Symmergent Gravity

and Its Black Hole Solutions

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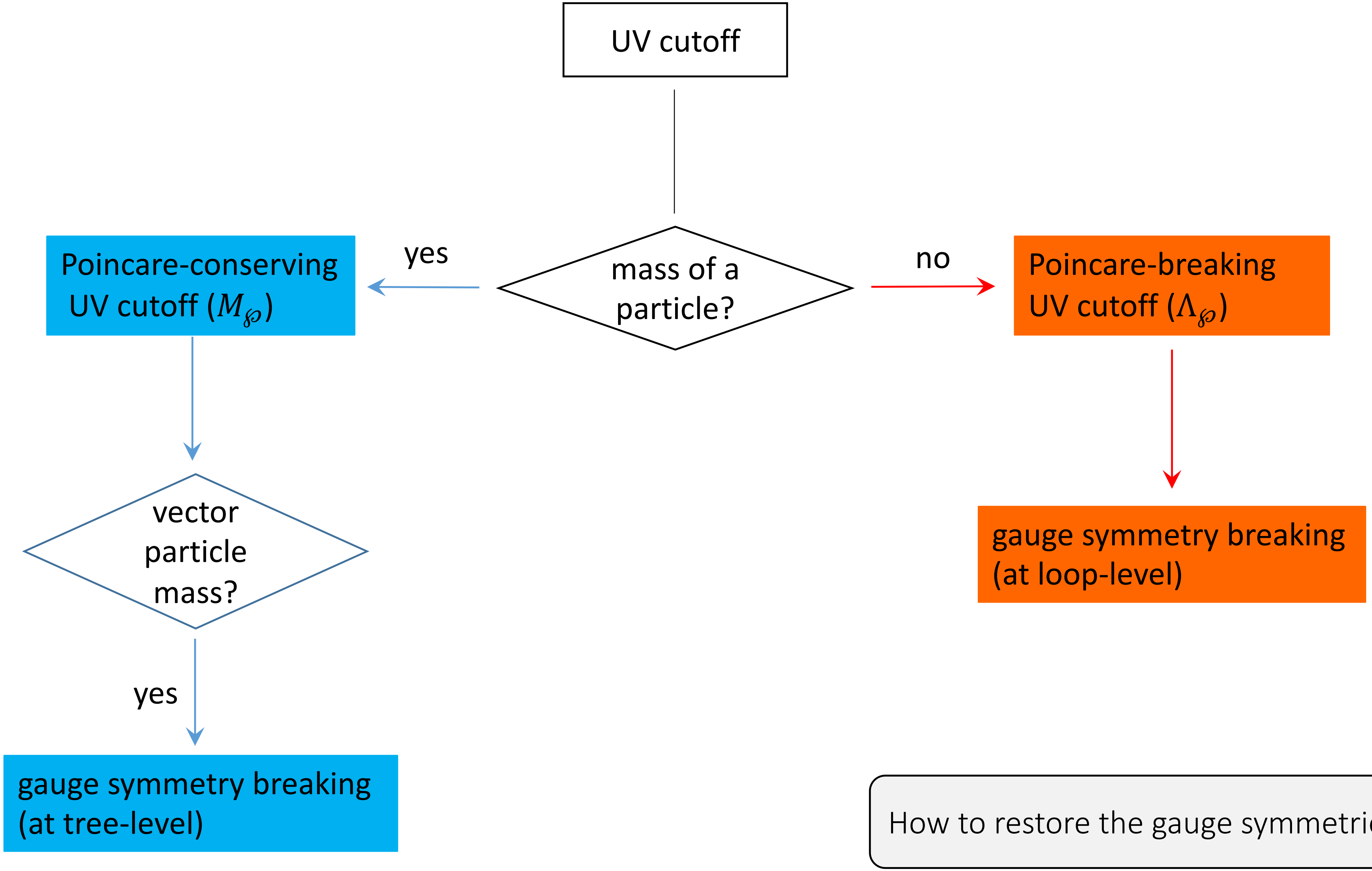
- QFTs are inherent to flat spacetime.
- QFTs are defined with an invariant action.
- QFTs make sense with a UV cutoff.

L. Ford, arXiv: 9707.062 [gr-qc]
R. Wald, arXiv: 0907.0416 [gr-qc]



UV cutoff

mass of a particle?

yes

Poincare-conserving UV cutoff ($M_{\wp}$)

vector particle mass?

yes

gauge symmetry breaking (at tree-level)

no

Poincare-breaking UV cutoff ($\Lambda_{\wp}$)

gauge symmetry breaking (at loop-level)

How to restore the gauge symmetries?

UV COMPLETION BY GAUGE INVARIANCE

Poincare-conserving UV cutoff $M_{\wp}$:

tree-level mass term = $M_{\wp}^2 \mathrm{tr}[V_\mu V^\mu]$

$M_{\wp}^2 \Longrightarrow$ "spurion S"
(Poincare-conserving)

$$\mathrm{tr}[S^\dagger V_\mu V^\mu S]$$

"spurion S" $\Longrightarrow$ "Higgs ϕ "

$$\mathrm{tr}[(D_\mu \phi)^\dagger D^\mu \phi]$$

P. Anderson, Phys. Rev. Phys. **130**, 439 (1962)
F.Englert & R. Brout, Phys. Rev. Lett. **13,** 321 (1964)
P. Higgs, Phys. Rev. Lett. **13,** 508 (1964)

Poincare-breaking UV cutoff $\Lambda_{\wp}$:

loop-level mass term= $\Lambda_{\wp}^2 \mathrm{tr}[V_\mu V^\mu]$

$\Lambda_{\wp}^2 \Longrightarrow$ "spurion Σ"
(Poincare-breaking)

$$\mathrm{tr}[\, V^\mu \Sigma_{\mu\nu} V^\nu]$$

The spurion $\Sigma_{\mu\nu}$ must be a Poincare-breaking one. It cannot involve S! What is it? What does correspond to the Higgs field ϕ?

DD, Phys. Rev. D 107, 105014 (2023)
DD, Gen Relativ Gravit 53, 22 (2021)
DD, Adv. High En. Phys. 4652048 (2019)
DD, Adv. High En. Phys. 6727805 (2016)

EFFECTIVE QFT: Dimensional Regularization

QFTs without UV cutoff:

- Dimensional Regularization ($D \to 4$): $I_n = \int \frac{d^4p}{(2\pi)^4} \frac{1}{(p^2-m^2+i0)^n} \Longrightarrow \mu^{4-D} \int \frac{d^Dp}{(2\pi)^D} \frac{1}{(p^2-m^2+i0)^n}$

C. Bollini & J. Giambiagi, Nuovo Cim. B12, 20 (1972)
G. ’t Hooft & M. Veltman, Nucl. Phys. B44, 189 (1972)

QFTs with UV cutoff:

- Question: How to extend the Dimensional Regularization to QFTs with UV cutoff such that logarithmic (global) and power-law (local) UV sensitivities come independently?

