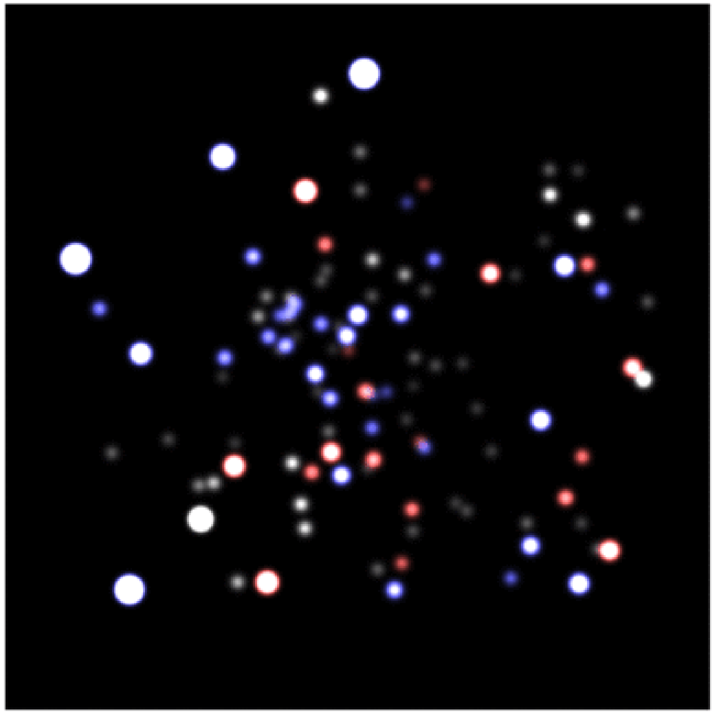
Energy extraction from black holes

Kyoto 2012 | March 28, 2012 | Kyoto, Japan



Credit: ESO/MPE (2010)

Vitor Cardoso (CENTRA/IST & Olemiss)

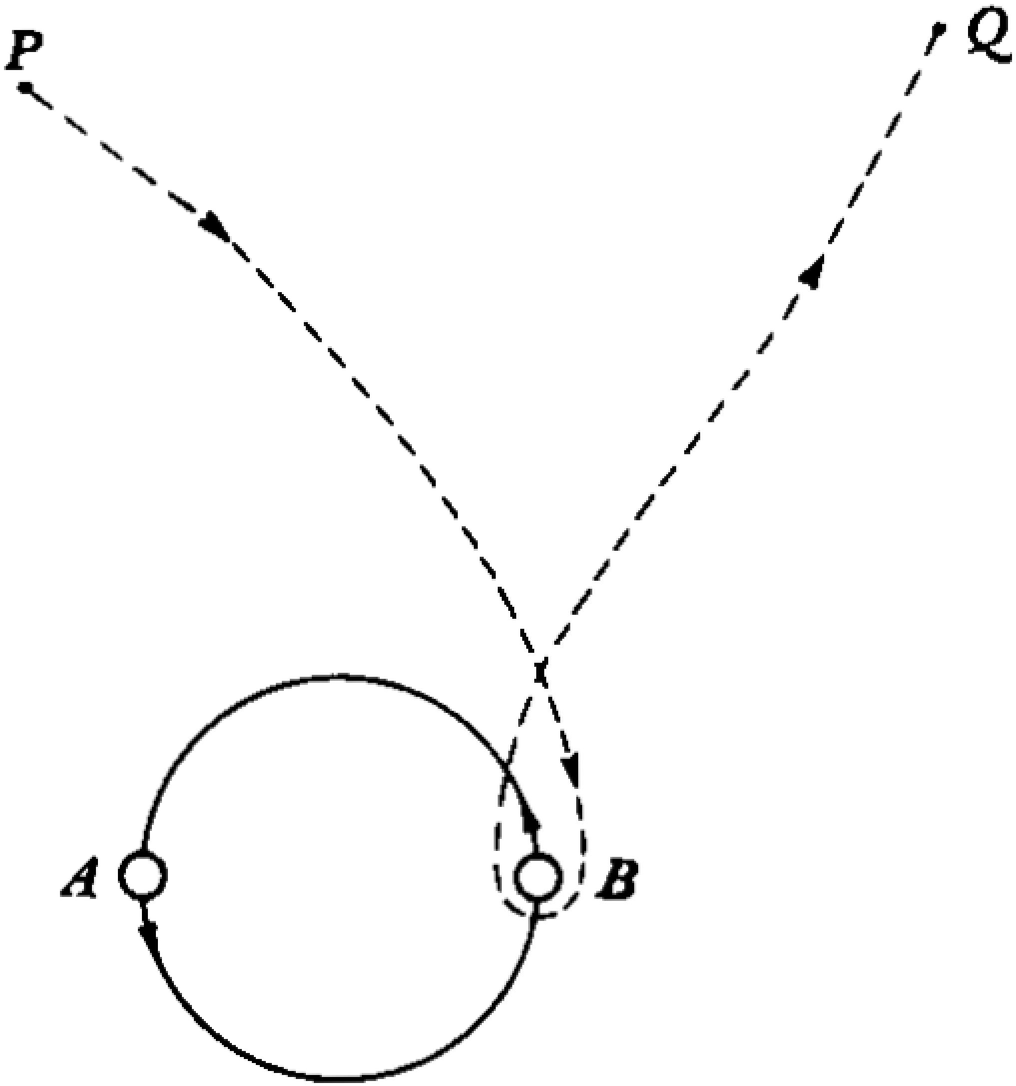
Cardoso et al, PRL107: 241101 (2011)

