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Light Scalars in Light of UV/IR Mixing

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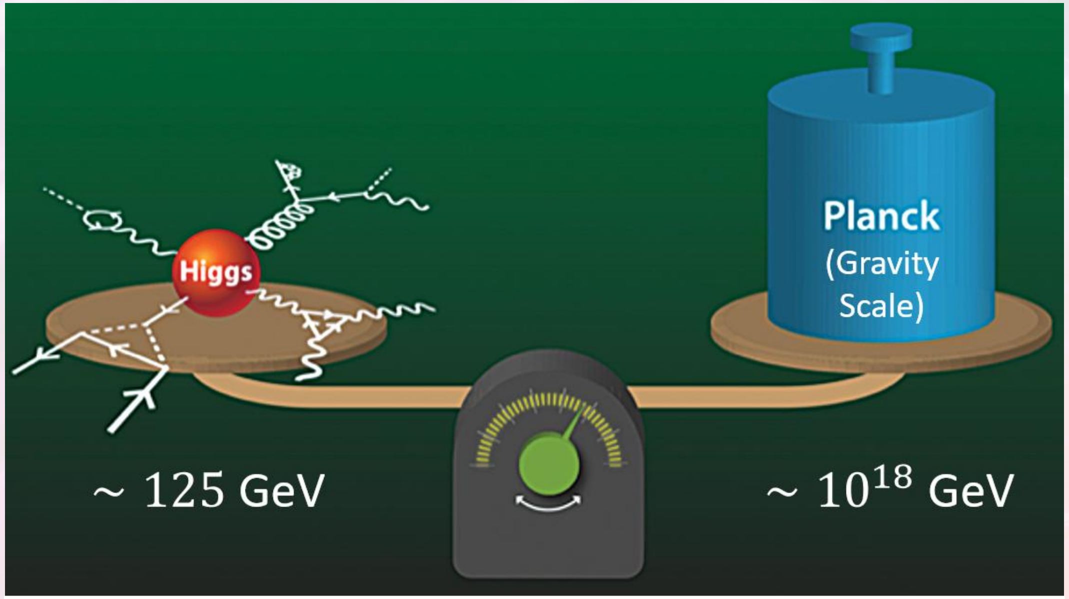
November 25, 2025

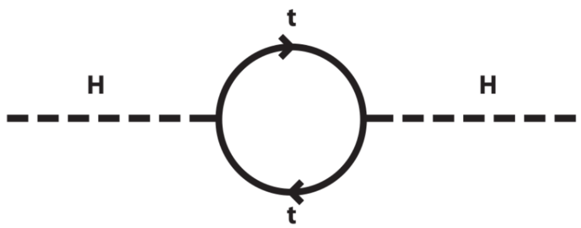
Based on arXiv:2511.01739

Hierarchy Problem

[A. Hebecker, Lect. Notes Phys. 979 (2021) 1-313]
[R.T. D'Agnolo, HDR Thesis, Paris-Saclay U., 2022]
[M. McCullough, TASI 2024, arXiv:2412.15744]

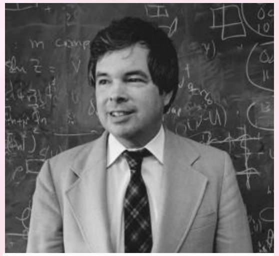


[N. Craig, CERN Courier, 2022]



Radiative corrections to the Higgs mass:

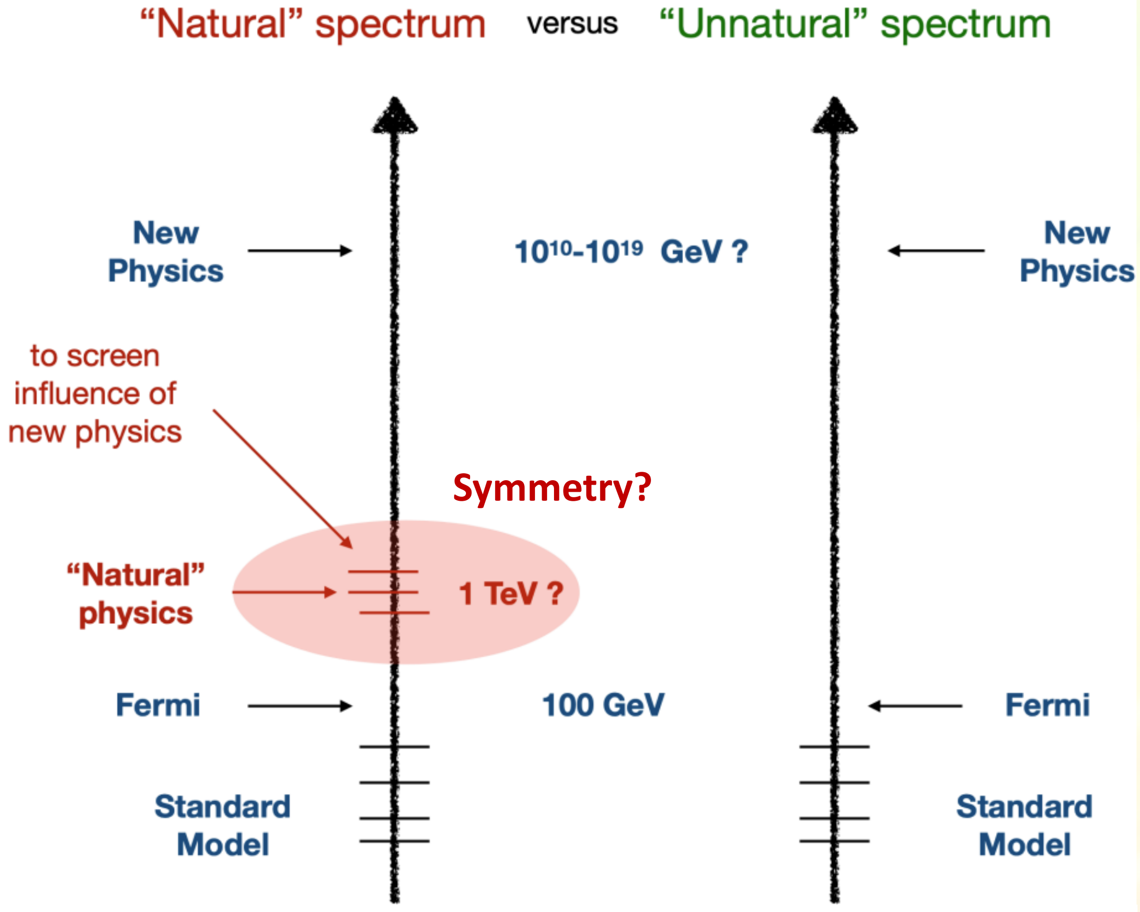
$$\delta m_H^2 \sim -\frac{3y_t^2}{4\pi^2}\Lambda_{UV}^2$$