- Useful hint: Dimensional Regularization with $D \to 0$ and $D \to 2$ gather, respectively, the μ^4 and μ^2 terms.

I. Jack & D. Jones, Nucl. Phys. B342, 127 (1990)
M. Al-Sarhi, D. Jones & I. Jack, Nucl. Phys. B345, 431 (1990)

EFFECTIVE QFT: Detached Regularization

- In conformity with the Cutoff and Dimensional Regularizations, one finds the Detached Regularization:

$$\int^{(\Lambda_{\wp})} \frac{d^4p}{(2\pi)^4} \frac{1}{(p^2-m^2+i0)^n} \Longrightarrow \left[\frac{1}{(8\pi)^{2-n}} \underbrace{\left(\delta_{[D]0}+\delta_{[D]2}\right)}_{D \to 0 \text{ and } D \to 2} \Lambda_{\wp}^{4-2n}\, \mu^{2n-D} + \underbrace{\delta_{[D]4}}_{D \to 4}\, \mu^{4-D}\right] \int \frac{d^Dp}{(2\pi)^D} \frac{1}{(p^2-m^2+i0)^n}$$

- Typical loop integral in Detached Regularization with $\overline{MS}$ Renormalization:

$$\int^{(\Lambda_{\wp})} \frac{d^4p}{(2\pi)^4} \frac{1}{(p^2-m^2+i0)^n} = \begin{cases} \dfrac{i\,\Lambda_{\wp}^4}{32\pi^2} & D=0, n=0 \\ \dfrac{-i\Lambda_{\wp}^2}{16\pi^2}\left(1-\log\dfrac{\mu}{m}\right) & D=2, n=1 \\ \dfrac{im^2}{16\pi^2}\left(1+2\log\dfrac{\mu}{m}\right) & D=4, n=1 \\ \dfrac{i}{8\pi^2}\log\dfrac{\mu}{m} & D=4, n=2 \end{cases}$$

- ▪ $\Lambda_{\wp}$ for power-law divergences
- ▪ μ for logarithmic divergences

DD, C. Karahan & O. Sargın, Phys. Rev. D 107, 045003 (2023)

EFFECTIVE QFT: Power-Law Corrections

$$\delta S_{pow} = \int d^4x \sqrt{-\eta} \left\{ -c_O(\log\mu)\Lambda_{\wp}^4 - \sum_m c_m(\log\mu)\, \Lambda_{\wp}^2 m^2 \;-\; c_\phi(\log\mu)\, \Lambda_{\wp}^2 \phi^\dagger\phi + c_V(\log\mu)\Lambda_{\wp}^2 \mathrm{tr}\left[V_\mu V^\mu\right] \right\}$$

flat metric $\eta_{\mu\nu}$

$$c^{(SM)}{}_{\phi=H} \approx \frac{3h_t^2}{4\pi^2}$$

$c^{(SM)}_{V=g^a}$	$\frac{21 g_3^2}{16\pi^2}$
$c^{(SM)}_{V=W^i}$	$\frac{21 g_2^2}{16\pi^2}$
$c^{(SM)}_{V=B}$	$\frac{39 g_1^2}{32\pi^2}$

$$\sum_m c_m(\log\mu)\, m^2 = \frac{1}{32\pi^2}\mathrm{str}[M^2]$$

$$S_{eff} = S_{tree}(\eta,\psi) + \delta S_{logarithmic}(\eta,\psi,\log\mu) + \delta S_{pow}(\eta,\psi,\log\mu\,,\Lambda_{\wp})$$

$$c_O = \frac{n_b - n_f}{128\pi^2}$$

$(\mathrm{mass})^2$ matrix of fields

n_b bosonic and n_f fermionic degrees of freedom

DD, Phys. Rev. D 107, 105014 (2023)
DD, C. Karahan & O. Sargın, Phys. Rev. D 107, 045003 (2023)

EFFECTIVE QFT: Flat Spacetime to Curved Spacetime

- General covariance
  - $\eta_{\mu\nu} \longrightarrow g_{\mu\nu}$ (switching to curved metric $g_{\mu\nu}$ with $\partial_\mu g_{\alpha\beta} \neq 0$)
  - $\partial_\mu \longrightarrow \nabla_\mu$ (switching to covariant derivative ∇_μ with $\nabla_\mu g_{\alpha\beta} = 0$)

- Problem with effective QFTs:
  - adding curvature terms to make $g_{\mu\nu}$ dynamical is inconsistent (adding bare constants to a loop-level effective QFT)
  - curvature can arise only with the gauge fields V^μ through the defining relation $\left[\nabla_\mu, \nabla_\nu\right] V^\lambda = R^\lambda_{\rho\mu\nu} V^\rho$

DD, Phys. Rev. D 107, 105014 (2023)

EFFECTIVE QFT: Flat Spacetime to Curved Spacetime

Kinetic construct (bulk)	Kinetic construct (bulk+boundary)
$I_V(\eta) = \int d^4x\sqrt{-\eta}\, c_V \mathrm{tr}\left[V^{\alpha\beta}V_{\alpha\beta}\right]$	$\tilde{I}_V(\eta) = \int d^4x\sqrt{-\eta}\, c_V \mathrm{tr}[V^{\alpha}(-D^2\eta_{\alpha\beta} + D_\alpha D_\beta + iV_{\alpha\beta})V^{\beta} + \partial_\alpha\left(V_\beta V^{\alpha\beta}\right)]$

$$I_V(\eta) = \tilde{I}_V(\eta)$$

Flat spacetime (metric=$\eta_{\mu\nu}$)	Curved spacetime (metric=$g_{\mu\nu}$)
$-I_V(\eta) + \tilde{I}_V(\eta) = 0$	$-I_V(g) + \tilde{I}_V(g) = -\int d^4x\sqrt{-g}\, c_V \mathrm{tr}[V^{\alpha}R_{\alpha\beta}({}^{g}\Gamma)\mathrm{V}^{\beta}]$

$$\eta_{\alpha\beta} \to g_{\alpha\beta}$$
$$\partial_\alpha \to \nabla_\alpha$$

Flat spacetime effective action	Curved spacetime effective action
$S_{eff}(\eta,\psi,\log\mu\,,\Lambda_{\wp}) - I_V\,(\eta) + \tilde{I}_V(\eta)$ $= S_{eff}(\eta,\psi,\log\mu\,,\Lambda_{\wp})$	$S_{eff}(g,\psi,\log\mu\,,\Lambda_{\wp}) - I_V(g) + \tilde{I}_V(g)$ $= S_{eff}\,(g,\psi,\log\mu\,,\Lambda_{\wp}) - \int d^4x\sqrt{-g}c_V \mathrm{tr}[V^{\alpha}R_{\alpha\beta}({}^{g}\Gamma)\mathrm{V}^{\beta}]$

no change !

change with curvature !

