



# Verification of Emergent Gravity Theories with Gauge Symmetry Restoration via Black Holes and Inflation

Takumi Horikoshi Kazuharu Bamba  
Fukushima University

Gravity theories in which gravity emerges when gauge symmetry is restored are also called symmergent gravity theories. Symmergent gravity has a coupling constant in higher-order curvature terms. These coupling constants are estimated from observations of black holes (BHs) and inflation; however, their values differ. In this study, we introduce a log correction term into the coupling constant to suggest that the difference in values may arise from spacetime dependence. We show that the corrected coupling constants for inflation and the Schwarzschild BHs can be the same as the observed values.

## Introduction

- The unification of quantum field theory and general relativity is still incomplete. One reason for this is the inability to quantize gravity. Currently, researchers are conducting studies through various approaches to integrate the two theories. One such approach is a theory called symmergent gravity [Durmus, Gen. Relativ. Gravit. 53, 22 (2021)], which is based on emergent gravity theory [İlim İrfan Çimdiker, Physics of the Dark Universe 30 (2020) 100736].
- BHs have extremely strong gravitational fields and are often used as laboratories to test gravitational theories. They are observed using the Event Horizon Telescope (EHT) [Akiyama et al. Astrophys. J. Lett. 875 (2019)]. Additionally, the Starobinsky model demonstrates that inflation is consistent with Planck observations [Akrami et al. [Planck], Astron. Astrophys. 641, A10 (2020)].

## Symmergent gravity

In symmergent gravity, gauge symmetry is restored and the Newton constant is induced due to a UV cutoff acting as a loop correction in the effective action on flat spacetime, which has a covariant correspondence with spacetime curvature. Furthermore, symmergent gravity belongs to the framework of  $f(R)$  gravity theories [Tsujiikawa et al. Living Rev. Rel. 13: 3, 2010] and possesses higher-order curvature terms.

$$f(R) = R - \pi G c_0 R^2$$

$c_0$  is the coupling constant arising from the 1-loop correction.

$$c_0 = \frac{n_B - n_F}{64\pi^2} \quad \begin{array}{l} n_B : \text{The total number of bosonic} \\ n_F : \text{The total number of fermionic} \end{array}$$

Analyses of BHs and inflation in the Schwarzschild, the Kerr, and the Reissner-Nordström (RN) spacetimes within symmergent gravity have been conducted. Additionally, the value of  $c_0$  is estimated based on observations from the EHT and Cosmic Microwave Background (CMB).

TABLE I : Value of  $c_0$ .

|                     |                   |                                                               |
|---------------------|-------------------|---------------------------------------------------------------|
| $c_0^{\text{inf}}$  | $-10^{10}$        | [Durmus et al. Physics of the Dark Universe 34 (2021) 100900] |
| $c_0^{\text{Schw}}$ | $-0.1$            | [Durmus et al. Eur. Phys. J. C 83, 250 (2023)]                |
| $c_0^{\text{Kerr}}$ | $-0.5 \sim -0.09$ | [Durmus et al. Class. Quantum Grav. 40 195003 (2023)]         |
| $c_0^{\text{RN}}$   | $10^{39}$         | [Nilay Bostan et al. JCAP 02 (2024) 028]                      |

( $c_0^{\text{Schw}}$  is a theoretical value.)

## Purpose and Methodology

It shows that the higher-order curvature coefficient,  $c_0$ , in symmergent gravity may depend on spacetime.

Since  $c_0$  arises from quantum loop effects, the coefficient is also thought to possess a quantum correction. We consider an effective coefficient incorporating a log correction with spacetime dependence [Xavier Calmet et al. Phys. Let. B 860 (2025) 139208].

$$c_0 = c_{00} + \beta \ln \left( \frac{\mathfrak{R}}{\mu^2} \right) \quad \begin{array}{l} \mathfrak{R} : \text{Curvature scale} \\ \mu : \text{The renormalization scale} \\ \beta : \text{Constant} \end{array}$$

Analyze and compare the corrected  $c_0$ .

## Results and Discussion

TABLE II : The Kretschmann invariant is expressed in terms of the Planck mass.

|                   |                            |
|-------------------|----------------------------|
| $K^{\text{inf}}$  | $10^{-20} M_{\text{PL}}^4$ |
| $K^{\text{Schw}}$ | $M_{\text{PL}}^8 / M^4$    |

The Kretschmann invariant  $K$  is used as the curvature scale  $\mathfrak{R}$ .

$$\mathfrak{R} \equiv K = R_{\alpha\beta\delta\gamma} R^{\alpha\beta\delta\gamma}$$

[Ioannis Gkigkitzis, et al. Physics International 5 (1), (2014)]

[Tahia F. Dabash, M.A. Bakry. (2025)]