K.G. Wilson

Wilsonian EFT

Top partner at $\Lambda_{UV} \sim 500$ GeV!



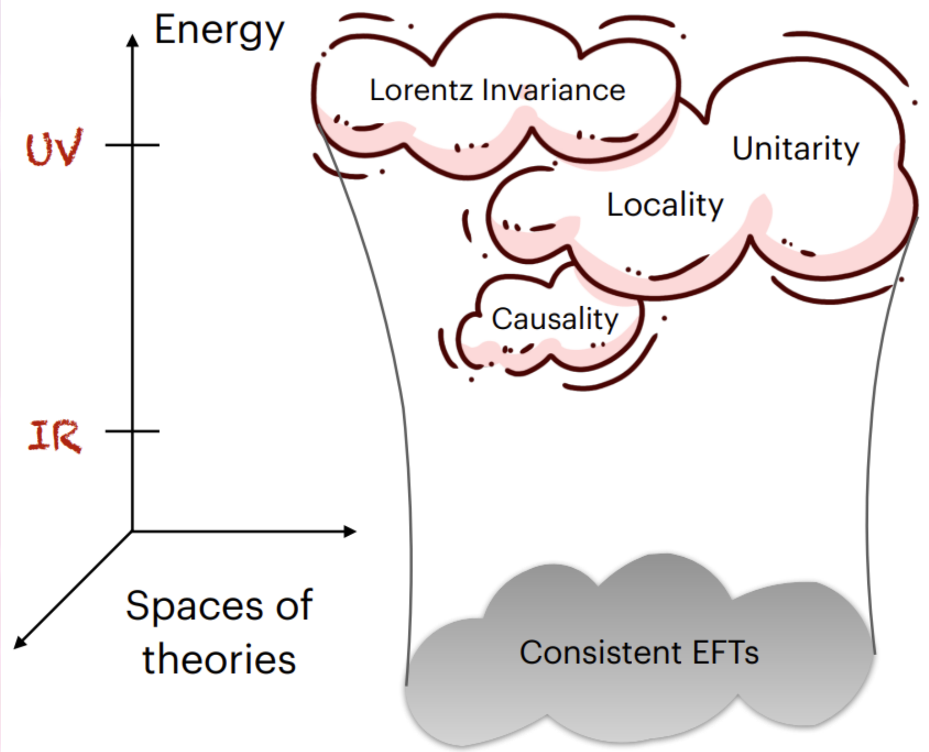
[S. Mooij, M. Shaposhnikov, Nucl. Phys. B 990 (2023) 116172]

LHC → ``Naturalness Hits a Snag with Higgs''

N. Craig, APS Physics 13 (2020) 174

Breaking the Wilsonian Picture

Wilsonian UV-completions

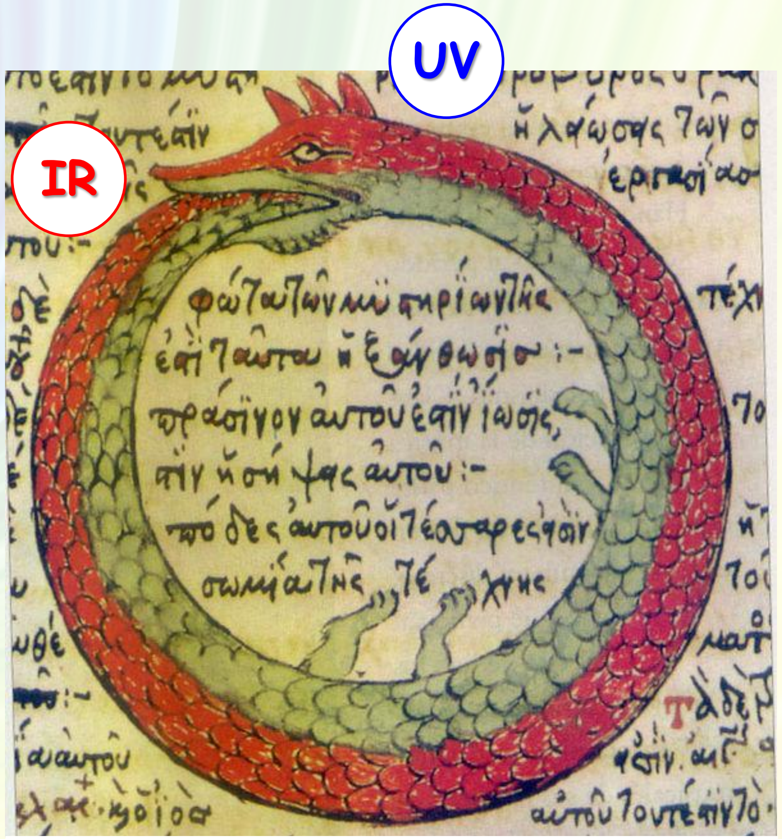


G. Isabella, PhD Thesis, Paris-Saclay University, 2023

Breaking of locality (microcausality)

`Pandora's box' of non-local QFT

`Ouroboros' of UV/IR mixing



Drawing from a late medieval Byzantine Greek alchemical manuscript [source]

Light scalars?