DD, Phys. Rev. D 107, 105014 (2023)
DD, Gen Relativ Gravit 53, 22 (2021)
DD, Adv. High En. Phys. 4652048 (2019)

EFFECTIVE QFT: Poincare-Breaking Spurion

$$\delta S_{pow} = \int d^4x\, \sqrt{-\eta}\, \left\{ -c_O\, \Lambda_{\wp}^4 - \sum_m c_m m^2 \Lambda_{\wp}^2 - c_\phi \Lambda_{\wp}^2 \phi^\dagger\phi + c_V \Lambda_{\wp}^2 \mathrm{tr}\left[V_\mu V^\mu\right] \right\}$$

Poincare-breaking spurion: $\Lambda_{\wp}^2 \eta_{\mu\nu} \longrightarrow \Sigma_{\mu\nu}$

General covariance: $\eta_{\mu\nu} \longrightarrow g_{\mu\nu}$

$\partial_\mu \rightarrow \nabla_\mu$

$$\delta S_{pow} = \int d^4x\, \sqrt{-g}\, \left\{ -\frac{c_O}{16}\left(g^{\mu\nu}\Sigma_{\mu\nu}\right)^2 - \frac{1}{4}\sum_m c_m m^2 g^{\mu\nu}\Sigma_{\mu\nu} - \frac{c_\phi}{4} g^{\mu\nu}\Sigma_{\mu\nu}\phi^\dagger\phi + c_V\left(\Sigma_{\mu\nu} - R_{\mu\nu}({}^g\Gamma)\right) \mathrm{tr}\left[V^\mu V^\nu\right] \right\}$$

yet-to-be specified spurion

DD, Phys. Rev. D 107, 105014 (2023)
DD, Gen Relativ Gravit 53, 22 (2021)

EFFECTIVE QFT: Poincare-Breaking Spurion to Curvature

- In an arbitrary second-quantized theory with no presumed properties, "… lack of translational invariance would just be interpreted as the effect of gravitational fields being present, which are not translational invariant."

C. Froggatt & H. Nielsen, Ann. Phys. 517, 115 (2007)

- QFTs are inherent to flat spacetime and their UV cutoff $\Lambda_\wp$ is the only translation (Poincare) breaking source. There must exist thus an affinity between the UV cutoff $\Lambda_\wp$ in flat spacetime and curvature in curved spacetime.

$\Gamma^\lambda_{\mu\nu}$ is independent of the Levi-Civita connection ${}^g\Gamma^\lambda_{\mu\nu}$ so the affine curvature $\mathbb{R}_{\mu\nu}(\Gamma)$ remains non-zero in flat spacetime.

- In view of this affinity, the spurion $\Sigma_{\mu\nu}$ can be taken as the Ricci curvature $\mathbb{R}_{\mu\nu}(\Gamma)$ of an affine connection $\Gamma^\lambda_{\mu\nu}$:

$$\Sigma_{\mu\nu} \Rrightarrow \mathbb{R}_{\mu\nu}(\Gamma) = \partial_\rho \Gamma^\rho_{\nu\mu} - \partial_\nu \Gamma^\rho_{\rho\mu} + \Gamma^\rho_{\rho\lambda}\Gamma^\lambda_{\nu\mu} - \Gamma^\rho_{\nu\lambda}\Gamma^\lambda_{\rho\mu}$$

$\mathbb{R}_{\mu\nu}(\Gamma)$ is a dynamical field at the same level as the Higgs field thanks to the dynamics of $\Gamma^\lambda_{\mu\nu}$.

DD, Phys. Rev. D 107, 105014 (2023)
DD, Gen Relativ Gravit 53, 22 (2021)

EFFECTIVE QFT: Metric-Palatini Gravity

- Affine curvature $\mathbb{R}(\Gamma)$ gives rise to metric-Palatini gravity:

$$\delta S_{pow} = \int d^4x \sqrt{-g} \left\{ -\frac{c_O}{16}\left(g^{\alpha\beta}\mathbb{R}_{\alpha\beta}(\Gamma)\right)^2 - \frac{g^{\alpha\beta}\mathbb{R}_{\alpha\beta}(\Gamma)}{16\pi G_N} - \frac{c_\phi}{4} g^{\alpha\beta}\mathbb{R}_{\alpha\beta}(\Gamma)\phi^\dagger\phi + c_V\left(\mathbb{R}_{\alpha\beta}(\Gamma) - R_{\alpha\beta}({}^{g}\Gamma)\right) \mathrm{tr}\left[V^\alpha V^\beta\right] \right\}$$

- Metrical gravity emerges once the affine connection $\Gamma^\lambda_{\alpha\beta}$ is integrated out. To that end, one solves the EoM of $\Gamma^\lambda_{\alpha\beta}$:

$${}^{\Gamma}\nabla_\lambda \mathrm{Q}_{\alpha\beta} = 0$$

$$Q_{\alpha\beta} = \left(\frac{1}{16\pi G_N} + \frac{c_S}{4} g^{\alpha\beta}\phi^\dagger\phi + \frac{c_O}{8} g^{\mu\nu} \right.$$

There must exist new particles beyond the known particles for $\mathrm{str}[M^2]$ to be able to generate $G_N^{-1} = 8\pi M_{Pl}^2$.

