

Spontaneous black-hole scalarization in asymptotically safe quantum gravity?



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Collaborators/supervisors:

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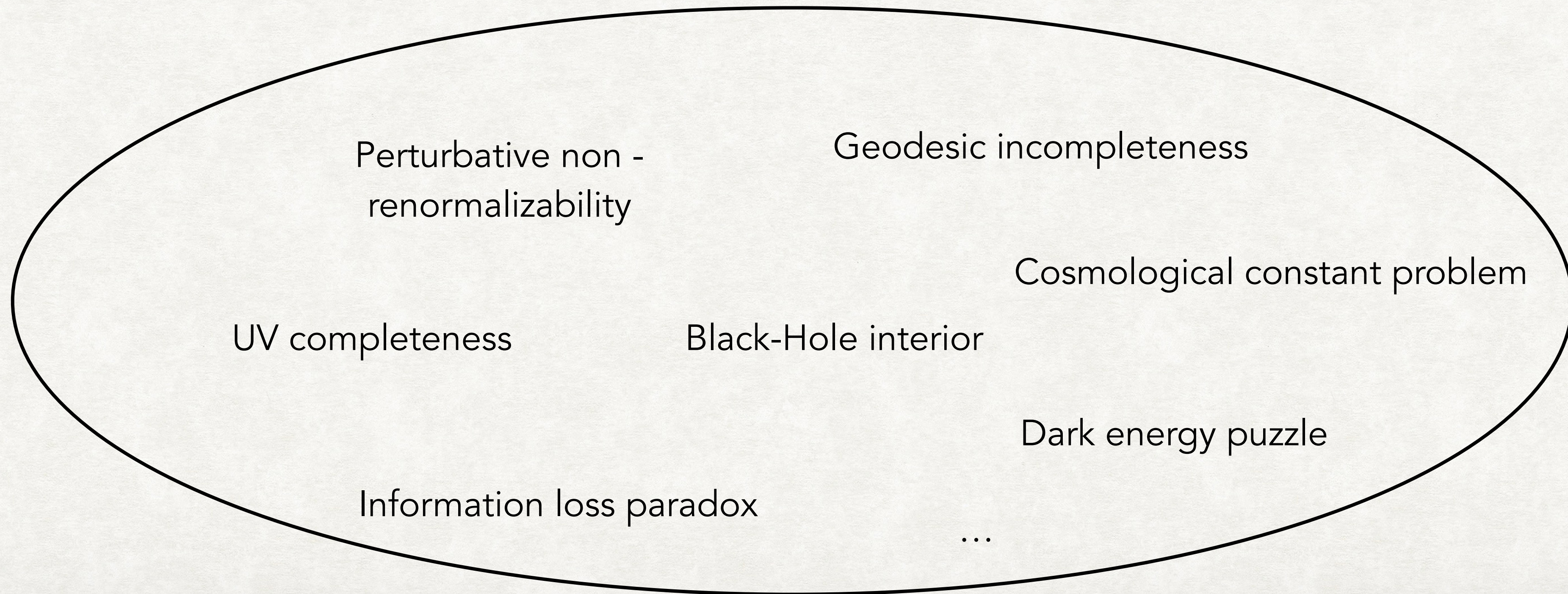
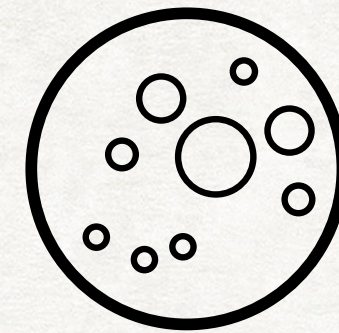
17/09/2026, *Puzzles of Quantum Gravity* - Lidia Marino - PhD student