Yunes, Pani, Cardoso, arXiv:1112.3351

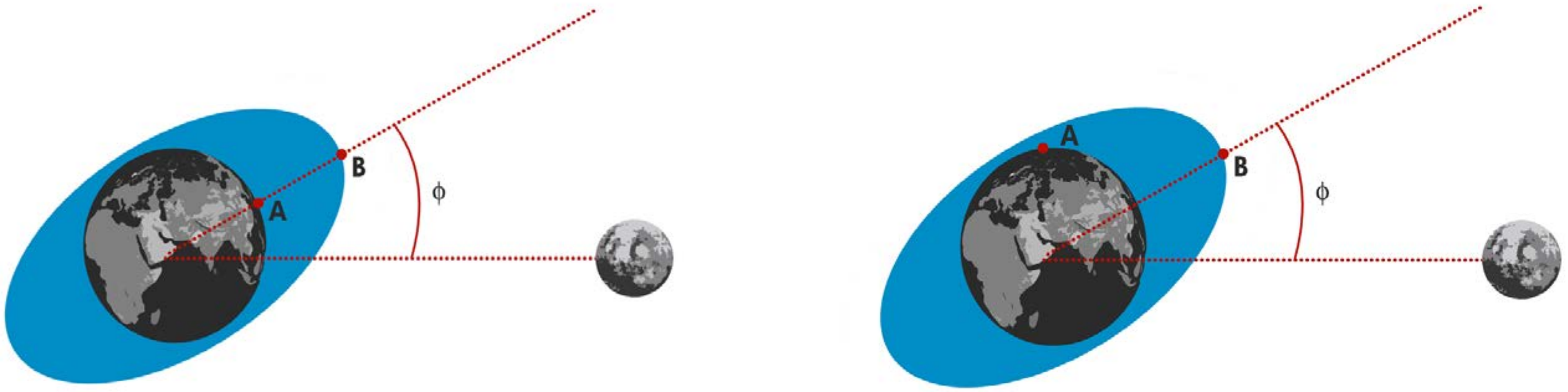
Cardoso & Pani, unpublished; Brito et al (2012)

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

Orbital energy: slingshot effect



Rotational energy: tidal acceleration



Earth-moon: 0.002s/cent

4cm/yr

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

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

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

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)