[N. Craig, S. Koren, JHEP 03 (2020) 037]
[F. Nortier, arXiv:2511.01739]

UV/IR Mixing in Gravity

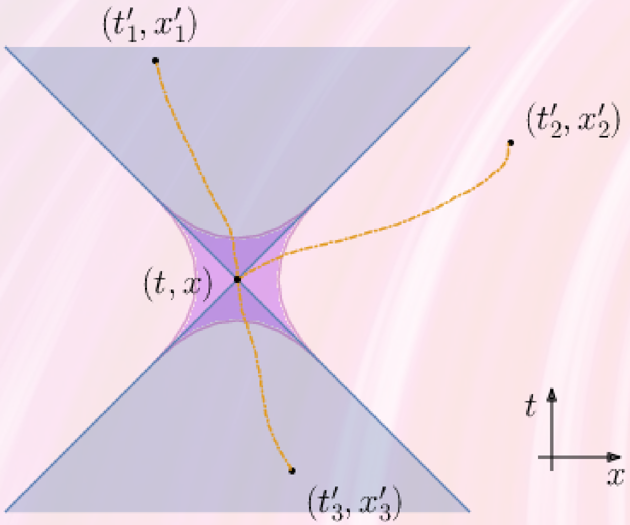
[O. Aharony, T. Banks, JHEP 03 (1999) 016]
[S.B. Giddings, Subnucl. Ser. 48 (2013) 93-147]

Planck length $\ell_{\mathrm{Pl}} = 1/M_{\mathrm{Pl}}$
$\equiv$ Minimal length scale
$\Rightarrow$ Non-locality!

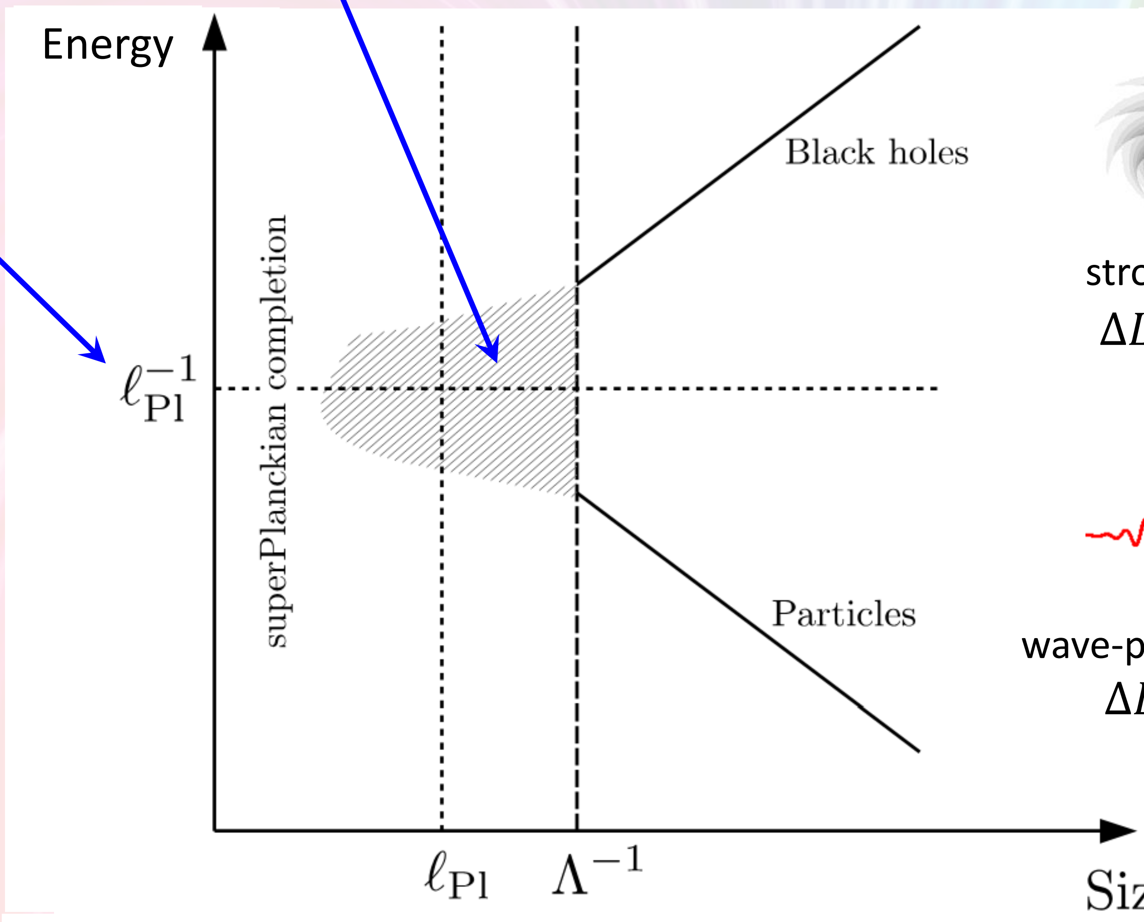
Strong gravity?
Strings?