General Relativity and its open questions

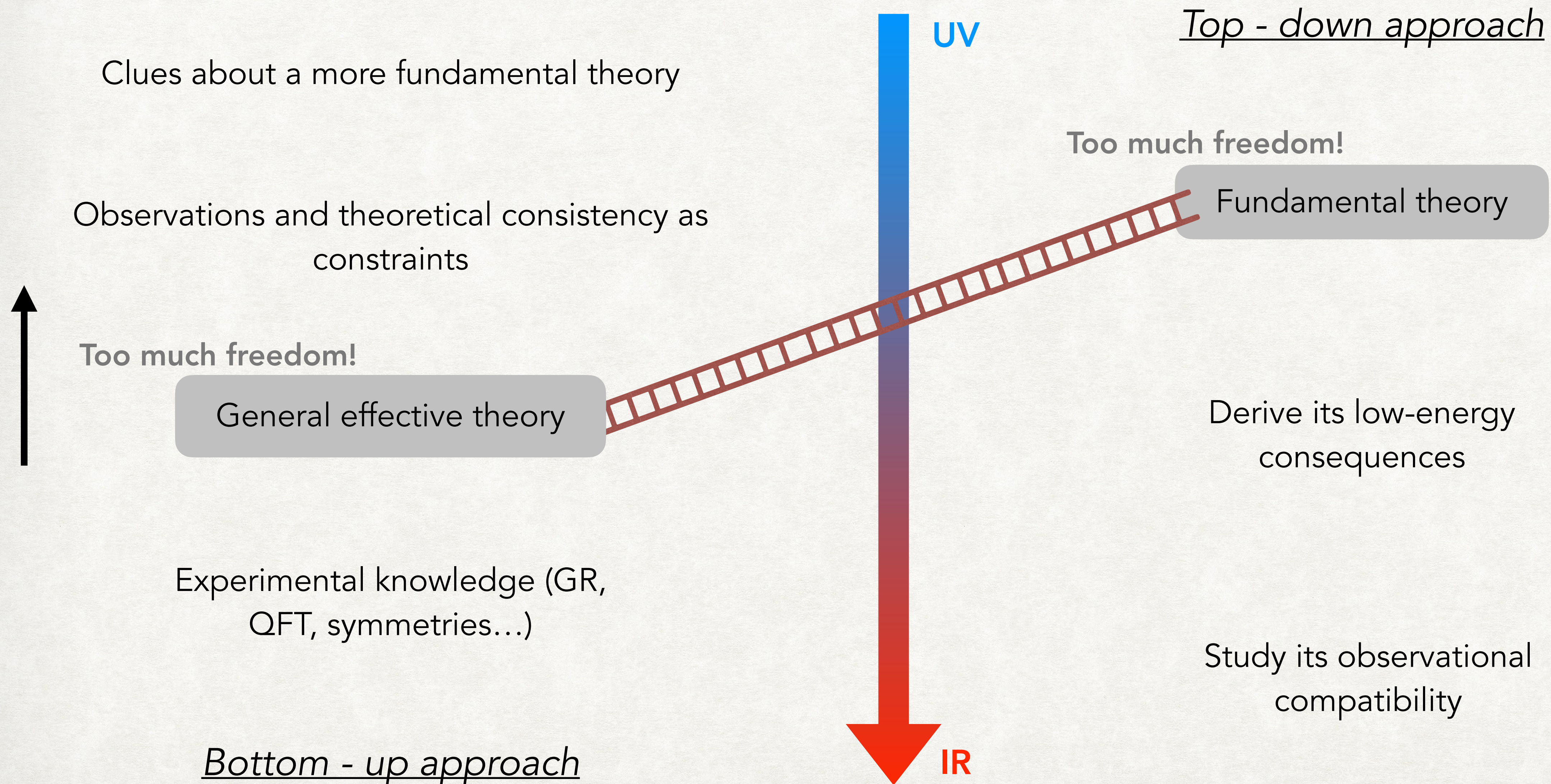
Quantum gravity



Cosmology



And now what?



