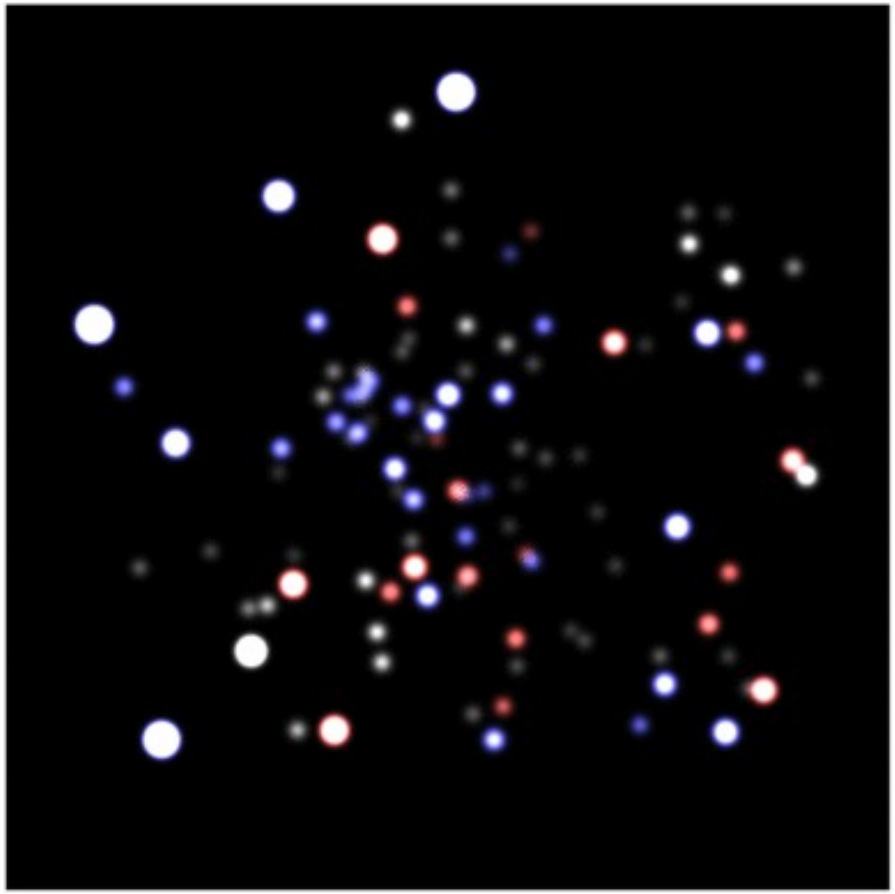
Energy extraction from black holes

BHs2011 19-20 Dec 2011 | Aveiro, Portugal

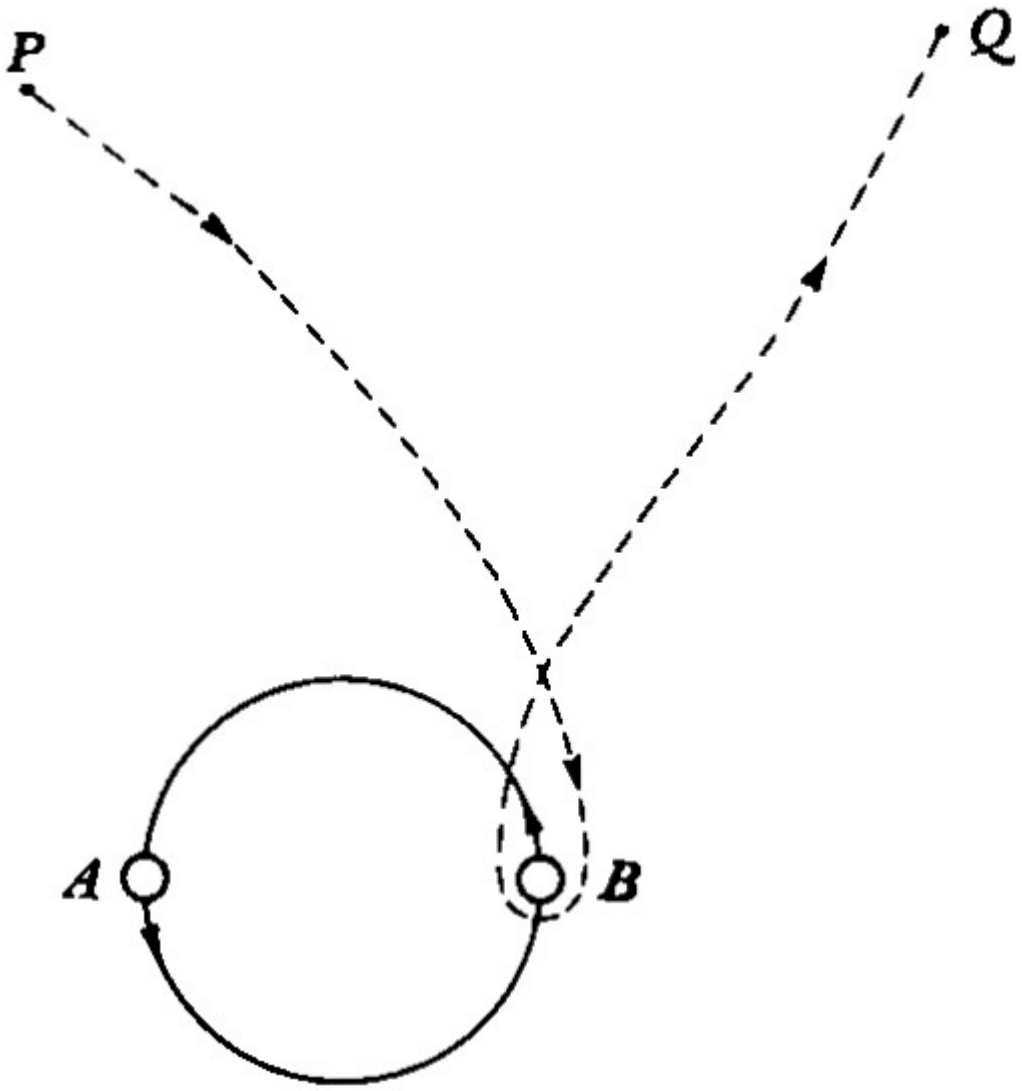


Credit: ESO/MPE (2010)

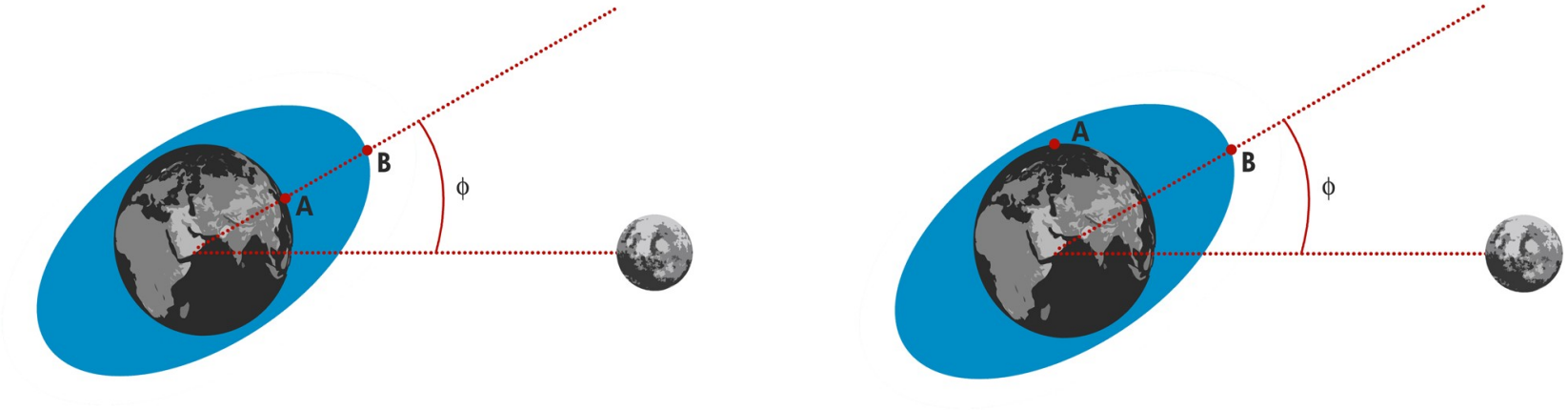
Vitor Cardoso (CENTRA/IST & Olemiss)

Credit: ESO/MPE/M.Schartmann (2011)

Orbital energy: slingshot effect



Rotational energy: tidal acceleration



$$\mu = \frac{\kappa}{2} m_p \left(\frac{R}{r_0}\right)^3$$

$$\phi = (\Omega_H - \Omega)\tau$$

$$\dot{E}_{\text{orbital}} = 3G\kappa m_p^2 \frac{R^5}{r_0^6} \Omega(\Omega_H - \Omega)\tau$$

Tidal acceleration is in general impossible for BHs!