Deep UV ↔ Deep IR

Fuzzy light cone

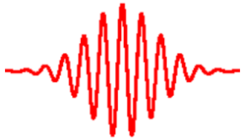


[J. Boos, Springer Theses, arXiv:2009.10856]

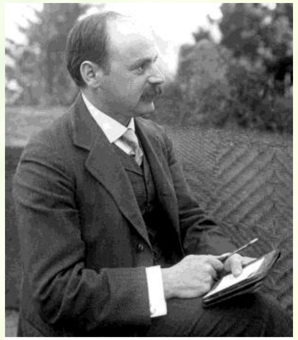


[S. Fichet, P. Saraswat, JHEP 01 (2020) 088]

strong gravity
$\Delta L \sim \ell_{\mathrm{Pl}}^2 E$



wave-particle duality
$\Delta L \sim 1/E$

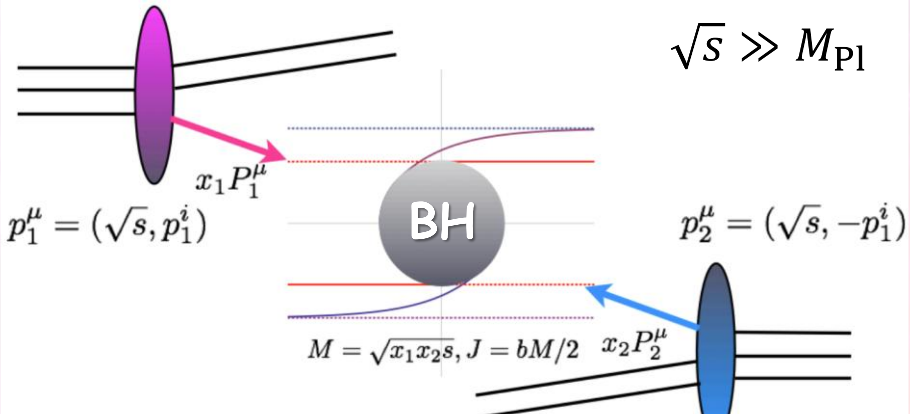


K. Schwarzschild

L. de Broglie

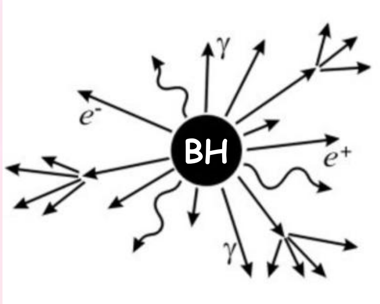
Classicalization in Gravity

[G. Dvali, C. Gomez, arXiv:1005.3497]
[G. Dvali et al., Phys. Rev. D 84 (2011) 024039]
[G. Dvali et al., JHEP 11 (2011) 070]



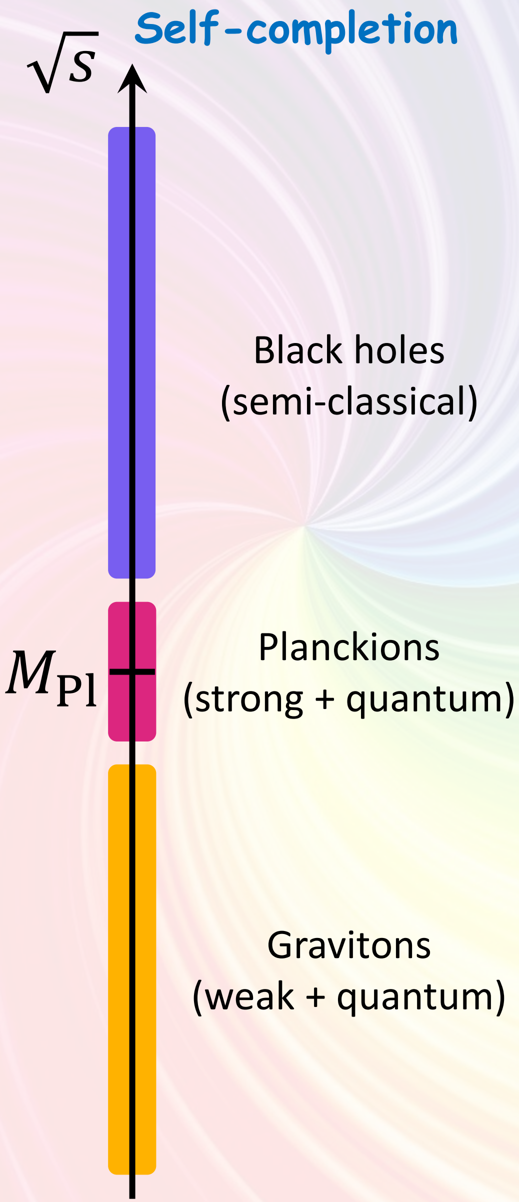
[S.C. Park, Prog. Part. Nucl. Phys. 67 (2012) 617-650]

$2 \to N_\circledast \gg 1$



Black hole decay
(Hawking radiation)

$$\omega \sim \frac{1}{R_S} \ll M_{\rm Pl} \ll \sqrt{s}$$



Hard scatterings of gravitons ($\sqrt{s} \gg M_{\rm Pl}$)

$$G + G \to G + G$$

→ Violation of perturbative unitarity!

Classicalization → Unitarity non-perturbatively!

Entropy suppression: $S_\circledast \sim N_\circledast \gg 1$

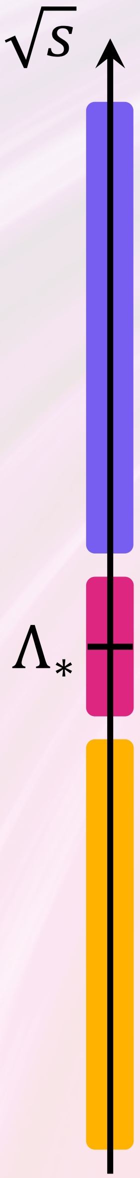
$$\boxed{\begin{gathered} 2 \to \mathrm{BH} \to 2 \\ \langle 2|2\rangle = \sum_{m=1}^{e^{S_\circledast}} \underbrace{\langle 2|\mathrm{BH}\rangle_m}_{\sim e^{-S_\circledast}} \cdot \underbrace{{}_m\langle \mathrm{BH}|2\rangle}_{\sim e^{-S_\circledast}} \sim e^{-S_\circledast} \end{gathered}}$$