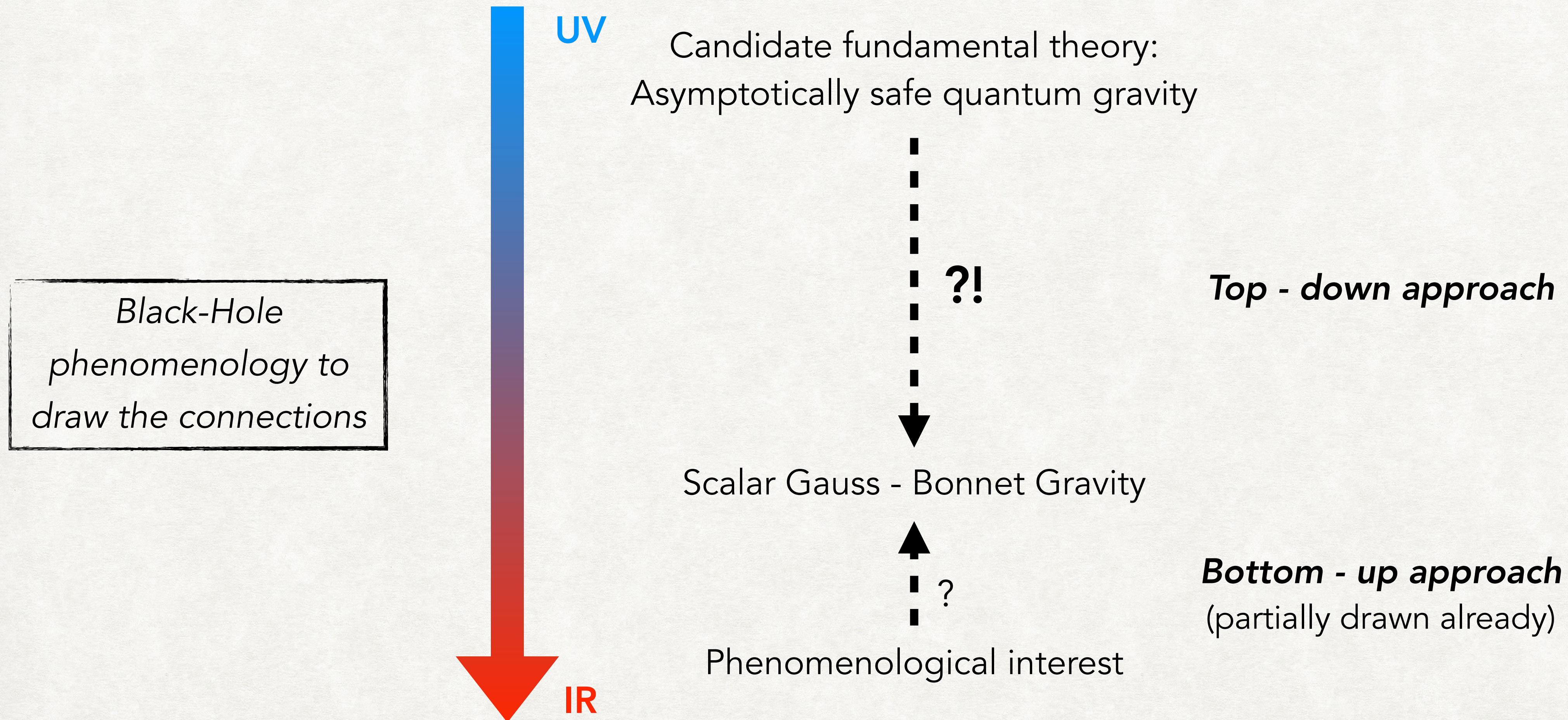
We do it with a class of theories:

Scalar Gauss-Bonnet Gravity

Compatible with string theory



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Bottom-up approach ↑

Scalar Gauss - Bonnet Gravity



Phenomenological interest

Phenomenological interest



'A black hole has no hair'...

Uniquely described by the Kerr solution, i.e. fully characterised only by their mass and spin. [Kerr, 1963]

Vast range of black hole masses observed: from $M \sim 10^1 M_\odot$ to $M \sim 10^{10} M_\odot$. [LIGO-Virgo collaboration '15-'17, EHT '19]

... or has it?

Interior of black holes has open problems (curvature singularity, cauchy horizon...).

A quantum gravity theory that solves them is expected to not leave the black-hole exterior unmodified.

Map out the space of possible modifications:

- no-hair theorem violations;
- future observations (LISA or the Einstein Telescope) could confirm this expectation.

[Sruthy, arXiv:2605.18428], [Codazzo, arXiv:2605.12249], [colpi, arXiv:2402.07571]

Scalar Gauss-Bonnet gravity



$$S = \frac{1}{16\pi} \int d^4x \sqrt{-g} \left(\underbrace{R}_{\text{General Relativity}} - \underbrace{\nabla_\mu \phi \nabla^\mu \phi}_{\text{Scalar field } \phi} + \frac{\alpha}{4} f(\phi) \mathcal{G} \right)$$

Mixed term:

- Gauss-Bonnet invariant $\mathcal{G}$;
- coupling constant α ;
- function of the scalar field $f(\phi)$.

$$\mathcal{G} = R^2 - 4R^{\mu\nu}R_{\mu\nu} + R^{\mu\nu\rho\sigma}R_{\mu\nu\rho\sigma}$$