$$\dot{E}_{\rm H} \sim \frac{G^7}{c^{13}} \frac{M^6 m_p^2}{r_0^6} \Omega(\Omega - \Omega_H)$$

$$\dot{E}_{\infty} \sim \frac{32}{5} \frac{G^4}{c^5} \frac{M^3 m_p^2}{r_0^5}$$

$$\frac{\dot{E}_{\rm H}}{\dot{E}_{\infty}} = \left(\frac{GM}{c^2 r_0}\right)^3 \frac{r_0\Omega}{c} \left(\frac{r_0\Omega - r_0\Omega_H}{c}\right) \sim (v/c)^8$$

Press & Teukolsky, Nature (1973)

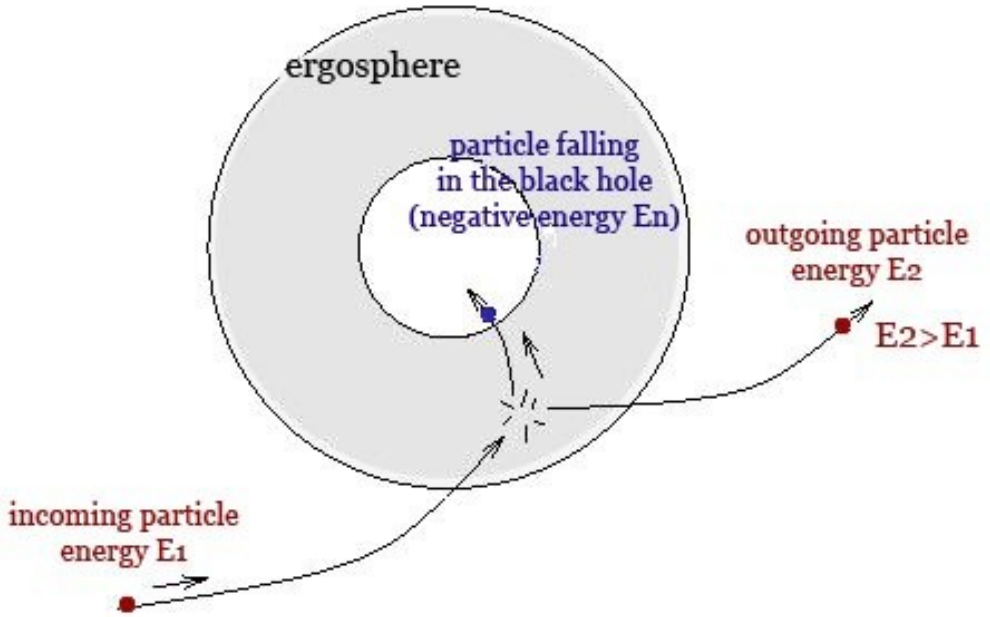
Ergo-region: asymptotic time-translation Kiling vector is space-like

$$E = -p^{\nu}\zeta_{\nu}$$

Penrose process

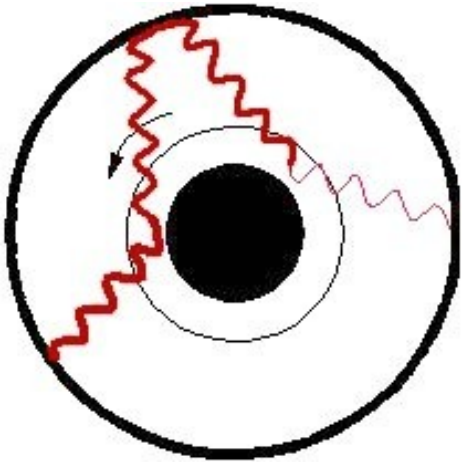
Superradiance

Hawking radiation



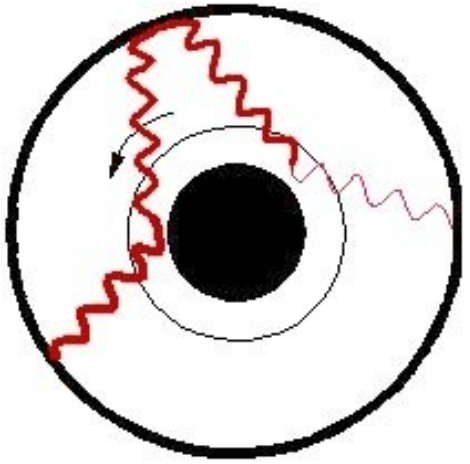
Insert a *mirror* around the BH

Make a “bomb”!