Multi-particle production by Hawking radiation:

$$\boxed{\begin{gathered} 2 \to \mathrm{BH} \to N_\circledast \\ \langle 2|N_\circledast\rangle = \sum_{n,m=1}^{e^{S_\circledast}} \underbrace{\langle 2|\mathrm{BH}\rangle_m}_{\sim e^{-S_\circledast}} \cdot \underbrace{{}_m\langle \mathrm{BH}|N_\circledast\rangle_n}_{\sim \delta_{mn}} \sim 1 \end{gathered}}$$

Classicalization of Scalars

[G. Dvali et al., JHEP 08 (2011) 108]
[G. Dvali et al., Phys. Lett. B 699 (2011) 78-86]
[C. Grojean, R.S. Gupta, JHEP 05 (2012) 114]
[F. Nortier, arXiv:2511.01739]



Classicalons
(semi-classical)

Fuzzyons
(strong + quantum)

Bosons
(weak + quantum)

- Scalar self-interactions with derivatives $\sim T_{\mu\nu}$ (energy-momentum tensor)
- Unitarization via $2 \rightarrow N_{\circledast} \gg 1$
- e.g.: dark energy theories (k-essence, Galileon)
- Massive bosons $\Rightarrow m < \omega \ll \Lambda_* = 1/\ell_*$ $\Rightarrow$ Little hierarchy for consistency!

$\delta m^2 \sim \Lambda_*^2$

mass

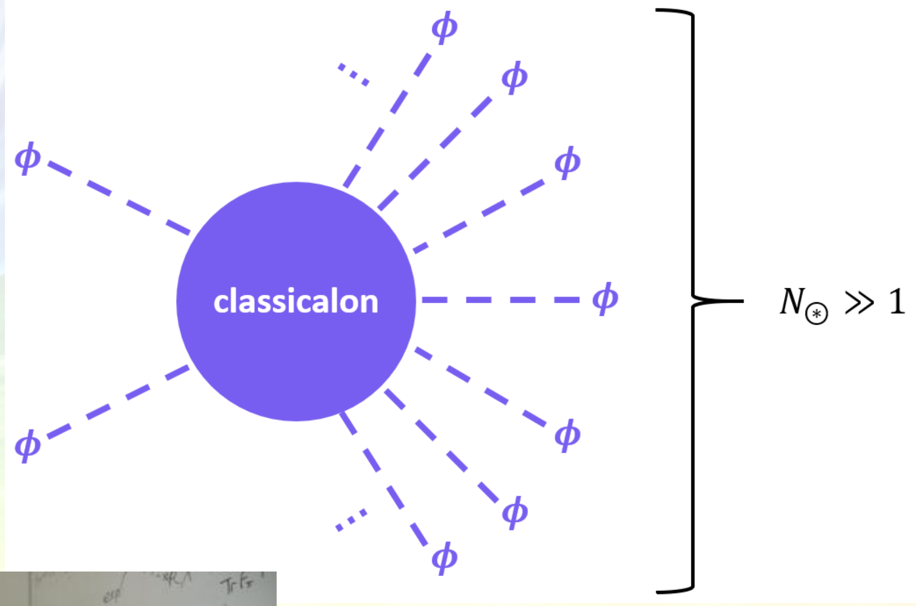
energy

Classicalizing scale

Classicalization radius:

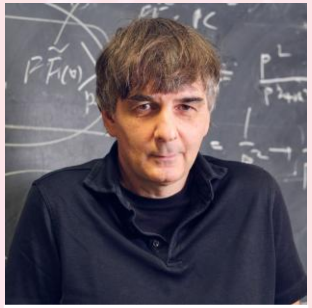
$$R_{\circledast} = \ell_* \left(\frac{M_{\circledast}}{4\pi\Lambda_*}\right)^{\beta} \gg \ell_* \,, \qquad \beta > 0$$

depends on self-interaction

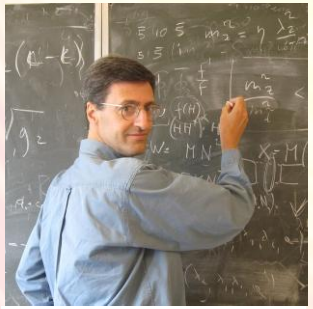


Particle in a box:

$$\omega^2 = m^2 + \left(\frac{\pi}{2R_{\circledast}}\right)^2$$


G. Dvali


C. Gomez


G.F. Giudice


A. Kehagias

K-essence Model

[A. Joyce et al., Phys. Rept. 568 (2015) 1-98]
[P. Brax et al., Phys. Rev. D 94 (2016) 4, 043529]
[F. Nortier, arXiv:2511.01739]

K-essence Lagrangian:

$$\mathcal{L}_k = \frac{1}{2}\partial^\mu\phi\partial_\mu\phi + \frac{c_2}{4\Lambda_*^4}\left(\partial^\mu\phi\partial_\mu\phi\right)^2 + \phi\cdot J(x)$$

Pointlike external source:

$$J(x) = -\frac{\mathcal{E}}{\Lambda_*}\delta^{(3)}(\vec{r})$$

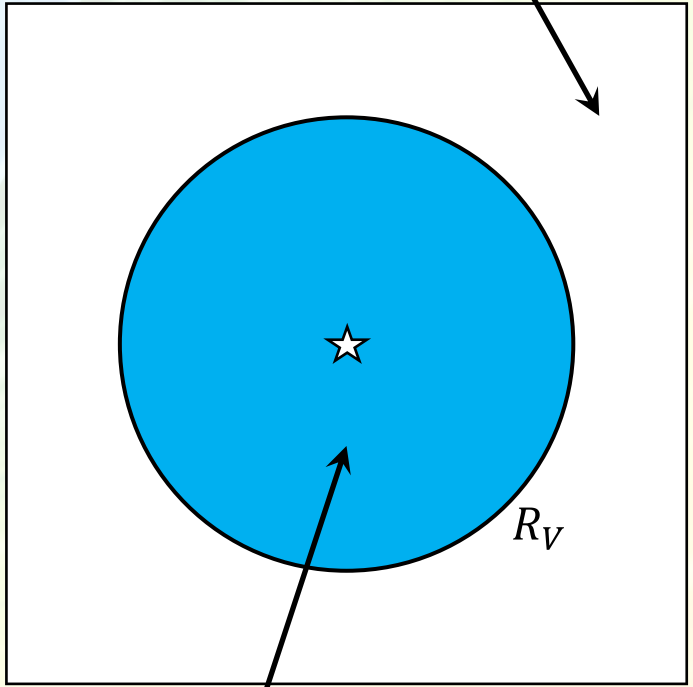
Linear regime

$$\frac{\bar{\phi}'(r)}{\Lambda_*^2} \sim \left(\frac{R_V}{r}\right)^2 \ll 1$$

Field equation for the background $\bar{\phi}(x)$:

$$\vec{\nabla}\cdot\left[\vec{\nabla}\bar{\phi} - \frac{c_2}{\Lambda_*^4}\left(\vec{\nabla}\bar{\phi}\right)^2\vec{\nabla}\bar{\phi}\right] = \frac{\mathcal{E}}{\Lambda_*}\delta^{(3)}(\vec{r}) \xRightarrow[\text{theorem}]{\text{Gauss}} \bar{\phi}'(r) - \frac{c_2}{\Lambda_*^4}\bar{\phi}'^3(r) = \frac{1}{4\pi r^2}\cdot\frac{\mathcal{E}}{\Lambda_*}$$

Real solution if $c_2 = -1$.



Classicalization radius from self-interactions ($\sqrt{s} \sim M_\circledast$):

$$R_\circledast = \ell_*\left(\frac{M_\circledast}{4\pi\Lambda_*}\right)^{\frac{1}{3}}$$

Vainshtein radius $\left(\bar{\phi}' \sim \Lambda_*^2\right)$:

$$R_V = \ell_*\sqrt{\frac{\mathcal{E}}{4\pi\Lambda_*}}$$

A.I. Vainshtein

Quantum fluctuations ($r \ll R_V$):

$$\delta\phi(x) = \phi(x) - \bar{\phi}'(r)$$

$$\delta\phi_Z(x) = \sqrt{Z_\phi}\cdot\delta\phi(x)$$

$$Z_\phi(r) \sim \left[\frac{\bar{\phi}'(r)}{\Lambda_*^2}\right]^2 \gg 1$$

Blueshifted interaction scale:

$$\frac{\Lambda_*^{\text{blue}}}{\Lambda_*} = \sqrt{Z_\phi} \gg 1$$

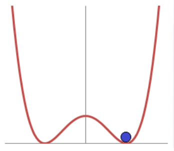
$$\frac{\bar{\phi}'(r)}{\Lambda_*^2} \sim \left(\frac{R_V}{r}\right)^{\frac{2}{3}} \gg 1$$

Non-linear regime

Vainshtein screening

K-chameleon Model

[F. Nortier, arXiv:2511.01739]



$\phi(x) \underset{\mathbb{Z}_2}{\rightarrow} -\phi(x)$

Potential ($\mathbb{Z}_2$-breaking):

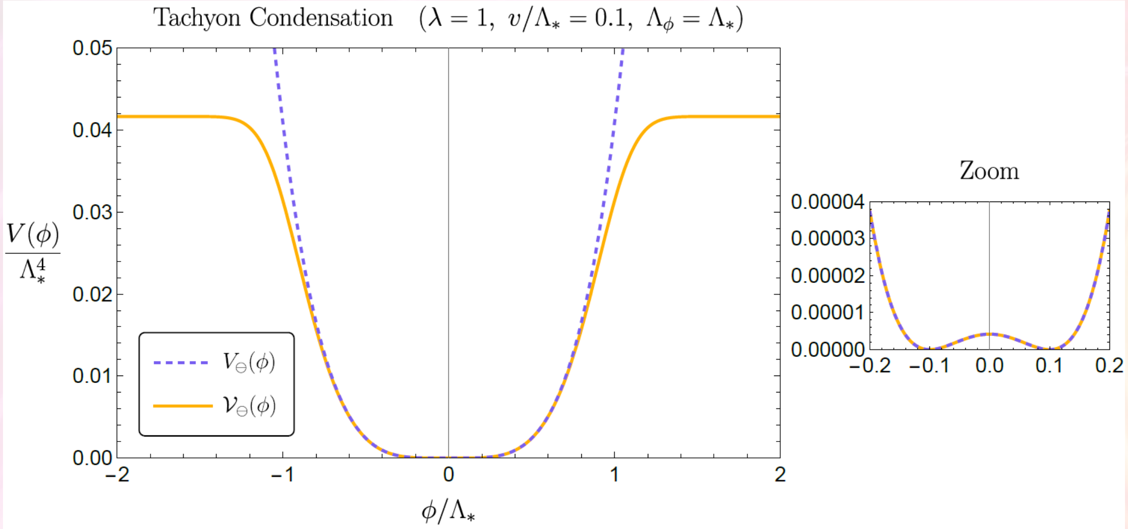
$$V_\ominus(\phi) = \frac{\lambda}{4!}(\phi^2 - v^2)^2$$

$\longrightarrow$ Dominates over non-linearities of k-essence

$\rightarrow$ Conflict with Vainshtein screening!