Geometric units: $G = c = 1$

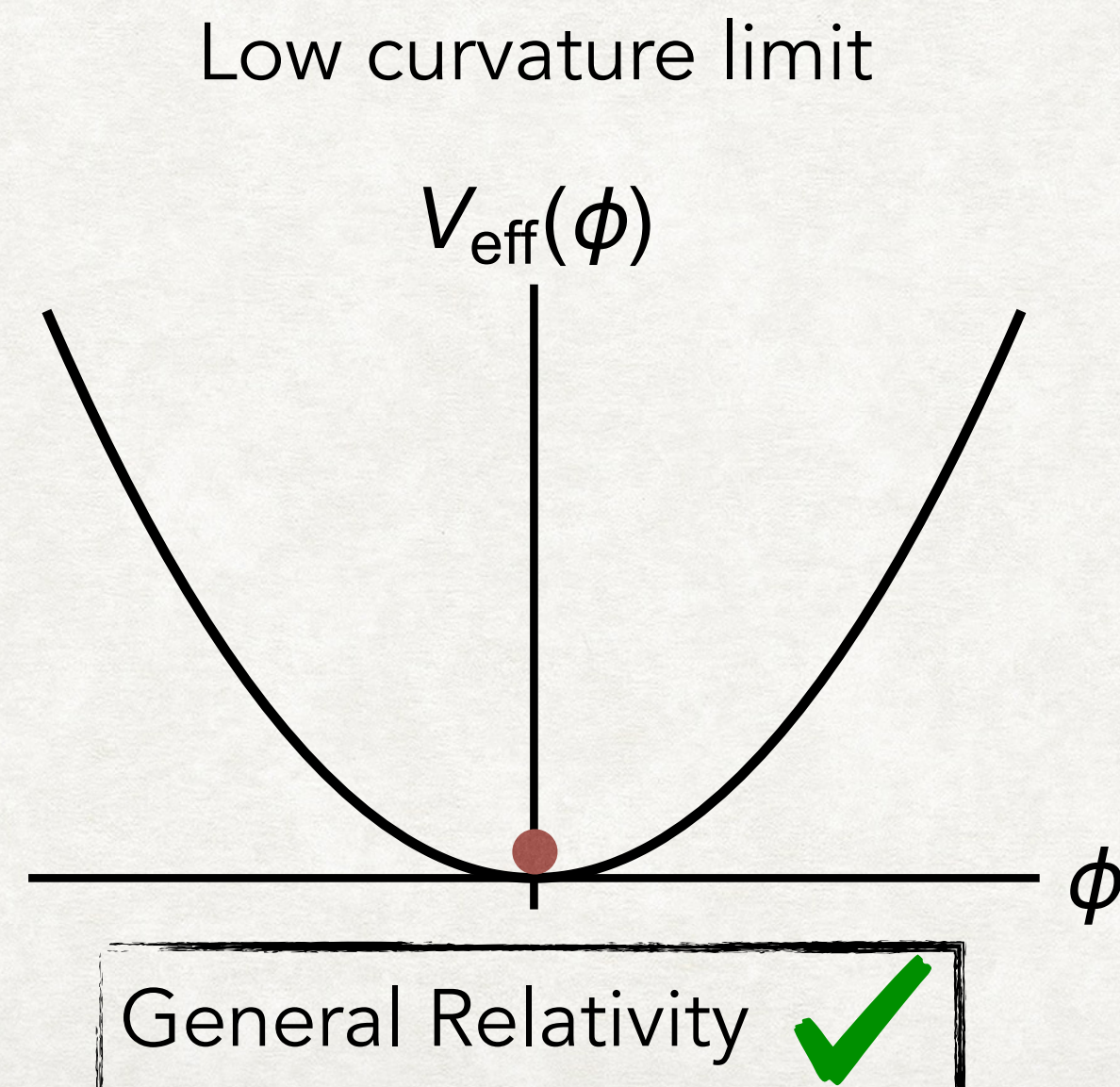
$$\Rightarrow L = M$$

$$[\phi] = 1$$

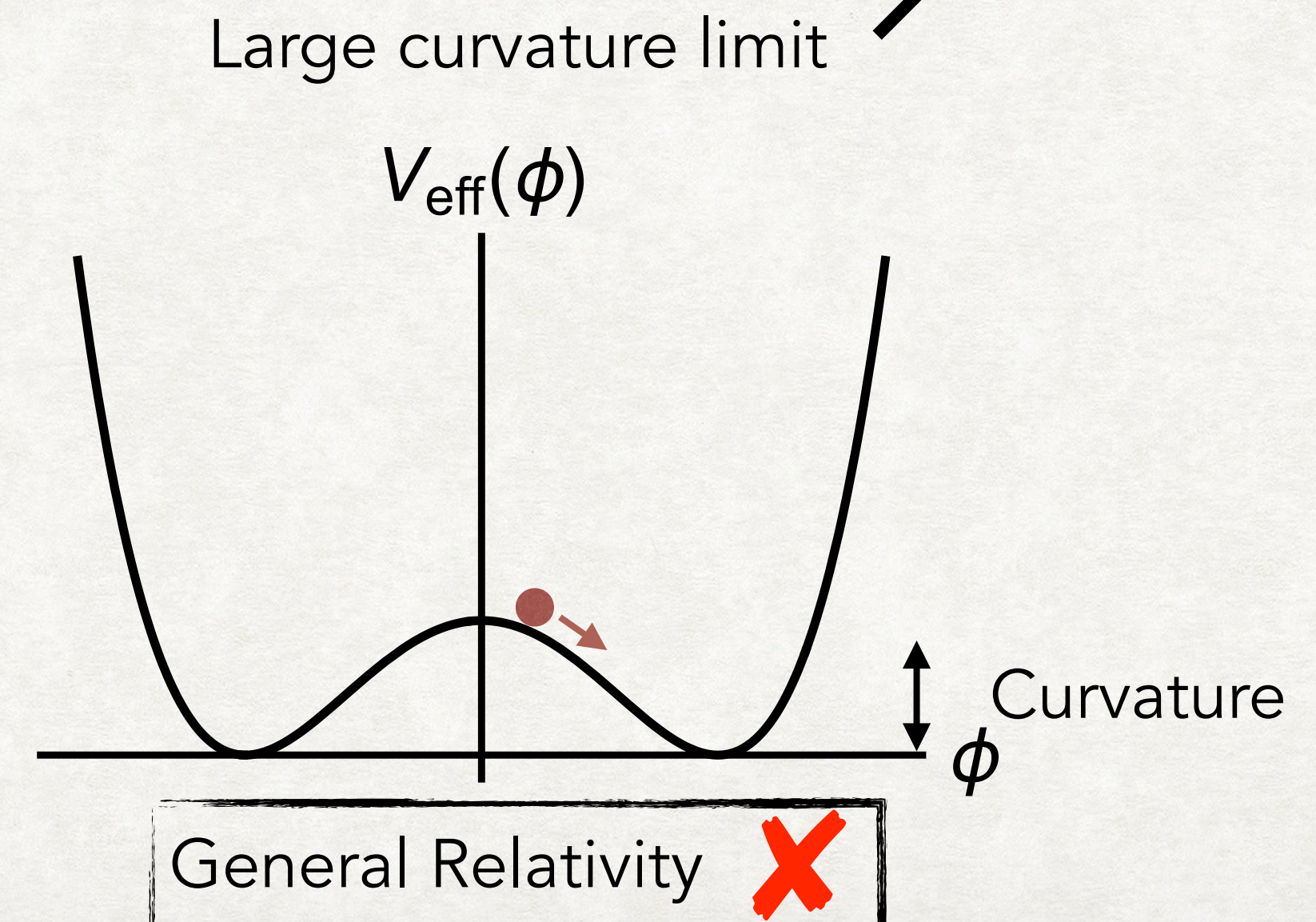
$$[\alpha] = M^2$$

Sketch of the mechanism:

Review at [Doneva et alia, arXiv:1904.06365]



Spontaneous
symmetry breaking



Alternative Black Hole
solutions!



Scalar Gauss-Bonnet gravity

$$S = \frac{1}{16\pi} \int d^4x \sqrt{-g} \left(\underbrace{R}_{\text{General Relativity}} - \underbrace{\nabla_\mu \phi \nabla^\mu \phi}_{\text{Scalar field } \phi} + \underbrace{\frac{\alpha}{4} f(\phi) \mathcal{G}}_{\text{Mixed term}} \right)$$

Mixed term:

- Gauss-Bonnet invariant $\mathcal{G}$;
- coupling constant α ;
- function of the scalar field $f(\phi)$.

$$\mathcal{G} = R^2 - 4R^{\mu\nu}R_{\mu\nu} + R^{\mu\nu\rho\sigma}R_{\mu\nu\rho\sigma}$$

Geometric units: $G = c = 1$

$$\Rightarrow L = M$$

$$[\phi] = 1$$

$$[\alpha] = M^2$$

$f(\phi) = \phi^3$ allows multiple types of alternative black-hole solutions, so called **spin-induced** and **curvature-induced**, to coexist within the same theory.

To do:

A. Start with a metric ansatz compatible with spinning black holes

B. Numerically solve the equations of motion [Fernandes, arXiv:2212.07293]

Summary of main results

[Eichhorn, Fernandes, LM, arXiv:2603.05064]