The new particles do not have to couple to known particles.

$$G_N^{-1} = 4\pi \sum_m c_m m^2 \xrightarrow[1-\mathrm{loop}]{} \frac{\mathrm{str}[M^2]}{8\pi}$$

DD, Phys. Rev. D 107, 105014 (2023)
DD, Gen Relativ Gravit 53, 22 (2021)

EFFECTIVE QFT: Emergent General Relativity

- General solution of the affine connection:

$$\Gamma^{\lambda}_{\alpha\beta} = {}^{g}\Gamma^{\lambda}_{\alpha\beta} + \frac{1}{2}(Q^{-1})^{\lambda\rho}\left(\nabla_{\alpha} Q_{\beta\rho} + \nabla_{\beta} Q_{\rho\alpha} - \nabla_{\rho} Q_{\alpha\beta}\right)$$

- Enormity of the Planck scale $G_N^{-1/2}$ leads to:

  - $\Gamma^{\lambda}_{\alpha\beta} = {}^{g}\Gamma^{\lambda}_{\alpha\beta} + 8\pi G_N\left(\nabla_{\alpha} Q^{\lambda}_{\beta} + \nabla_{\beta} Q^{\lambda}_{\alpha} - \nabla^{\lambda} Q_{\alpha\beta}\right) + \mathcal{O}(G_N^2)$

  - $\mathbb{R}_{\alpha\beta}(\Gamma) = R_{\alpha\beta}({}^{g}\Gamma) + 8\pi G_N\left(\nabla^{\mu}\nabla_{\alpha}\delta^{\nu}_{\beta} + \nabla^{\nu}\nabla_{\alpha}\delta^{\mu}_{\beta} - \Box\delta^{\mu}_{\alpha}\delta^{\nu}_{\beta} - \nabla_{\alpha}\nabla_{\beta} g^{\mu\nu} + (\alpha \leftrightarrow \beta)\right) Q_{\mu\nu} + \mathcal{O}(G_N^2)$

derivatives of the scalars ϕ and gauge fields V_i^{α}

DD, Phys. Rev. D 107, 105014 (2023)
DD, Gen Relativ Gravit 53, 22 (2021)

EFFECTIVE QFT: Emergent General Relativity

gauge symmetries got restored!

- $\int d^4x \sqrt{-g}\{c_V(\mathbb{R}_{\alpha\beta}(\Gamma) - R_{\alpha\beta}({}^g\Gamma))\,\mathrm{tr}[V^\alpha V^\beta]\} = \int d^4x \sqrt{-g}\,\{0 + \mathcal{O}(G_N)\}$

GR emerged!

- $\int d^4x \sqrt{-g}\left\{-\frac{1}{16\pi G_N} g^{\alpha\beta}\mathbb{R}_{\alpha\beta}(\Gamma)\right\} = \int d^4x \sqrt{-g}\,\left\{-\frac{R(g)}{16\pi G_N} + \mathcal{O}(G_N)\right\}$

quadratic corrections to scalar masses give cause to non-minimally coupled scalar fields

- $\int d^4x \sqrt{-g}\{-c_\phi g^{\alpha\beta}\mathbb{R}_{\alpha\beta}(\Gamma)\phi^\dagger\phi\} = \int d^4x \sqrt{-g}\,\left\{-\frac{c_\phi}{4}R(g)\phi^\dagger\phi + \mathcal{O}(G_N)\right\}$

quartic corrections to vacuum energy give rise to quadratic curvature terms

- $\int d^4x \sqrt{-g}\left\{-\frac{c_O}{16}\left(g^{\alpha\beta}\mathbb{R}_{\alpha\beta}(\Gamma)\right)^2\right\} = \int d^4x \sqrt{-g}\,\left\{-\frac{c_O}{16}(R(g))^2 + \mathcal{O}(G_N)\right\}$

DD, Phys. Rev. D 107, 105014 (2023)
DD, Gen Relativ Gravit 53, 22 (2021)

EFFECTIVE QFT: Renormalized QFT + Emergent GR

$$S_{QFT+GR} = \underbrace{S\,(g,\psi\ ) + \delta S(g,\psi)}_{} + \int d^4x\,\sqrt{-g}\,\Big\{\underbrace{-\frac{R(g)}{16\pi G_N} - \frac{c_O}{16}R(g)^2 - \frac{c_\phi}{4}R(g)\phi^\dagger\phi + \mathcal{O}(G_N)}_{}\Big\}$$

QFT with

- dimensional-regularization in curved background geometry,
- loop corrections computed in the flat spacetime QFT

$R + R^2$ gravity with

- non-minimal coupling to scalars,
- loop-induced coefficients originating from the flat spacetime QFT.

symmetry-restoring emergent gravity = “symmergent gravity”

DD, Phys. Rev. D 107, 105014 (2023)
DD, Gen Relativ Gravit 53, 22 (2021)

Symmergent Gravity: Main Properties and Salient Predictions

new massive particles are a must for Newton’s constant to take the right value

new particles do not have to couple to the SM particles

Higgs mass stability requires new particles (*e.g.* dark matter) to couple to SM particles weakly/feebly.

Higgs mass stability requires neutrinos to be Dirac

Higgs-curvature coupling (10 % in the SM) can reveal Higgs couplings to new particles

pure Einstein gravity is attained if nature has equal numbers of bosonic and fermionic degree of freedom

cosmic inflation is naturally of the Starobinsky type but scalar field inflation can also be realized

black hole shadow, photon radius, deflection angle and quasiperiodic oscillations can provide viable testbeds

detection of new particles can wait for high-luminosity LHC

the Universe may contain dark stars, dark planets, even dark galaxies.

DD, Phys. Rev. D 107, 105014 (2023)
DD, Gen Relativ Gravit 53, 22 (2021)
DD, Galaxies 9, 2 (2021)
DD, Adv. High En. Phys. 4652048 (2019)
DD, Adv. High En. Phys. 6727805 (2016)

K. Cankoçak *et al.*, Eur. Phys. J. C80, 1188 (2020)
DD, C. S. Ün, arXiv: 2005.03589 [hep-ph] (2020)

I. Çimdiker, DD, A. Övgün, Phys. Dark Univ. 34**,** 100900 (2021)
J. Rayimbaev *et al*., Annals of Physics 454, 169335 (2023)
R. Pantig, A. Övgün, DD, Eur. Phys. J. C83, 250 (2023)
S. Jalalzadeh *et al*., Phys. Dark. Univ. 40, 101227 (2023)

Symmergent Black Holes: The Action

$$S_{sgr} = \int d^4x\, \sqrt{-g} \left\{ -\frac{R(g)}{16\pi G_N} - \frac{c_O}{16} R(g)^2 - V_{tot} \right\}$$

$$V_{tot} = V_{tree} + \delta V$$

$$\delta V = \frac{1}{64\pi^2} \mathrm{str}[M^4]$$

$$\delta V = \frac{m_0^4}{64\pi^2}\left(n_b - n_f\right) = \frac{1}{24\pi G_N^2 c_O}$$