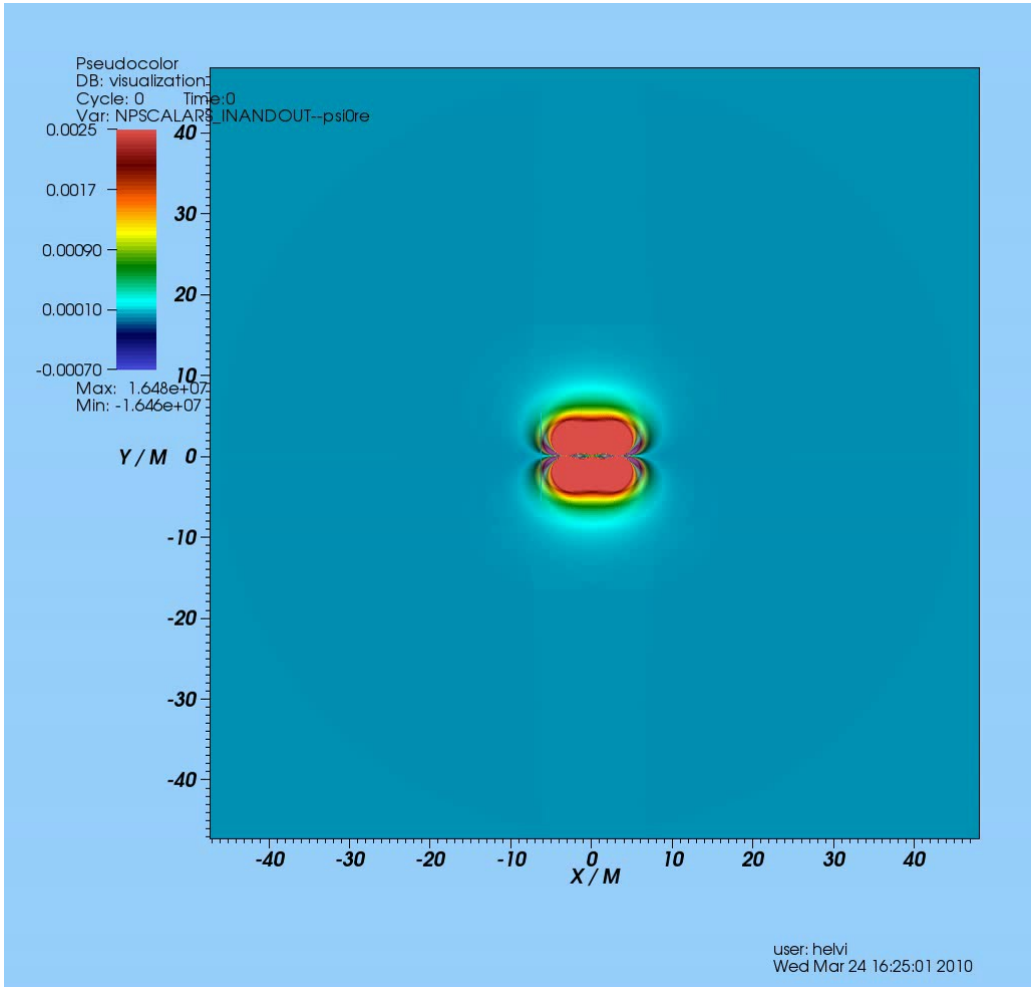
(Zel’dovich, 1971; Press & Teukolsky 1973)

anti-de Sitter



Small Kerr-AdS BHs are unstable

(Cardoso & Dias ‘04; Kodama ’07; Uchikata, Yoshida & Futamase ’09)



(Witek et al, ‘10)

Horizonless geometries?

Theorem *(Friedman, 1978)*:

Every stationary, AF, horizonless spacetime with an ergoregion is unstable

(Intuition: negative-energy states are amplified, no horizon to absorb them)

Gravastars *(Mazur & Mottola '01)*

Boson Stars *(Kaup '68; Ruffini & Bonazzola '69)*

Wormholes *(Morris & Thorne '88)*

Superspinars *(Gimon & Horava '09)*

Ergoregion instability rules out "all" of these!

(Cardoso et al, '08; Pani et al '10;)

Resonant excitation of BH modes? Resonant tides?