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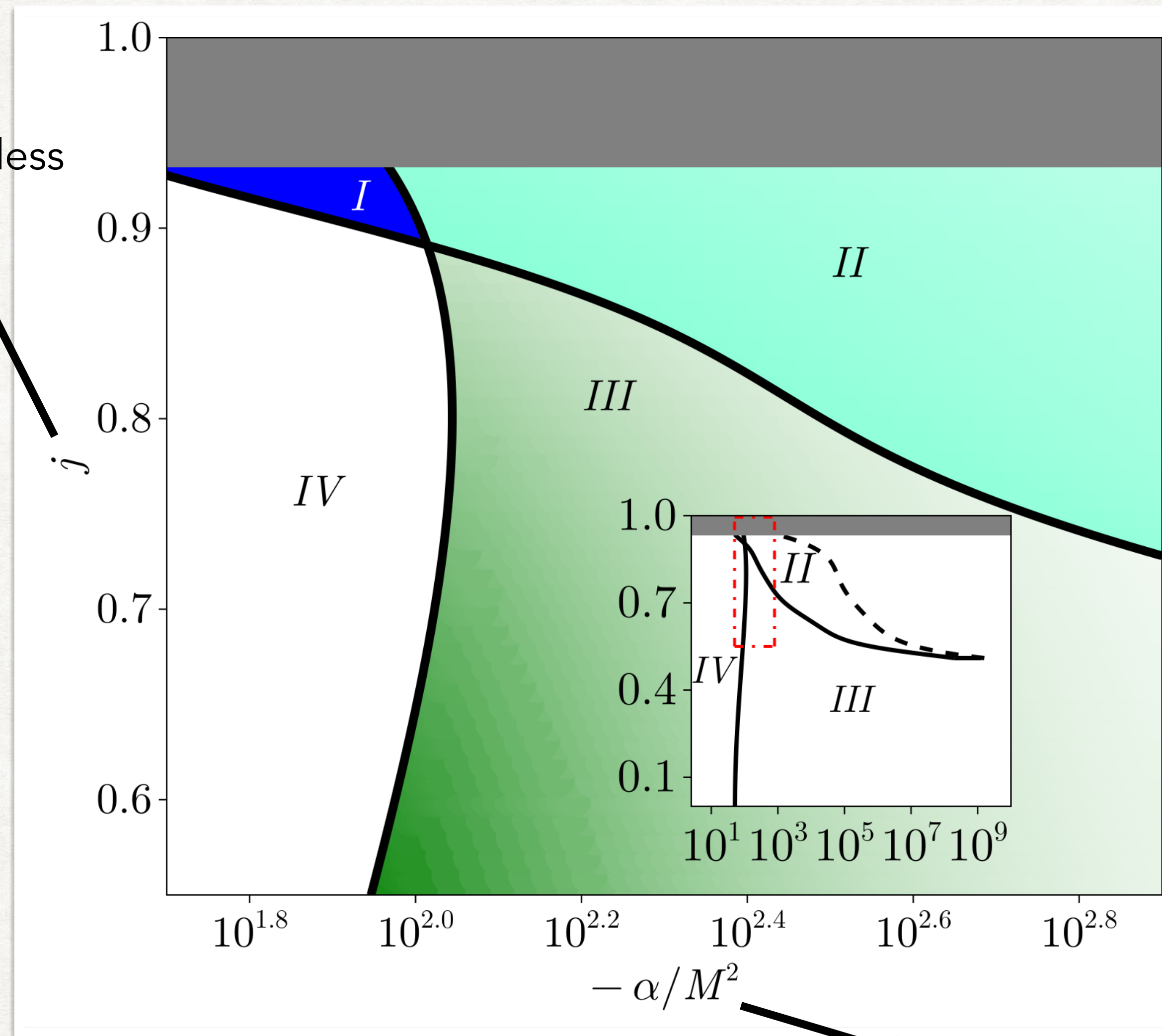
Numerically
challenging

Regions:

- I. Spin and Kerr Black holes;
- II. Spin, curvature and Kerr black holes;
- III. Curvature and Kerr black holes;
- IV. Kerr black holes.

Strong breaking of BH uniqueness

Dimensionless
spin



Coupling α over
black-hole mass

Remember our original goal: map out all the possible modifications.

What else could we do?

Modify the chosen theory:

- Different scalar field functions
- Add lower or higher curvature terms



A lot of new theories,
also structurally different

For each of them, one could study:

- Stability of the solutions
- Impact on other compact objects (neutron stars)
- Effects on observations (gravitational waves)
- Phase transitions between different branches
- ...

A lot of work...

How to discriminate between all the possible theories
and restrict the freedom we have?



Top-down approach!