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

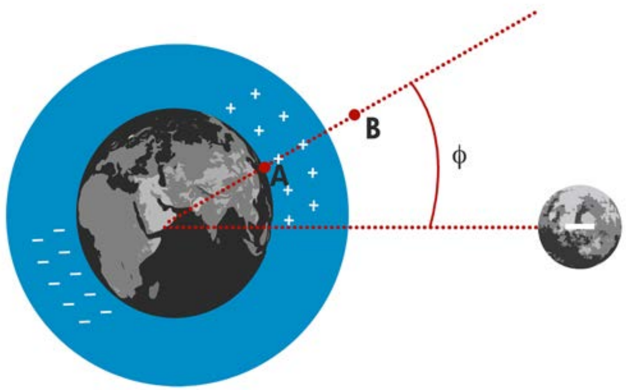
Proxy for more complex interactions

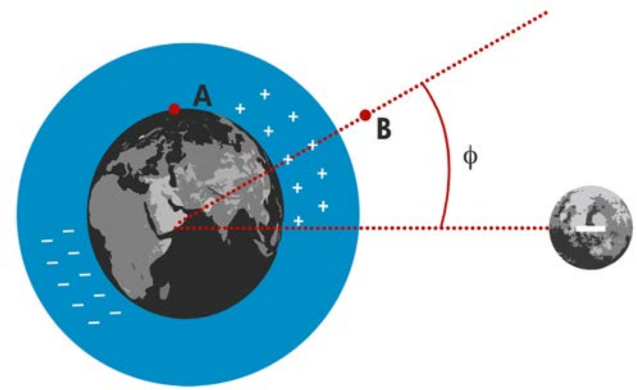
Arise as interesting alternatives of GR

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

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

We are in the Yukawa Institute





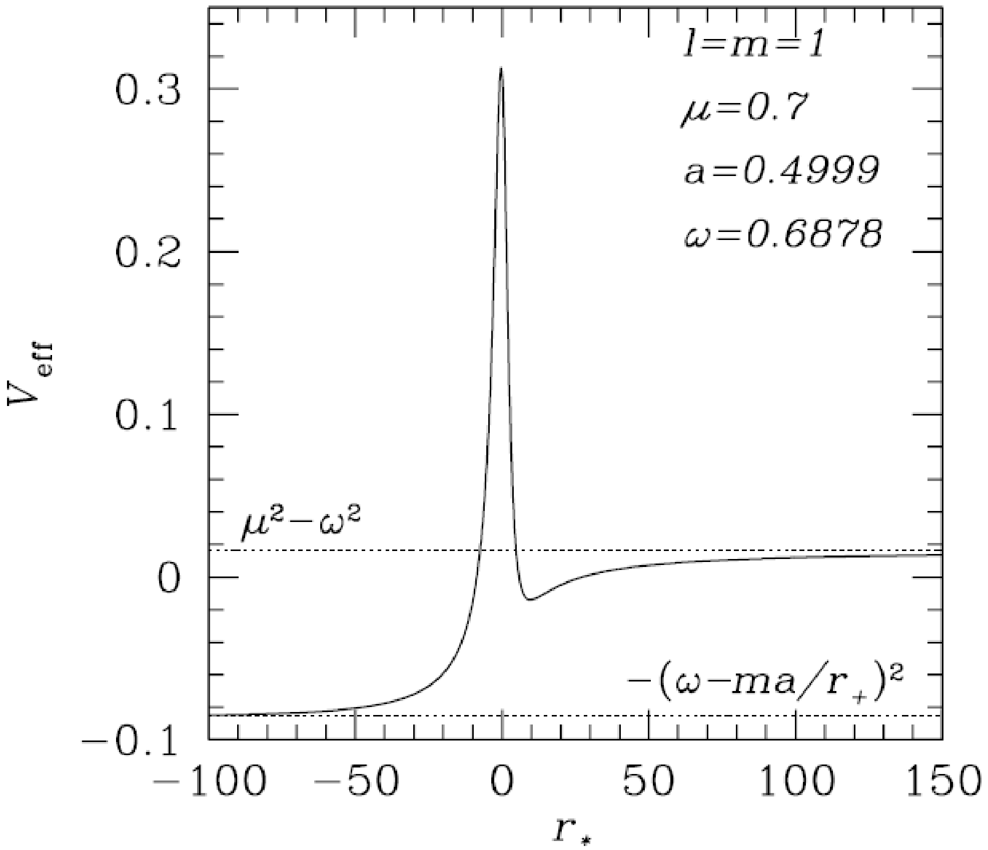
$$\sigma_{\text{pol}} = 3\epsilon_0 \left(\frac{\epsilon_r - 1}{2\epsilon_r + 1} \right) E_0 \cos\theta$$

