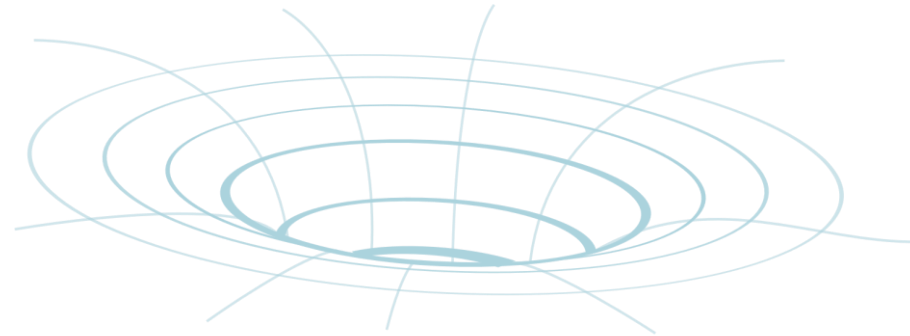


Causality Constraints on Mergers beyond General Relativity



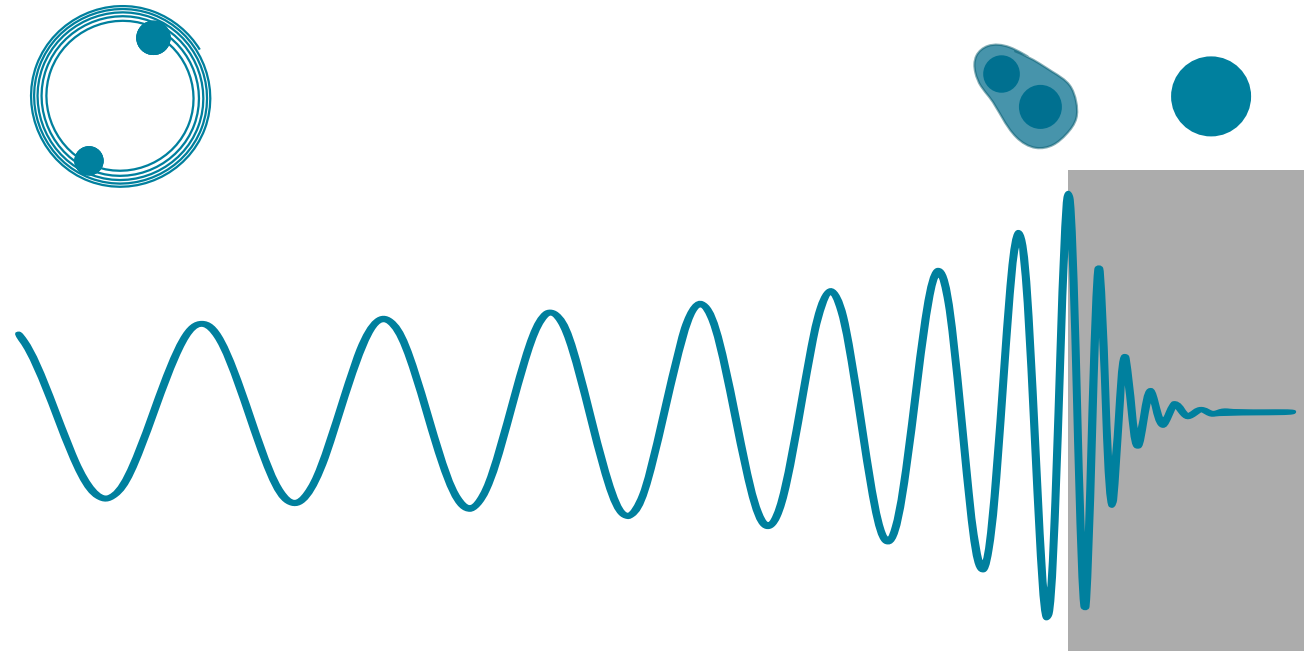
Francesco Serra

Scuola Normale Superiore, INFN Pisa

Based on:

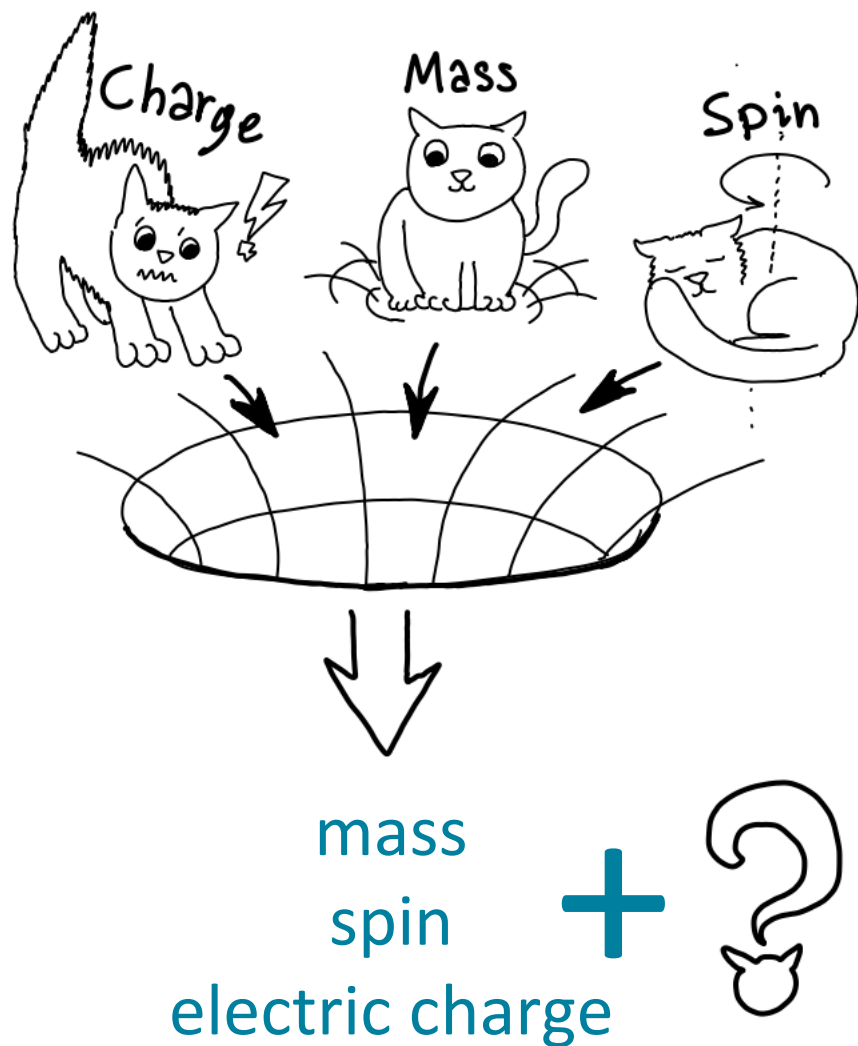
FS, J. Serra, L.G. Trombetta, E. Trincherini – 2205.08551

Test effects beyond GR with gravitational waves



What is the nature of these compact objects?

Black hole hair



Are black holes characterized by these quantities alone?

Black holes in scalar-tensor theories

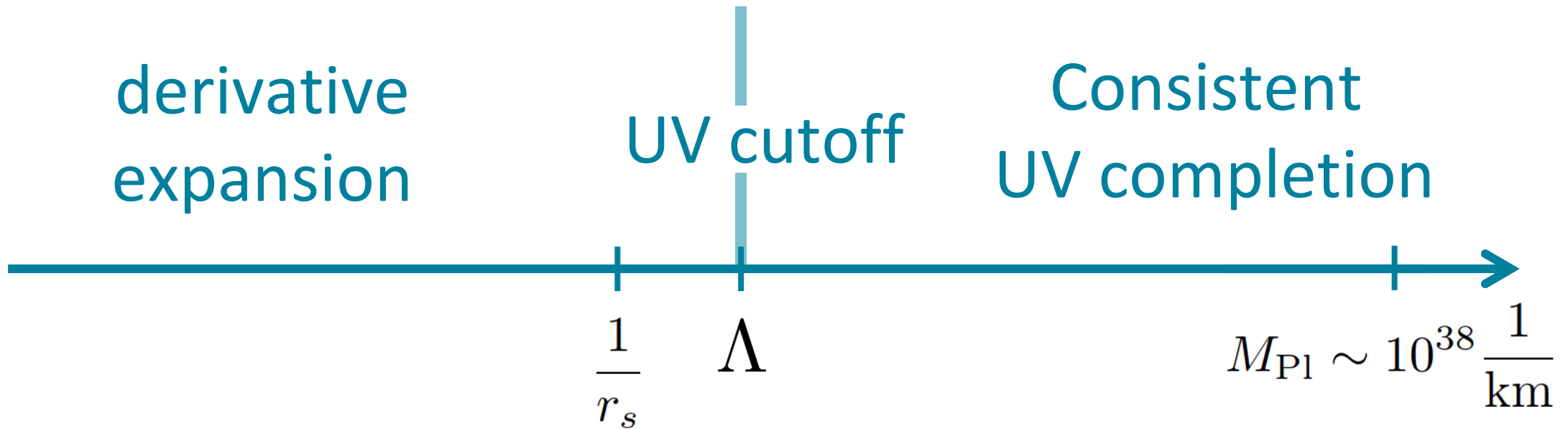
- Scalar only coupled to gravity & $\phi \rightarrow \phi + c$
- The scalar Gauss-Bonnet example