Top-down approach ↓

Candidate fundamental theory:
Asymptotically safe quantum gravity



Scalar Gauss - Bonnet Gravity



Top-down approach ↓

Candidate fundamental theory:
Asymptotically safe quantum gravity



Scalar Gauss - Bonnet Gravity

Full effective action with **all**
quantum fluctuations

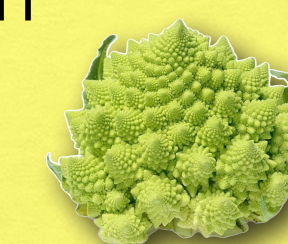
IR

Integration over quantum fluctuations

FRG

Action with **no** quantum
fluctuations

UV



Scalar Gauss-Bonnet gravity

HeP units: $\hbar = c = 1$
 $\Rightarrow L = M^{-1}$



$$\Gamma_{eff} = \int d^4x \sqrt{g} \left[\frac{(\partial\phi)^2}{2} - \frac{R}{16\pi\bar{G}} + \frac{\bar{\Lambda}}{8\pi\bar{G}} + V(\phi) + H(\phi)R + F(\phi)\mathcal{G} \right]$$

The bar indicates dimensionful quantities

Lower order in curvature terms are generated by the flow

Free parameters

Predictions

$$\begin{aligned} V(\phi) &\simeq \bar{\lambda}_1 \phi + \frac{\bar{m}^2}{2} \phi^2 + \frac{\bar{\lambda}_3}{6} \phi^3 \\ H(\phi) &\simeq \bar{\xi}_1 \phi + \frac{\bar{\xi}_2}{2} \phi^2 + \frac{\bar{\xi}_3}{6} \phi^3 \\ F(\phi) &\simeq \bar{\alpha}_1 \phi + \frac{\bar{\alpha}_2}{2} \phi^2 + \frac{\bar{\alpha}_3}{6} \phi^3 \end{aligned}$$

Truncate at third order:
keep the dominant contributions
and all the free parameters