(if bosons and fermions
had equal masses m_0)

$$\delta V = \frac{(1-\hat{\alpha})}{24\pi G_N^2 c_O}$$

(one possible
parametrization)

J. Rayimbaev *et al*., Annals of Physics 454, 169335 (2023)
R. Pantig, A. Övgün, DD, Eur. Phys. J. C83, 250 (2023)

Symmergent Black Holes: Field Equations

$$R_{\mu\nu} - \frac{1}{2} R\, g_{\mu\nu} - 2\pi G_N c_O \left(R_{\mu\nu} - \frac{1}{4}\, R g_{\mu\nu} + g_{\mu\nu} - \nabla_\mu \nabla_\nu \right) R - 8\pi G_N V_{tot} = 0$$

- One class of solutions corresponds to constant scalar curvature ($R = R_0 = -8\pi G_N V_{tot}$)
  - dS solution ($V_{tot} > 0$ or $n_B > n_F$)
  - AdS solution ($V_{tot} < 0$ or $n_B < n_F$)
  - c_O disappears from asymptotically-flat zero-R solution

W. Nelson, Phys. Rev. D 82, 104026 (2010)
H. Lü *et al*. Phys. Rev. Lett. 114, 171601 (2015)

- Another class corresponds to corresponds to variable scalar curvature ($R \neq \text{constant}$)
  - There exist asymptotically-flat solutions explicitly involving c_O

H. Buchdahl, Nuovo Cim. 23, 141 (1962)
H. Nguyen, Phys. Rev. D 107, 104009 (2023)
B. Puliçe, R. Pantig, A. Övgün, DD, work in progress (2023)

Symmergent Black Holes: Schwarzschild-dS/AdS Solutions

gravity theory ($V_{tree} = 0$)	static spherically-symmetric solutions
Symmergent gravity action: $\int d^4x \sqrt{-g}\left(-\frac{R}{16\pi G_N} - \frac{c_O}{16}R^2 - \frac{1-\hat{\alpha}}{(8\pi G_N)^2 c_O}\right)$	Schwarzschild-dS/AdS solution: $(ds)^2 = h(r)(cdt)^2 - \frac{(dr)^2}{h(r)} - r^2\left((d\theta)^2 + \sin^2\theta\,(d\phi)^2\right)$

$$c_O = \frac{n_b - n_f}{248\pi^2}$$

$\hat{\alpha} =$ a constant parametrizing symmergent vacuum energy

$$h(r) = 1 - \frac{r_s}{r} - \frac{(1-\hat{\alpha})r^2}{24\pi G_N c_O}$$

I. Çimdiker, DD, A. Övgün, Phys. Dark Univ. 34, 100900 (2021)

Symmergent Black Holes: Asymptotically-Flat Variable-R Solutions

gravity theory ($V_{tot} = 0$)	static spherically-symmetric solutions
Symmergent gravity action: $\int d^4x\ \sqrt{-g}\ \left(-\frac{R}{16\pi G_N} - \frac{c_O}{16} R^2\right)$	Buchdahl-Nguyen solution: $(ds)^2 = A(r)\ (dt)^2 - \frac{(dr)^2}{B(r)} - C(r)\left((d\,\theta)^2 + \sin^2\theta\ (d\phi)^2\right)$

$$\boxed{A(r) = e^{-\varphi(r)}\left(1 - \frac{r_s}{r}\right)}$$

$$\boxed{B(r) = e^{\varphi(r)}\left(1 - \frac{r_s}{r}\right)}$$

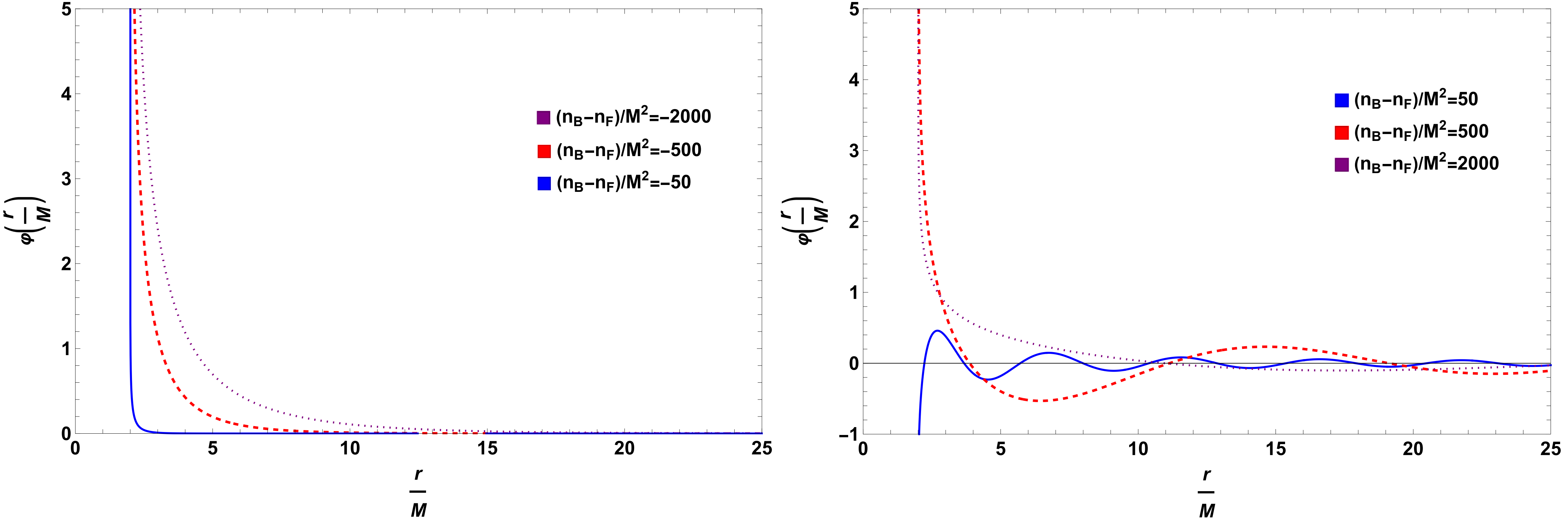
$$\boxed{C(r) = e^{-\varphi(r)} r^2}$$

$$\frac{d}{dr}\left((r^2 - r r_s)\frac{d\varphi(r)}{dr}\right) = -\gamma r^2 \varphi(r)$$

$$\gamma = -\frac{1}{6\pi c_O} = -\frac{64\pi}{3(n_b - n_f)}$$

H. Buchdahl, Nuovo Cim. 23, 141 (1962)
H. Nguyen, Phys. Rev. D 107, 104009 (2023)
B. Puliçe, R. Pantig, A. Övgün, DD, work in progress (2023)