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

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

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

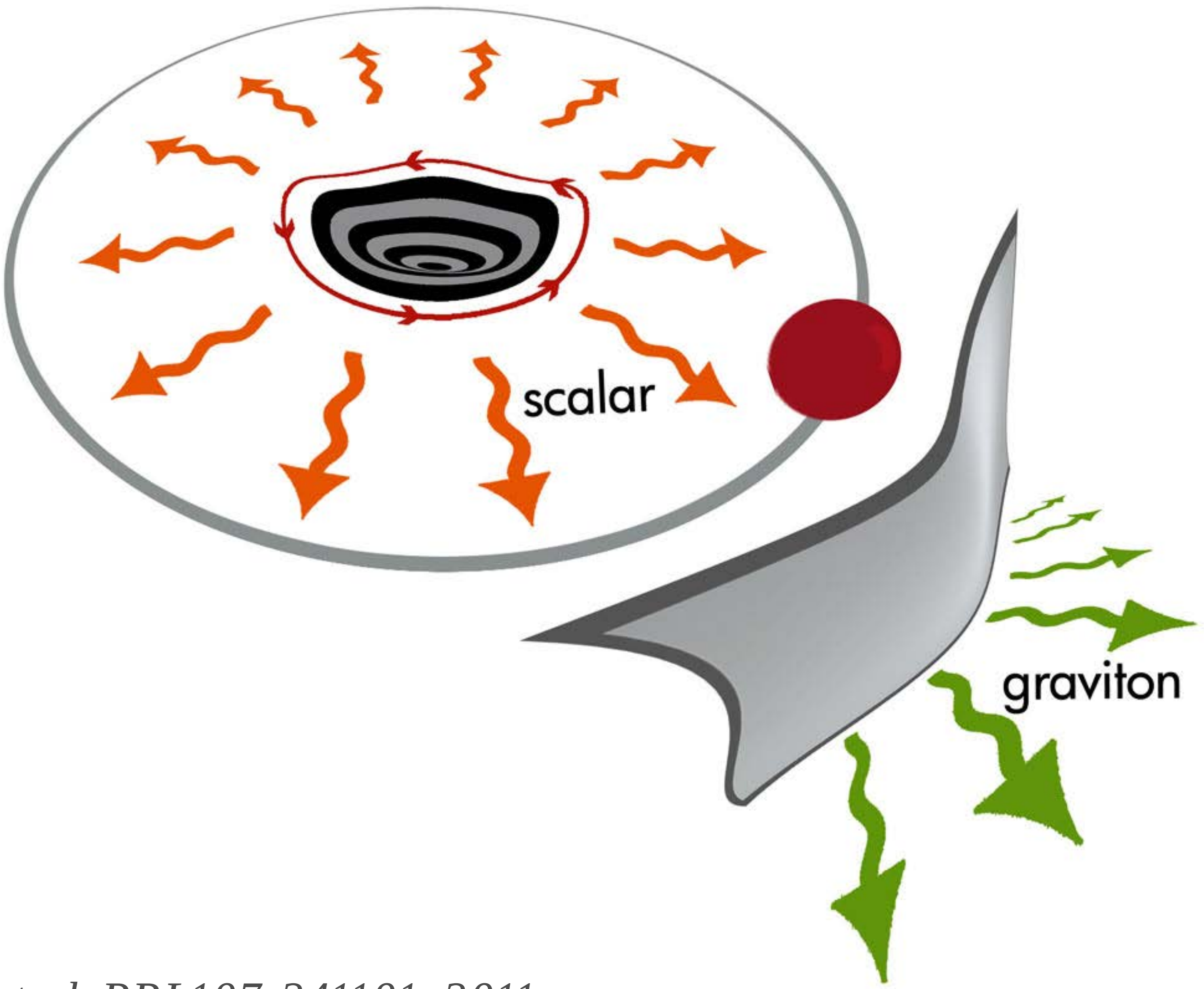
Massive fields



Massive fields around Kerr are unstable

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

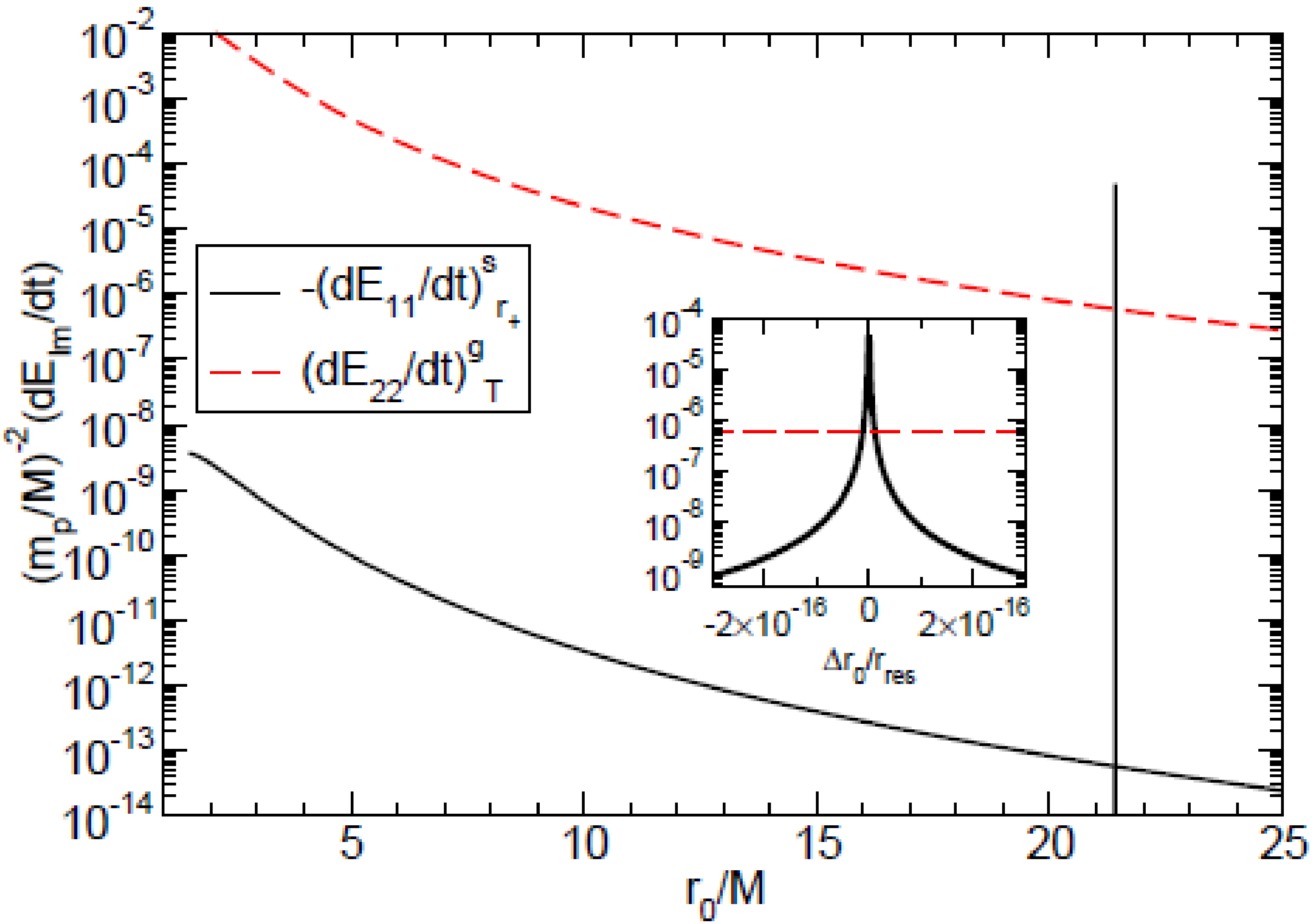
Floating orbits



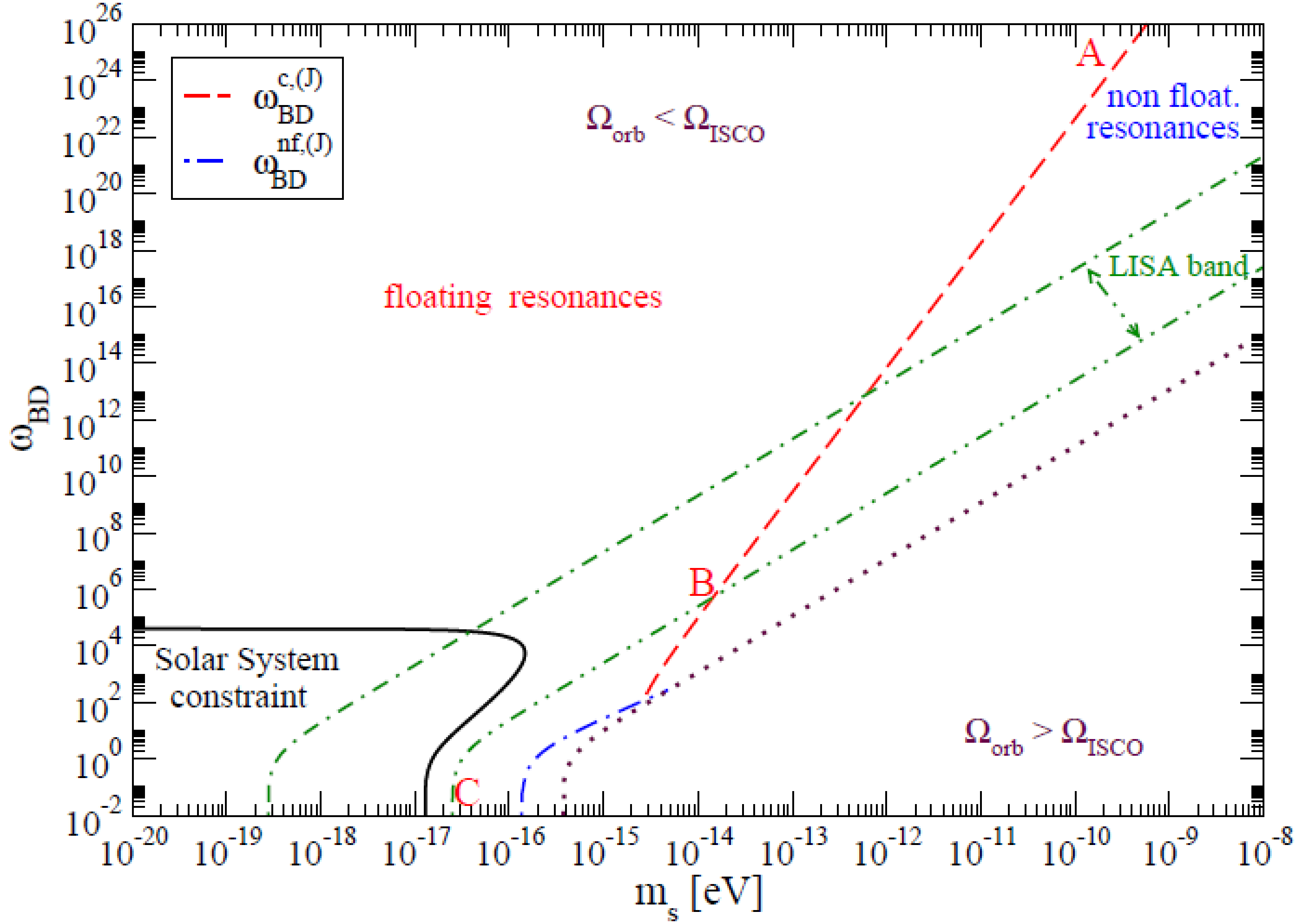
Cardoso et al, PRL107:241101, 2011

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

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



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}
$(m_p/M)^{-2}(dE_{lm}/dt)$