Massless modes of BHs are localized around *the light ring...*

...and the null geodesic lies inside the ISCO

(massive) scalar fields

Interesting as effective description

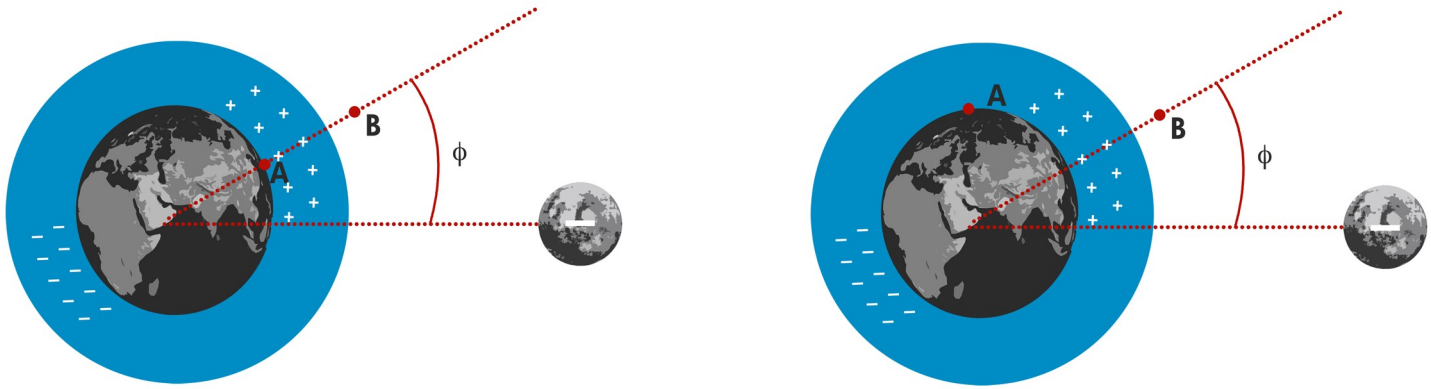
Proxy for more complex interactions

Arise as interesting alternatives of GR

Brans-Dicke or generic scalar-tensor theories; quadratic f(R)

GW spectrum encodes the gravity theory

Axiverse scenarios (moduli and coupling constants in QCD, Peccei-Quinn mechanism, QCD



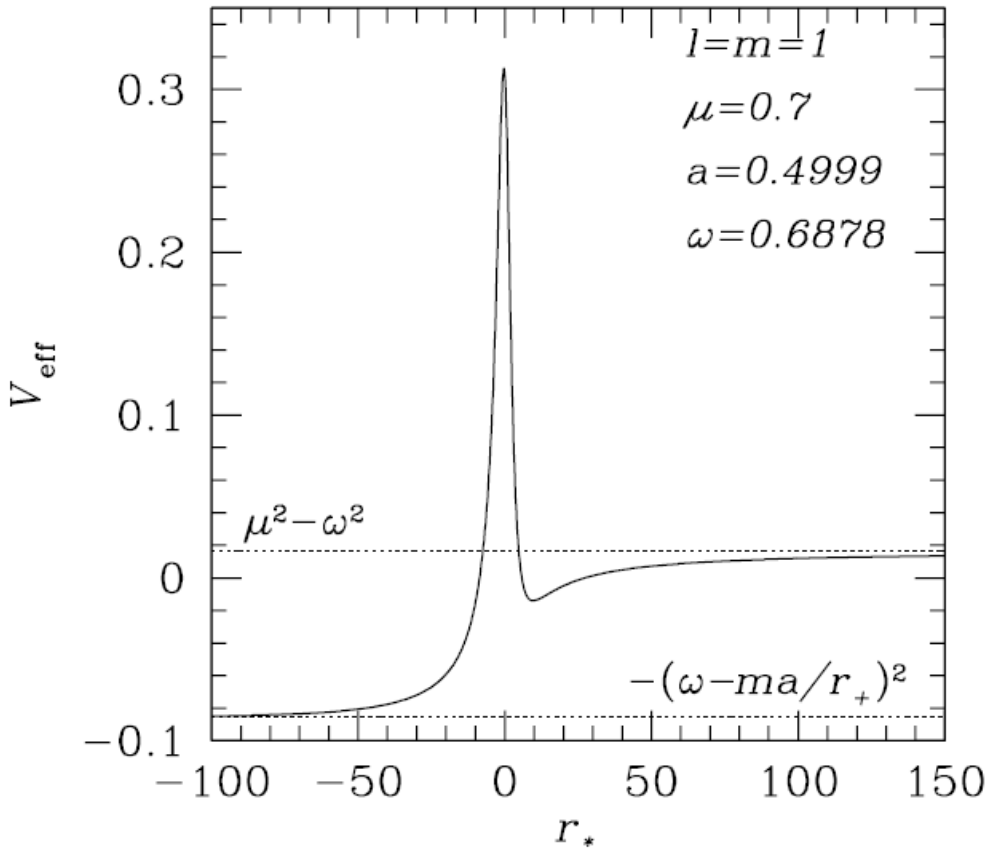
$$\sigma_{\text{pol}} = 3\epsilon_0 \left(\frac{\epsilon_r - 1}{2\epsilon_r + 1} \right) E_0 \cos\theta$$

$$p = 4\pi\epsilon_0 \left(\frac{\epsilon_r - 1}{2\epsilon_r + 1} \right) R^3 E_0$$

$$\dot{E}_{\text{orbital}} = \left(\frac{\epsilon_r - 1}{2\epsilon_r + 1} \right) \frac{q_p^2 R^3 \tau}{r_0^4} \Omega(\Omega_H - \Omega)$$

$$\omega_{\rm res}^2 = \mu_s^2 - \mu_s^2 \left(\frac{\mu_s M}{l+1+n} \right)^2 \qquad \omega_I = \mu_s \frac{(\mu_s M)^8}{24} \left(a/M - 2\mu_s r_+ \right)$$