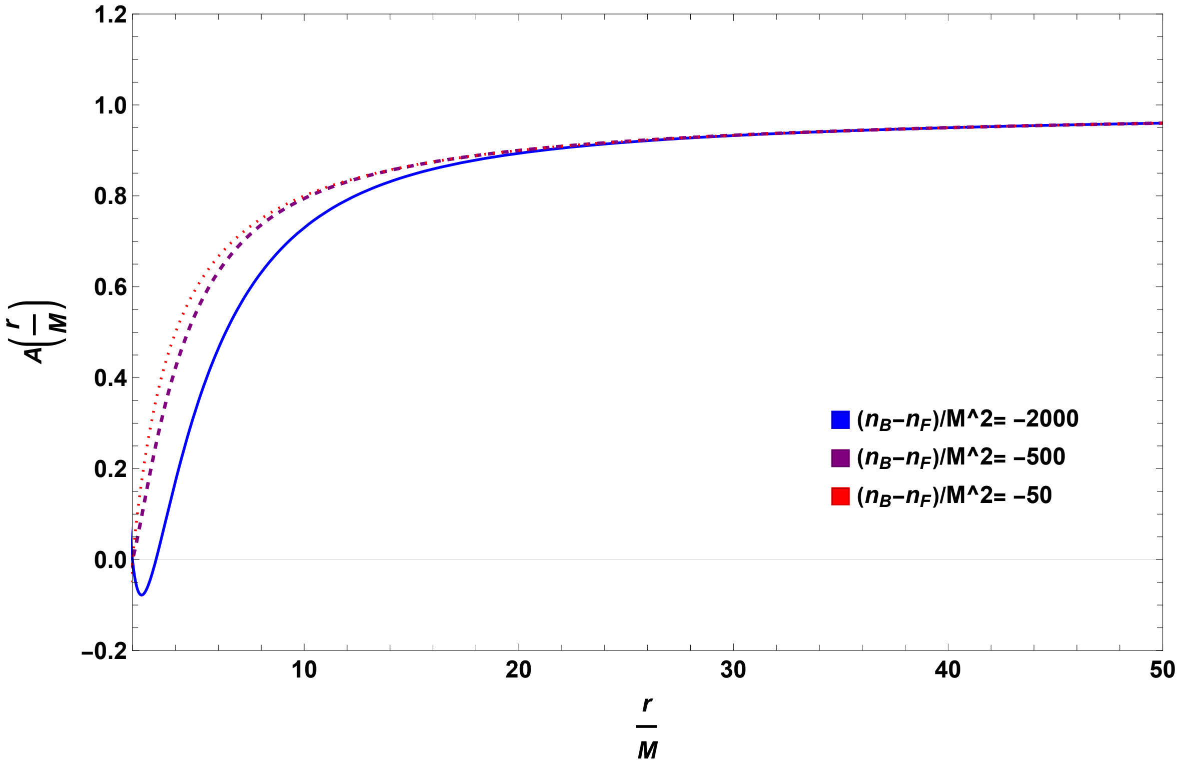
Symmergent Black Holes: Asymptotically-Flat Variable-R Solutions

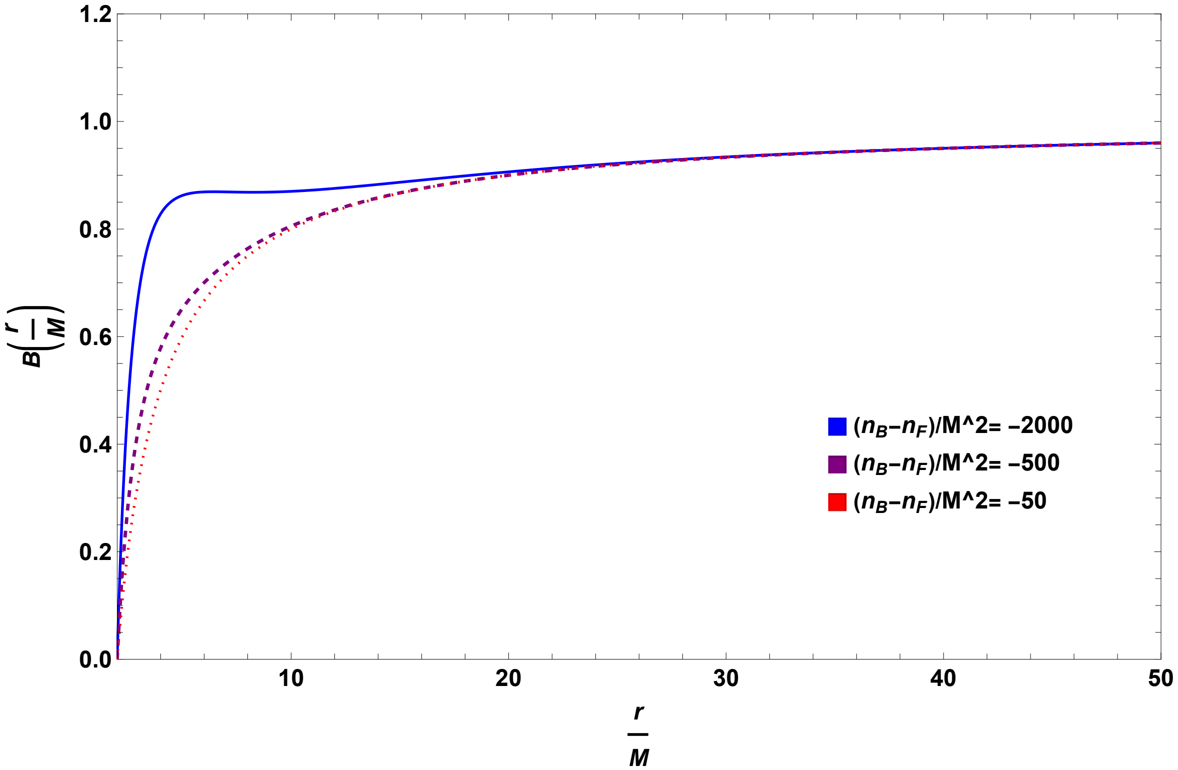


- **Conformal factor** $\varphi(r)$ diverges at the Schwarzschild horizon $r = r_s \equiv 2M$ and gets suppressed exponentially (sinusoidally) at large r for $n_B - n_F < 0$ ($n_B - n_F < 0$).