$-(dE_{11}/dt)^s_{r_+}$
$(dE_{22}/dt)^g_T$
5
10
15
20
25
r_0/M
10^{-4}
10^{-5}
10^{-6}
10^{-7}
10^{-8}
10^{-9}
-2×10^{-16}
0
2×10^{-16}
$\Delta r_0/r_{res}$



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

Tidal acceleration in higher dimensions

$$\frac{\dot{E}_{\rm H}}{\dot{E}_{\infty}} \sim (v/c)^{\frac{-(D-5)(D+1)}{D-3}} \qquad s=2$$

$$\frac{\dot{E}_{\rm H}}{\dot{E}_{\infty}} \sim (v/c)^{\frac{-(D-5)(D-1)}{D-3}} \qquad s=0$$

D>5 particles do not merge, tidal effects are too large?

(scalar field case: yes - Brito et al, in progress)

Circular orbits are unstable, on much smaller timescale...what happens?!

Tidal acceleration is equivalent to superradiance in BH physics

In absence of other dissipative effects tidal dissipation leads to floating

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

- Equal-mass case, what happens to floating?
- Eccentricity OK, what about other sources of noise? Higher multipoles?
- Spinning companion, is floating enhanced? Does is still require massive fields?
- Tidal acceleration requires dissipation (EH). Can it occur for spinning objects without horizon? In principle no, but Blandford-Zjanek seems to, or does it? (see Ruiz et al, arXiv:1203.4125)
- Higher dimensional spacetime: tidal dissipation is dominant mechanism. Consequence for mergers?

Thank you