IR constraints on free
parameters

Reduce the number of
trajectories we have

Derive predictions for each
trajectory

Numerically solve the EoMs for that
set of couplings

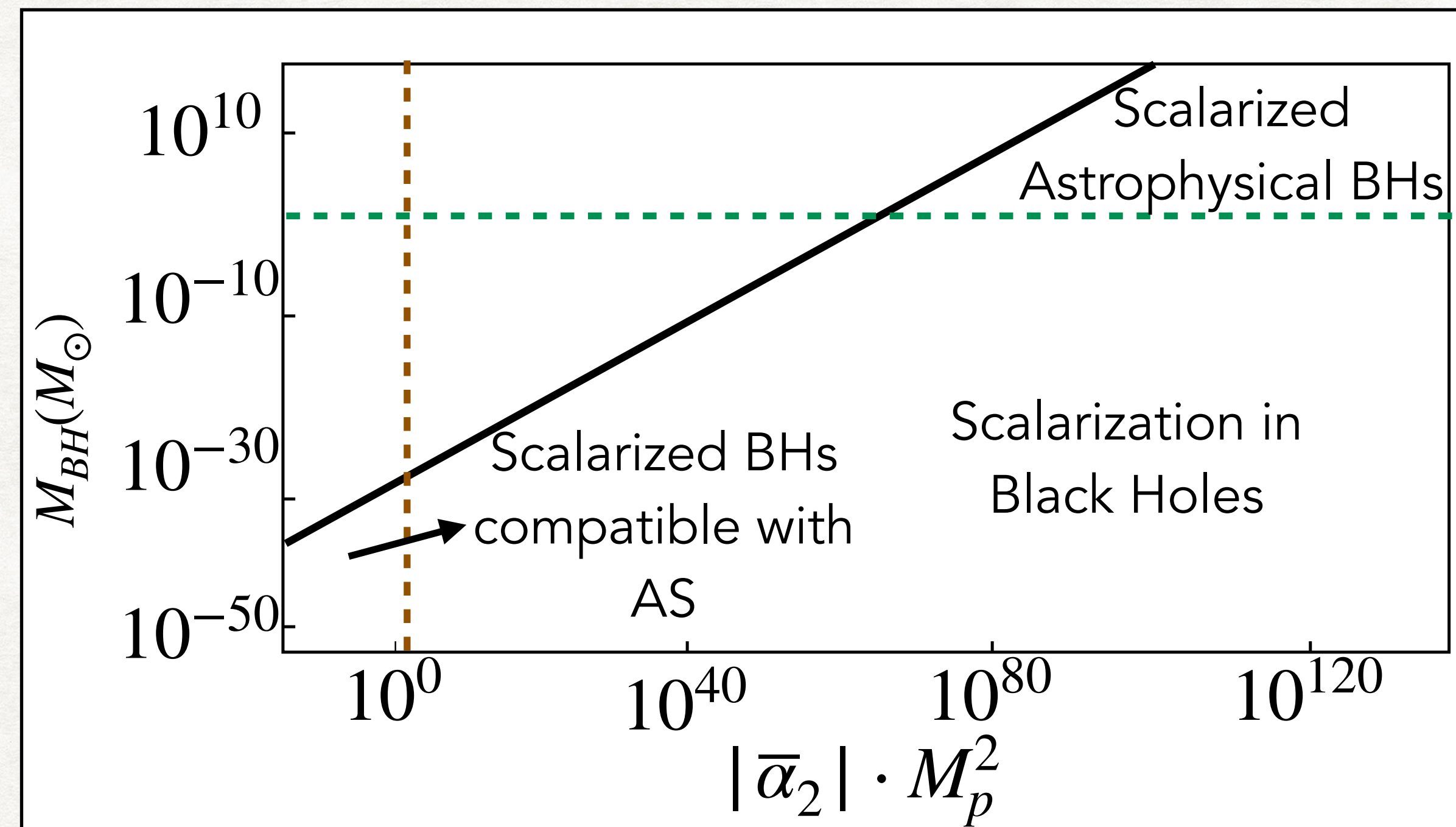
Summary of main results

[De Brito, Eichhorn, Fernandes, LM, out soon!]



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To ensure Asymptotic Safety we need: $\bar{\alpha}_1 \cdot M_p \sim 0$; $\bar{\alpha}_3 \cdot M_p^3 \sim 0$ and $\bar{\alpha}_2 \cdot M_p^2 = f(\xi_2, \bar{m}^2)$.

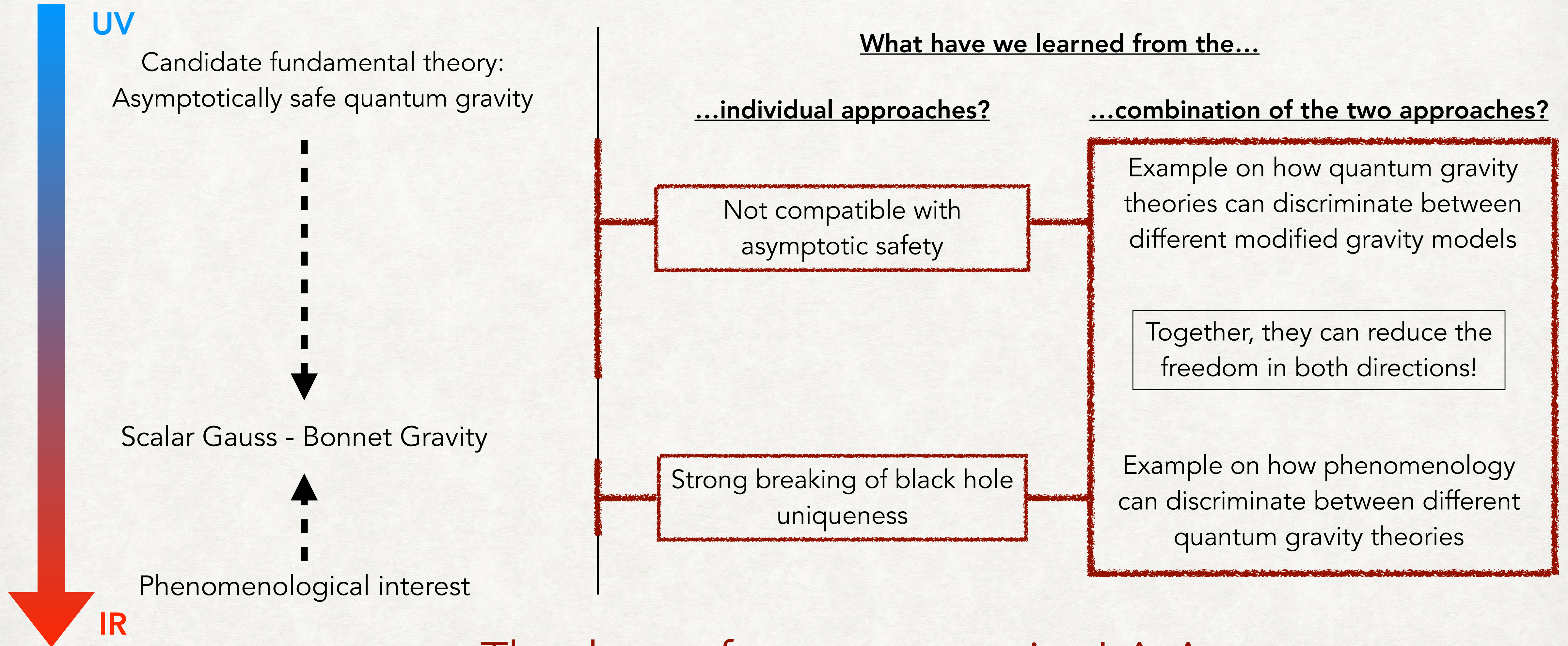


Astrophysical Black Holes cannot scalarize!

Conclusions and take away



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Thank you for your attention! ^_^