B. Puliçe, R. Pantig, A. Övgün, DD, work in progress (2023)

Symmergent Black Holes: Asymptotically-Flat Variable-R Solutions

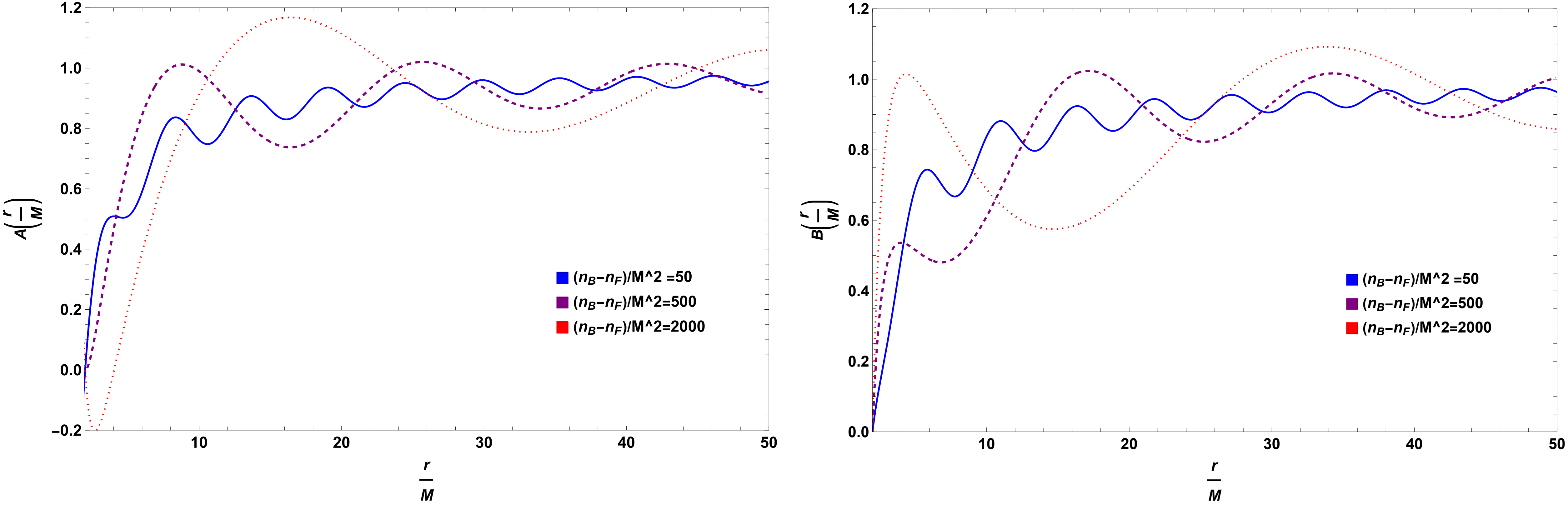




- Metric potentials $A(r)$ and $B(r)$ approach to the flat spacetime limit of $A(r) = B(r) = 1$ at large r. The approach is exponential and different $n_B - n_F < 0$ values are hard to distinguish observationally.

B. Puliçe, R. Pantig, A. Övgün, DD, work in progress (2023)

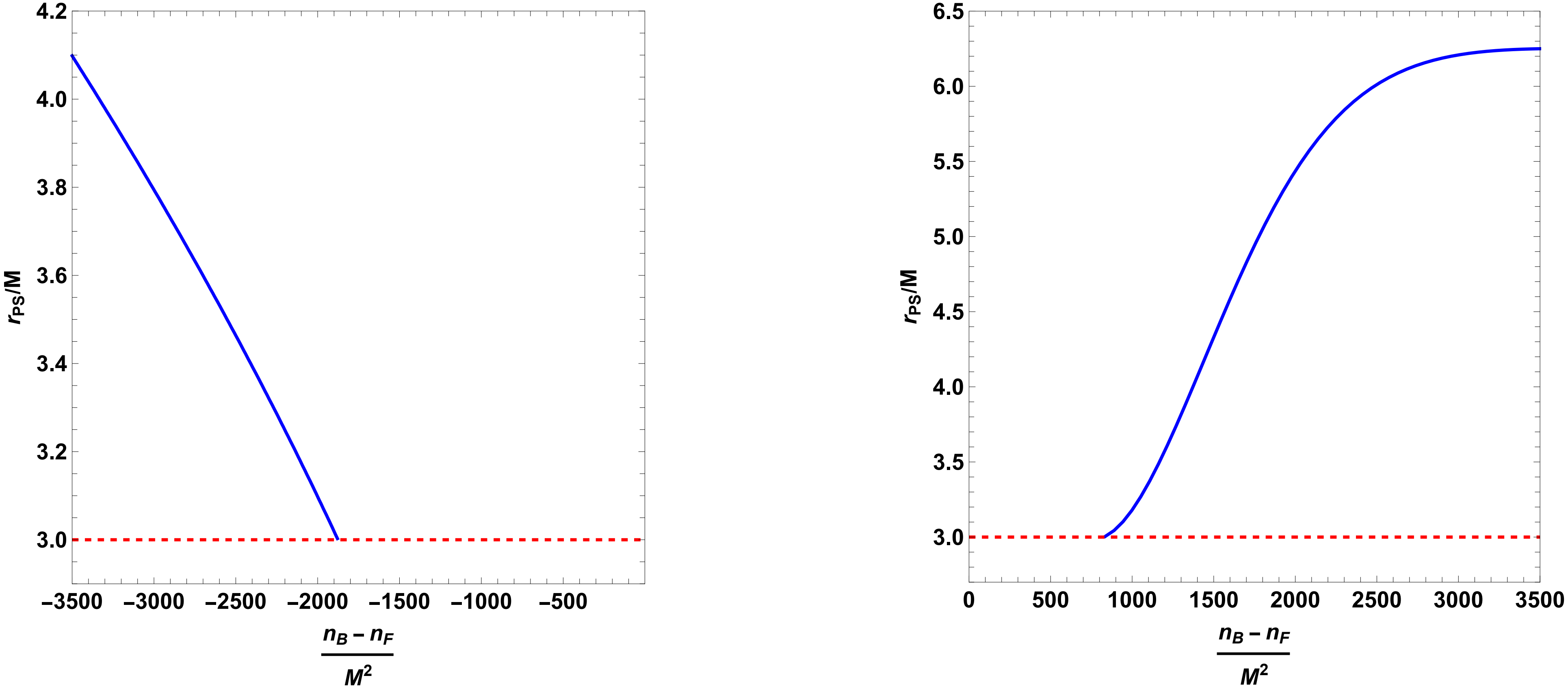
Symmergent Black Holes: Asymptotically-Flat Variable-R Solutions



- ➢ Metric potentials $A(r)$ and $B(r)$ approach to the flat spacetime limit of $A(r) = B(r) = 1$ at large r. The approach is sinusoidal and gradual and different $n_B - n_F > 0$ values could be distinguished observationally.