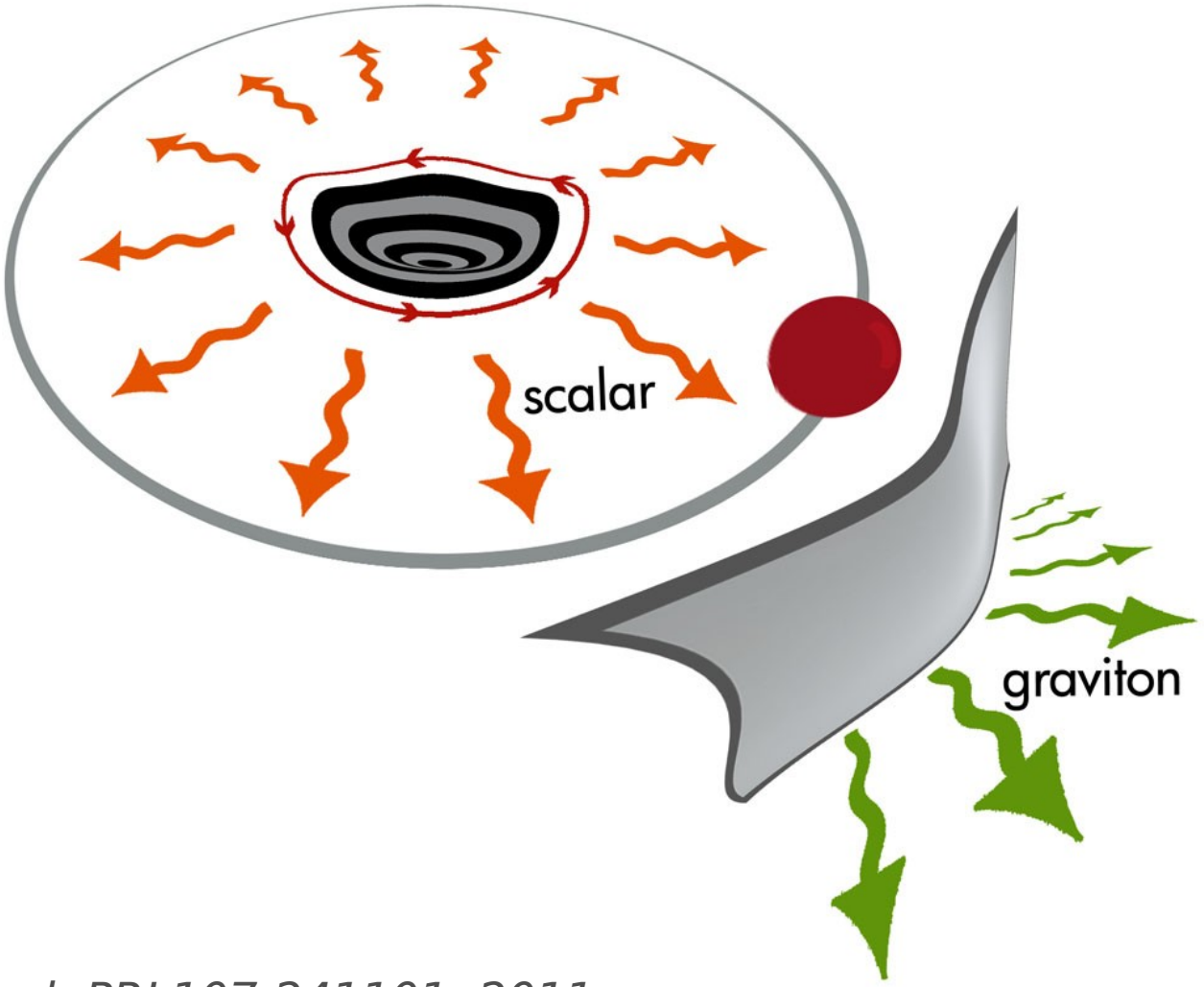
Massive fields



Massive fields around Kerr are unstable

(Damour et al ‘76; Detweiler, ’80; Cardoso & Yoshida ’05; Dolan ‘07)