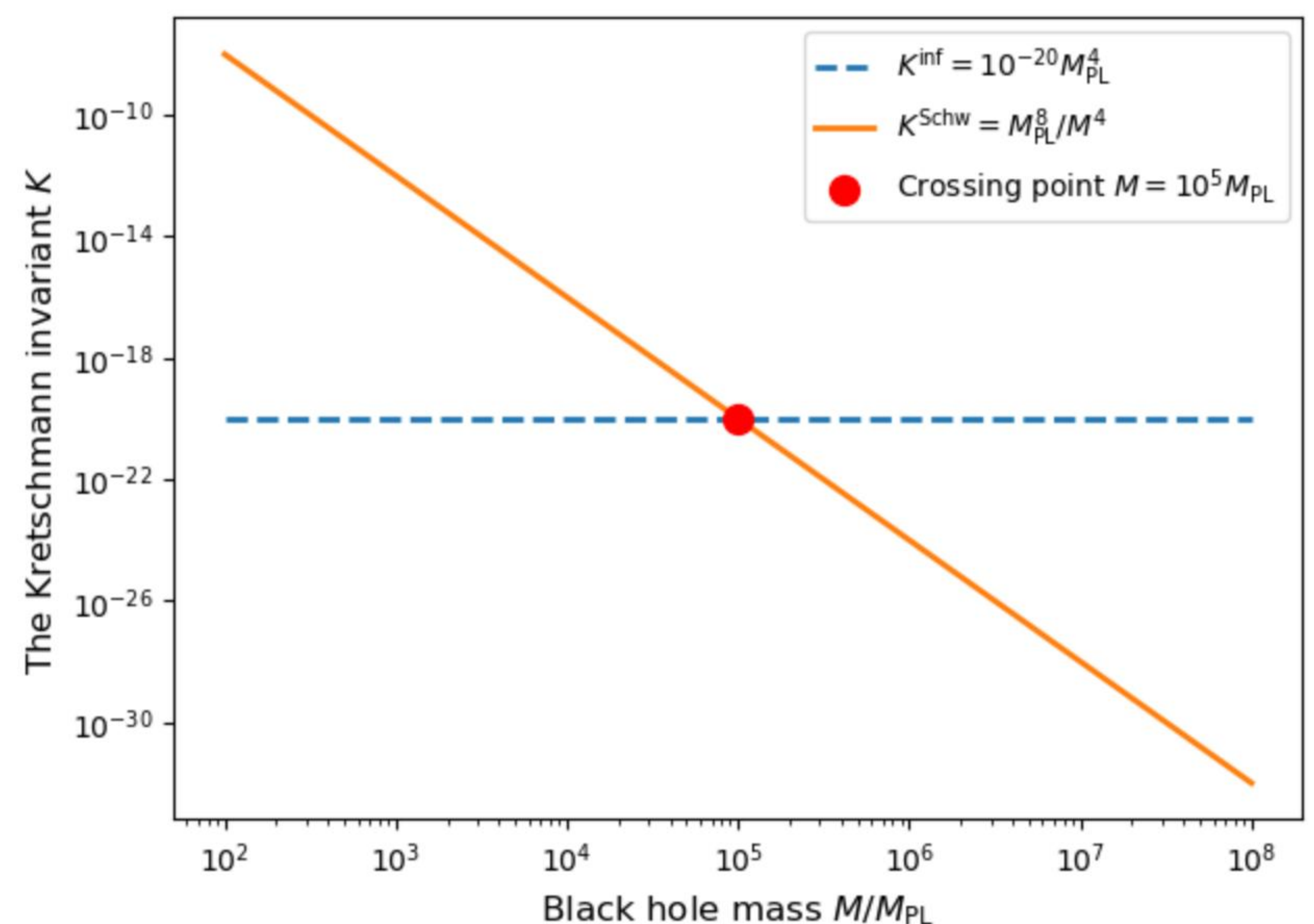


FIG. 1 : The relationship between  $c_0$  and BH mass  $M$  in inflation and the Schwarzschild BHs.

From TABLE II,

$$\frac{c_0^{\text{inf}}}{c_0^{\text{Schw}}} = \ln \left( \frac{K^{\text{inf}}}{K^{\text{Schw}}} \right) = -20 \ln 10 + 4 \ln \left( \frac{M}{M_{\text{PL}}} \right)$$

If  $M$  is sufficiently large ( $M \sim 10^6 M_{\odot} \sim 10^{44} M_{\text{PL}}$ )

$$\frac{c_0^{\text{inf}}}{c_0^{\text{Schw}}} \simeq 3.6 \times 10^2$$

Since the ratio is 0 or greater,

- $|c_0^{\text{Schw}}| < |c_0^{\text{inf}}|$ .
- Both  $c_0$  may be negative.

From FIG. 1, the log-log graph of the Schwarzschild BH's  $c_0$  is linear. The  $c_0$  of inflation is independent of mass. The intersection point of the graph is  $M \sim 10^5 M_{\text{PL}}$ , at which point the same  $c_0$  is valid for both inflation and BHs. This suggests the existence of primordial BHs.

## Conclusions

We demonstrated that the difference in coupling constants in symmergent gravity during inflation and black hole formation may stem from the influence of time-dependent log corrections. When  $c_0$  becomes equivalent, the existence of PBHs is naturally suggested.