B. Puliçe, R. Pantig, A. Övgün, DD, work in progress (2023)

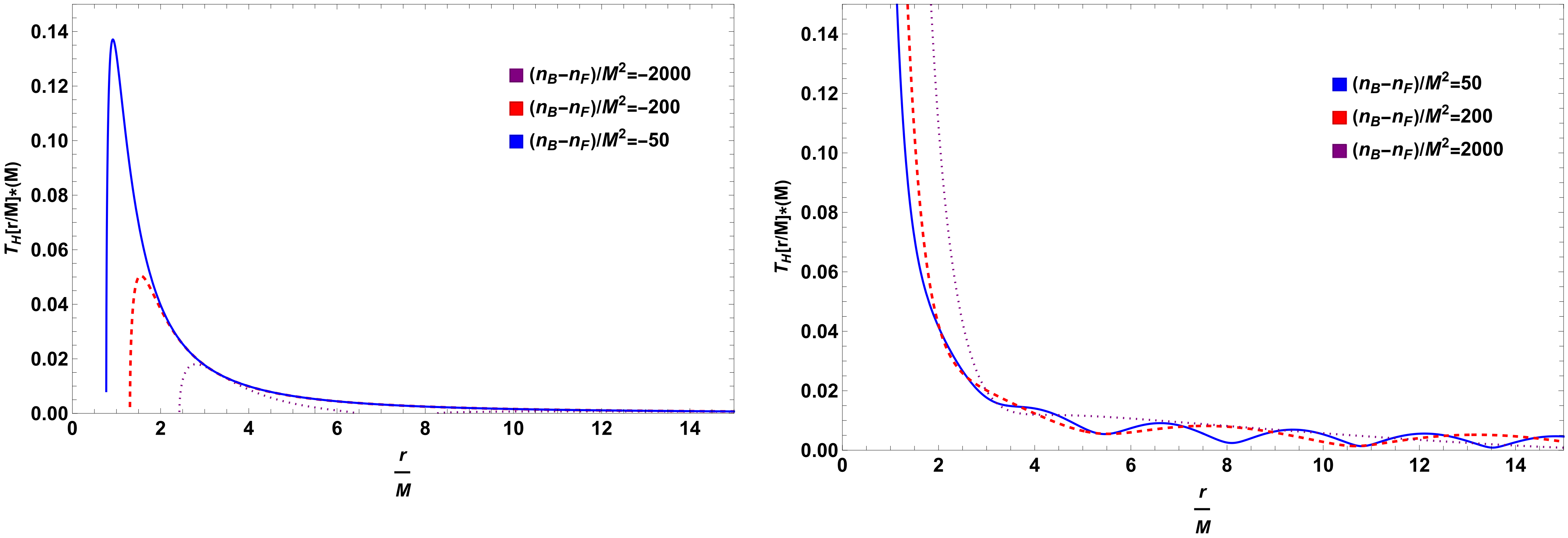
Symmergent Black Holes: Asymptotically-Flat Variable-R Solutions



- Photonsphere radius r_{PS} for $n_B - n_F < 0$ (left) and $n_B - n_F > 0$ (right).

B. Puliçe, R. Pantig, A. Övgün, DD, work in progress (2023)

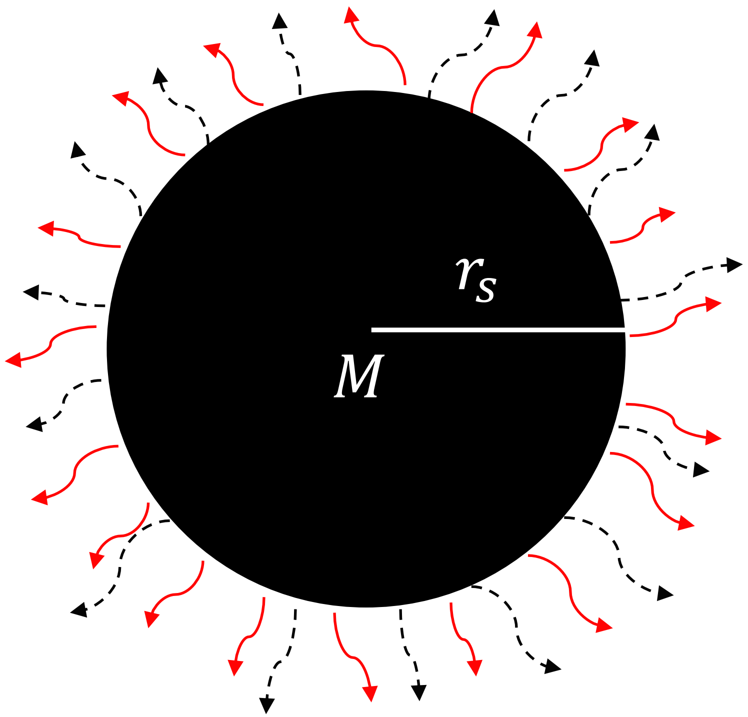
Symmergent Black Holes: Asymptotically-Flat Variable-R Solutions

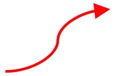


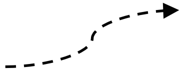
- Hawking temperature as a function of the radial coordinate r for $n_B - n_F < 0$ (left) and $n_B - n_F > 0$ (right).

B. Puliçe, R. Pantig, A. Övgün, DD, work in progress (2023)

Symmergent Black Holes: Asymptotically-Flat Variable-R Solutions



Hawking radiation from photon, neutrino etc. : 

Hawking radiation from new dark fields: 

Black hole temperature and evaporation rate change if symmergent particles are included!

Hawking radiation=$\{\gamma, \nu\}$ + $\{\text{light symmergent particles}\}$

D. Gogoi, A. Övgün, DD, work in progress (2023)

B. Puliçe, R. Pantig, A. Övgün, DD, work in progress (2023)

Thank you.