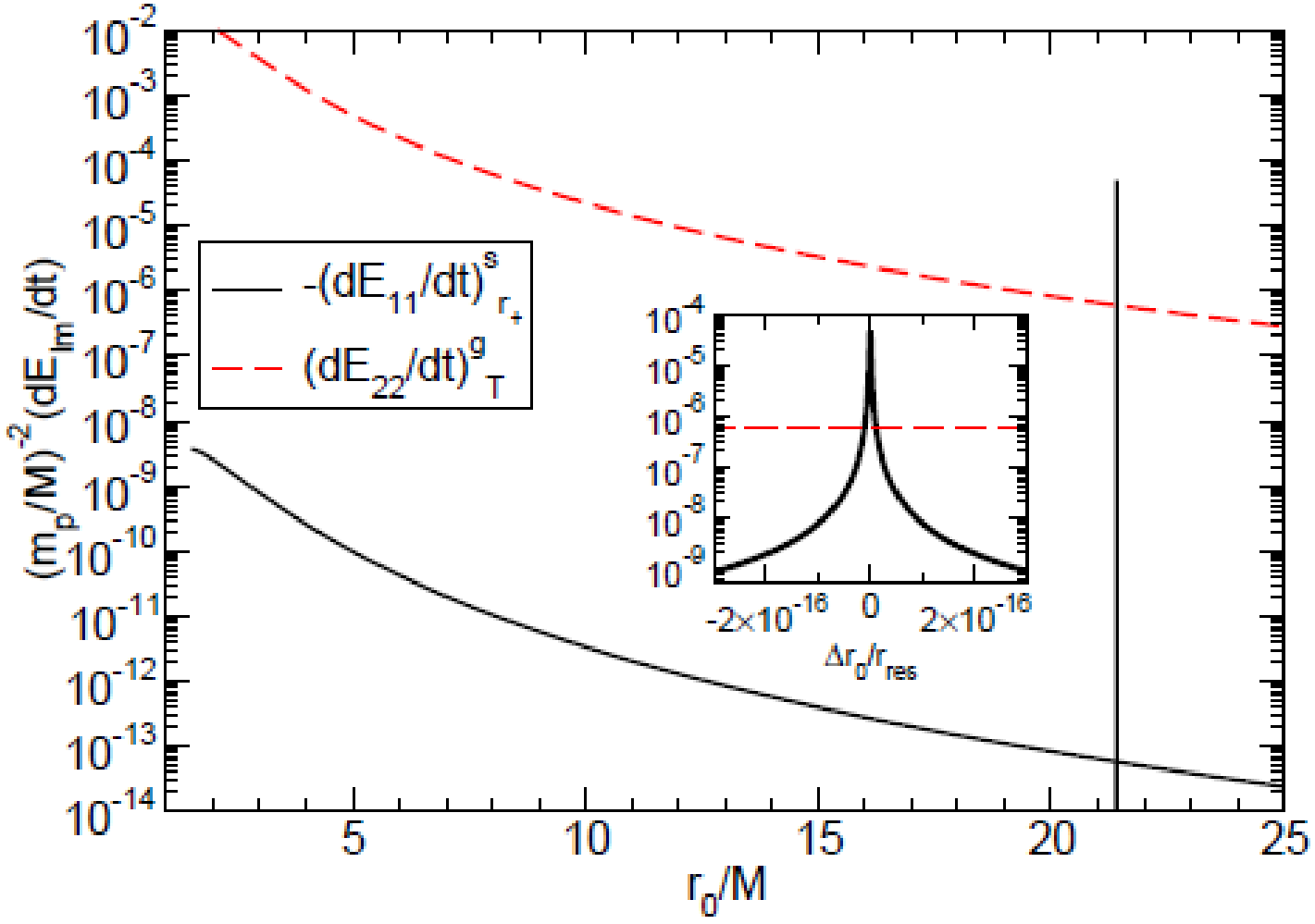
Floating orbits

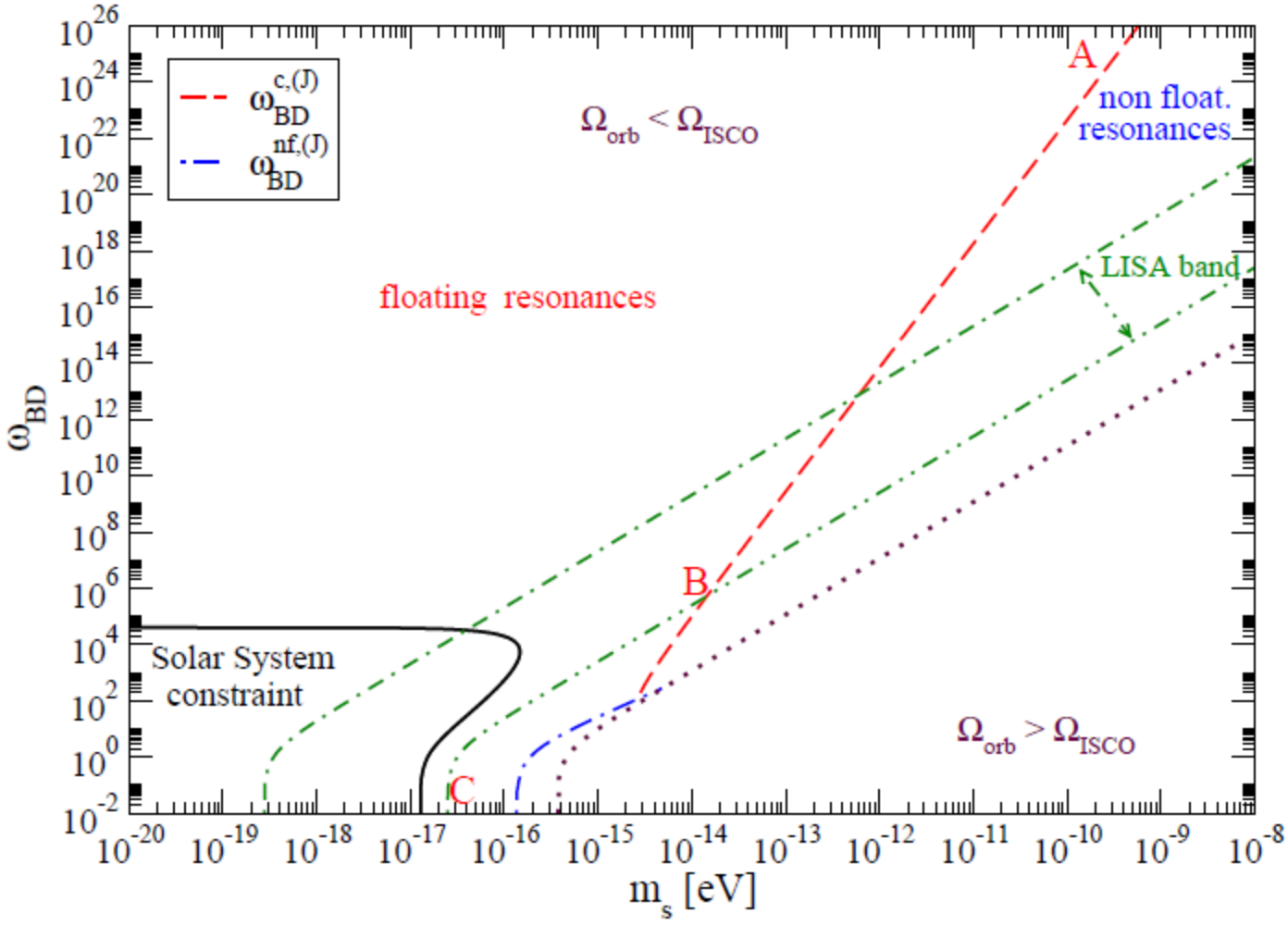


Cardoso et al, PRL107:241101, 2011

$$\left[\Box - \mu_s^2\right] \varphi = \alpha \mathcal{T}$$

$$\dot{E}_{r_+}^{s,\text{peak}} \sim -\frac{3\alpha^2 \sqrt{\frac{r_0}{M}} m_p^2 M}{16\pi r_+ \left(M^2 - a^2\right) \left(\frac{a}{2r_+} - \left(\frac{M}{r_0}\right)^{3/2}\right) \mathcal{F}}$$


10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
10^{-8}
10^{-9}
10^{-10}
10^{-11}
10^{-12}
10^{-13}
10^{-14}
$(m_p/M)^{-2}(dE_{lm}/dt)$
5
10
15
20
25
r_0/M
$-(dE_{11}/dt)^{s}_{r_+}$
$(dE_{22}/dt)^{g}_{T}$
10^{-4}
10^{-5}
10^{-6}
10^{-7}
10^{-8}
10^{-9}
-2×10^{-16}
0
2×10^{-16}
$\Delta r_0/r_{res}$


$\omega_{BD}^{c,(J)}$
$\omega_{BD}^{nf,(J)}$
$\Omega_{orb} < \Omega_{ISCO}$
A
non float. resonances
LISA band
floating resonances
B
Solar System constraint
C
$\Omega_{orb} > \Omega_{ISCO}$
ω_{BD}
m_s [eV]

Tidal acceleration is equivalent to superradiance in BH physics

In absence of other dissipation mechanisms, tidal dissipation leads to floating orbits

Floating orbits can be instrumental to constrain or prove existence of massive scalars coupled to matter... still a lot to do

Cardoso, Chakrabarti, Pani, Berti, Gualtieri, PRL107: 241101 (2011)

Yunes, Pani, Cardoso, arXiv:1112.3351

Cardoso, Pani, in progress (2012)

Thank you