$$S = \int d^4x \sqrt{-g} \left(\frac{M_{\text{Pl}}^2}{2} R - \frac{1}{2} (\partial\phi)^2 + \alpha M_{\text{Pl}} \phi \mathcal{R}_{\text{GB}}^2 \right)$$

Detectable when $\sqrt{\alpha} \sim \text{km}$

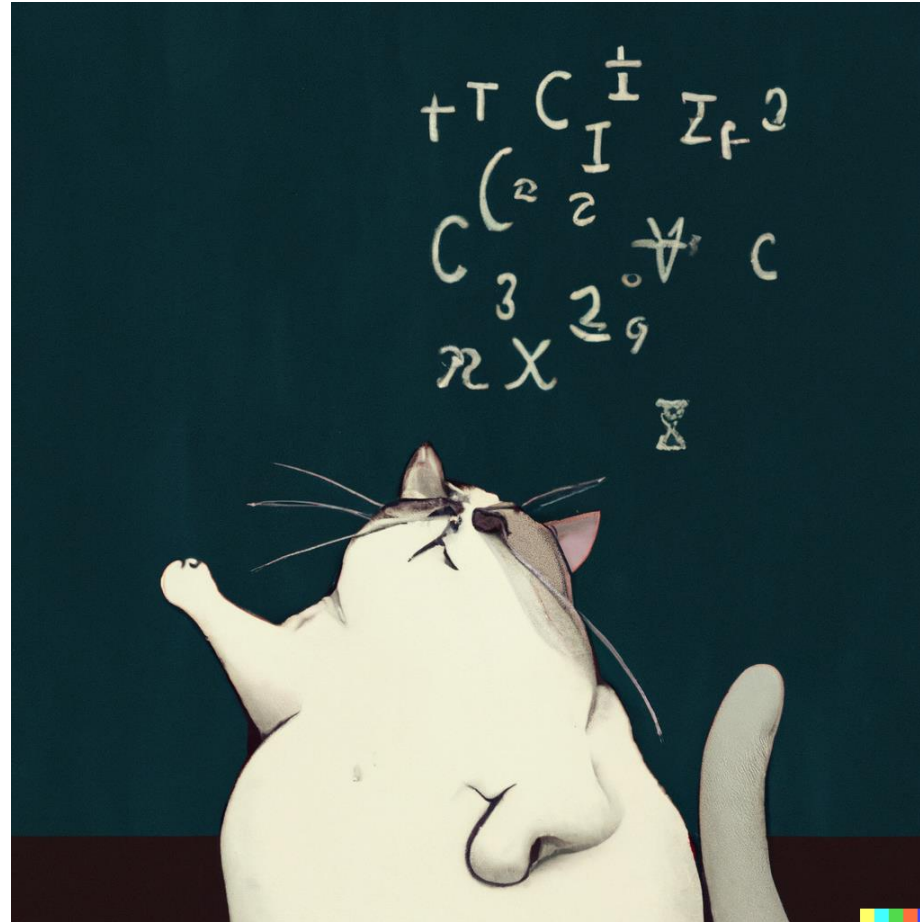
$$\mathcal{R}_{\text{GB}}^2 \equiv R^{\mu\nu\rho\sigma} R_{\mu\nu\rho\sigma} - 4R^{\mu\nu} R_{\mu\nu} + R^2$$

Effective field theories beyond GR



What are the consequences
of having a large coefficient α ?