Solution = Chameleon screening ($\Lambda_\phi \sim \Lambda_* \gg v$):

$$\mathcal{V}_\ominus(\phi) = \frac{\lambda}{4!}\Lambda_\phi^4 \tanh\left[\frac{(\phi^2 - v^2)^2}{\Lambda_\phi^4}\right] \begin{cases} \xrightarrow{|\bar{\phi}| \gg \Lambda_\phi} \Lambda_\phi^4 \\ \xrightarrow{|\bar{\phi}| \ll \Lambda_\phi} V_\ominus(\phi) \end{cases}$$



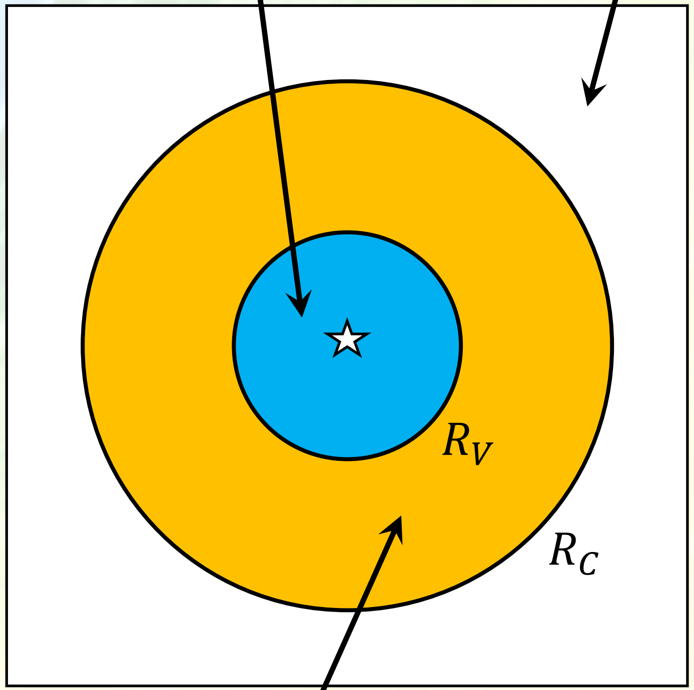
Chameleon radius:

$$\frac{R_C}{R_V} = \frac{\Lambda_*}{\Lambda_\phi} \cdot \frac{R_V}{\ell_*} \gg 1$$

Vainshtein screening:

$|\bar{\phi}'| \gg \Lambda_*^2$

VEV



Chameleon screening:

$|\bar{\phi}| \gg \Lambda_\phi$

Quantum fluctuations are suppressed in screening regions:

$$\tanh\left[\left(\frac{\bar{\phi} + \delta\phi}{\Lambda_\phi}\right)^4\right] \xrightarrow[|\bar{\phi}| \gg \Lambda_\phi]{} 1 - 2e^{-2\left(\frac{\bar{\phi}}{\Lambda_\phi}\right)^4} \sum_{n=0}^{N_0} \left(\frac{\delta\phi}{\bar{\phi}}\right)^n P_n\left(\frac{\bar{\phi}}{\Lambda_\phi}\right) + o\left[\left(\frac{\delta\phi}{\bar{\phi}}\right)^{N_0}\right]$$

K-chameleon & Yukawa Coupling

[F. Nortier, arXiv:2511.01739]

Yukawa coupling to a fermion:

$$\mathcal{L}_\psi = \frac{i}{2}\bar{\psi}\gamma^\mu \overleftrightarrow{\partial}_\mu \psi - y\left(\phi \psi_R^\dagger \psi_L + \mathrm{h.c.}\right)$$

Parities ($\mathbb{Z}_2$-symmetry):

$$\psi_L(x) \underset{\mathbb{Z}_2}{\rightarrow} + \psi_L(x), \qquad \psi_R(x) \underset{\mathbb{Z}_2}{\rightarrow} - \psi_R(x), \qquad \phi(x) \underset{\mathbb{Z}_2}{\rightarrow} - \phi(x)$$

Problem with radiative corrections to $\delta\phi_Z$ mass:

$$\frac{\delta m^2(r)}{\Lambda_*^2} \sim \frac{y^4}{16\pi^2}\left(\frac{r}{\ell_*}\right)^2 \gg 1$$

Chameleon screening ($\Lambda_\psi \sim \Lambda_*$):

$$y \to y_c[\phi] = y e^{-\left(\frac{\phi}{\Lambda_\psi}\right)^2}$$

Solve the problem with radiative corrections:

$$\frac{\delta m^2(r)}{\Lambda_*^2} \sim \frac{y^4}{16\pi^2} e^{-4\left[\frac{\bar{\phi}(r)}{\Lambda_\psi}\right]^2}\left(\frac{r}{\ell_*}\right)^2 \ll 1$$

Classicalization

New derivative interaction ($\Lambda'_* \sim \Lambda_*$):

$$\mathcal{L}_\psi - \left(\frac{\partial^\mu\phi\partial_\mu\phi}{2\Lambda_*^2}\right)\left(\frac{i\bar{\psi}\gamma^\mu\overleftrightarrow{\partial}_\mu\psi}{2\Lambda'^2_*}\right)$$

$$\psi_Z(x) = \sqrt{Z_\psi}\cdot\psi(x)$$

$$Z_\psi(r) \sim \left[\frac{\bar{\phi}'(r)}{\sqrt{2}\Lambda_*\Lambda'_*}\right]^2 \gg 1$$

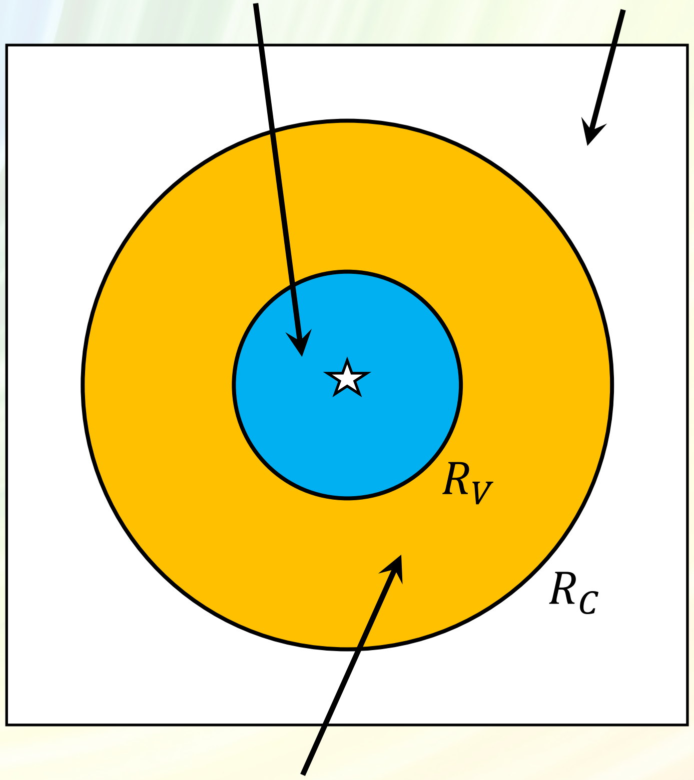
Blueshifted interaction scales:

$$\frac{\Lambda_*^{\mathrm{blue}}}{\Lambda_*} = \sqrt{Z_\phi} \gg 1 \quad \text{and} \quad \frac{\Lambda'^{\,\mathrm{blue}}_*}{\Lambda'_*} = \sqrt{Z_\psi} \gg 1$$

Vainshtein screening:

$|\bar{\phi}'| \gg \Lambda_*^2$

VEV



Chameleon screening:

$|\bar{\phi}| \gg \Lambda_\phi$

Summary & Outlook

Summary:

→ UV/IR mixing is a radical approach to the hierarchy problem motivated by the little hierarchy problem.

→ Black holes realize a UV/IR mixing in gravity: Classicalization is a generalization to fields of other spins.

→ Scalar fields with derivative interactions naturally incorporate classicalization via Vainshtein screening.

→ The addition of a potential or non-derivative couplings to other fields needs to implement chameleon screening.

Outlook:

→ Gauge fields + Higgs mechanism?

→ Phenomenology of classicalons?

Thank you for your Attention!

Backup Slides

Classical vs Quantum Non-linearities in Gravity

[K. Hinterbichler, Rev. Mod. Phys. 84 (2012) 671-710]
[A. Joyce et al., Phys. Rept. 568 (2015) 1-98]

Linerarized gravity:

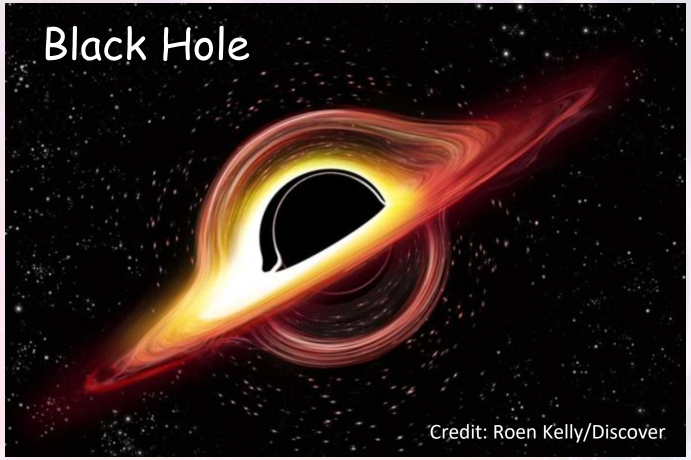
$$g_{\mu\nu} = \eta_{\mu\nu} + \frac{h_{\mu\nu}}{M_{\mathrm{Pl}}}$$

↓

Pointlike mass:

$$M \gg M_{\mathrm{Pl}}$$

$$h \sim \frac{M}{M_{\mathrm{Pl}} r}$$



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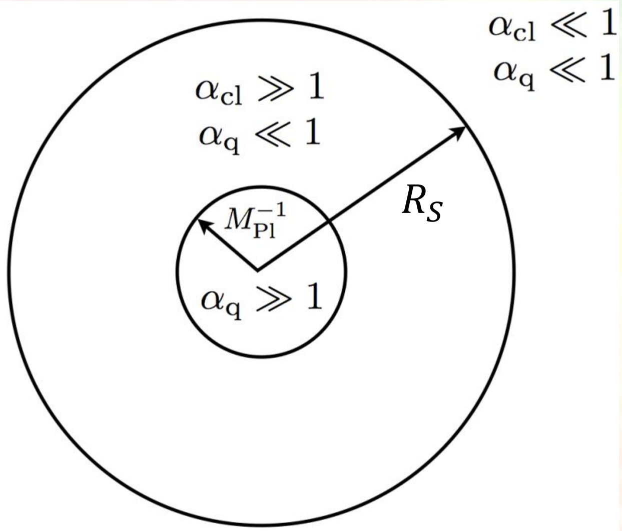

J. Khoury, arXiv:1312.2006

General relativity
(classical non-linearities α_{cl})

$$\mathcal{L}_{\mathrm{GR}} \sim M_{\mathrm{Pl}}^2 \sqrt{-g}\mathcal{R} \sim h\partial^2 h + \sum_{n\geq 2} \frac{h^n \partial^2 h}{M_{\mathrm{Pl}}^{n-1}}$$

$$\Rightarrow \alpha_{\mathrm{cl}} \sim \frac{h}{M_{\mathrm{Pl}}} \sim \frac{M}{M_{Pl}^2 r} \sim \frac{R_S}{r}$$

Higher curvature terms
(quantum corrections α_{q})

$$\mathcal{L}_{\mathrm{h.c.}} \sim \sqrt{-g}\mathcal{R}^2 + \sqrt{-g}\mathcal{R}_{\mu\nu}\mathcal{R}^{\mu\nu} + \cdots$$

$$\sim \sum_{n\geq 2,\, m\geq 4} \frac{\partial^m h^n}{M_{\mathrm{Pl}}^{m+n-4}}$$

$$\Rightarrow \alpha_{\mathrm{q}} \sim \frac{\partial^2}{M_{\mathrm{Pl}}} \sim \frac{1}{M_{\mathrm{Pl}}^2 r^2}$$