconstrained parameter