Theoretical constraints on scalar-GB

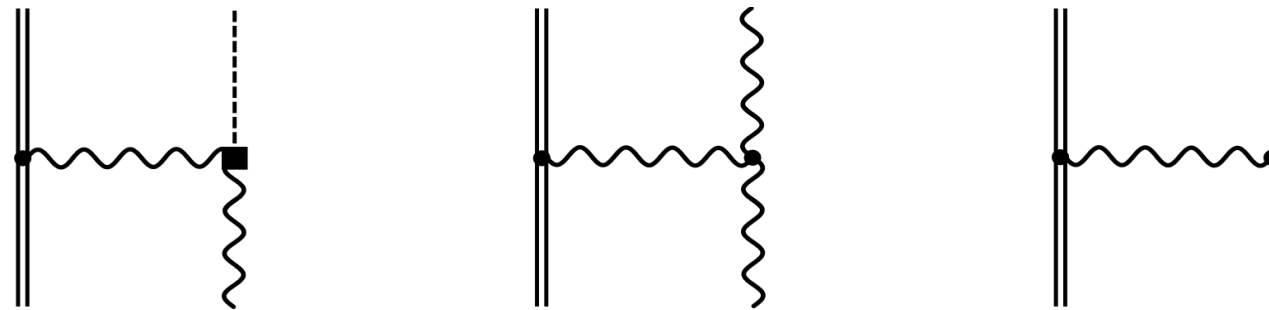


Causality constraints

- Forbid macroscopic time advances

Problem when $\Delta t < 0$ & $|\Delta t| > \frac{1}{\omega}$

- Time delay/advance from scattering
at impact parameter b



Causality requires low UV cutoff

$$\Delta t_{\pm} = 2r_s \left(\underbrace{\log \frac{b_0}{b}}_{\text{Shapiro}} \pm \underbrace{\sqrt{2} \frac{\alpha}{b^2}}_{\text{scalar-GB}} \right)$$

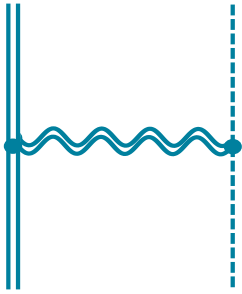
UV completion needed at small impact parameter

$$\Lambda \lesssim 1/\sqrt{\alpha}$$

The EFT is still
weakly coupled!

Which UV completion?

Only known **cure** for time advance at $b \lesssim \sqrt{\alpha}$
is a **tower of spinning states** (Camanho+1407)



$$\sqrt{\alpha} \sim \text{km} \longrightarrow \text{masses} \sim 10^{-9} \text{ eV}$$

would affect experiments!

(see e.g. Caron-Huot+2201)

Moral of the story:

observing effects from a shift-symmetric scalar
in BH mergers seems **not at all likely**

Other compact objects beyond GR?

- $m \neq 0$ scalar clouds
- scalarized BHs
- ECOs – firewalls
- ...

Are there EFT constraints on these scenarios?

Does your UV
completion
make sense?!



mysterious
hairy compact
object

What about a pseudoscalar?

Axion Chern-Simons hair:

$$S = \int d^4x \sqrt{-g} \left(\frac{M_{\text{Pl}}^2}{2} R - \frac{1}{2} (\partial\phi)^2 + M_{\text{Pl}} \tilde{\alpha} \phi R_{\mu\nu\rho\sigma} \tilde{R}^{\mu\nu\rho\sigma} \right)$$

$$\tilde{R}^{\mu\nu\rho\sigma} = \frac{1}{2} \epsilon^{\mu\nu\alpha\beta} R_{\alpha\beta}{}^{\rho\sigma}$$

Detectable when $\sqrt{\tilde{\alpha}} \sim \text{km}$

Causality strikes again!

$$\Lambda \lesssim 1/\sqrt{\tilde{\alpha}}$$