Non-Singular Astrophysical Blakhole : Infinite Derivative Gravity

$$V(r) \sim \frac{1}{r}$$

Anupam Mazumdar

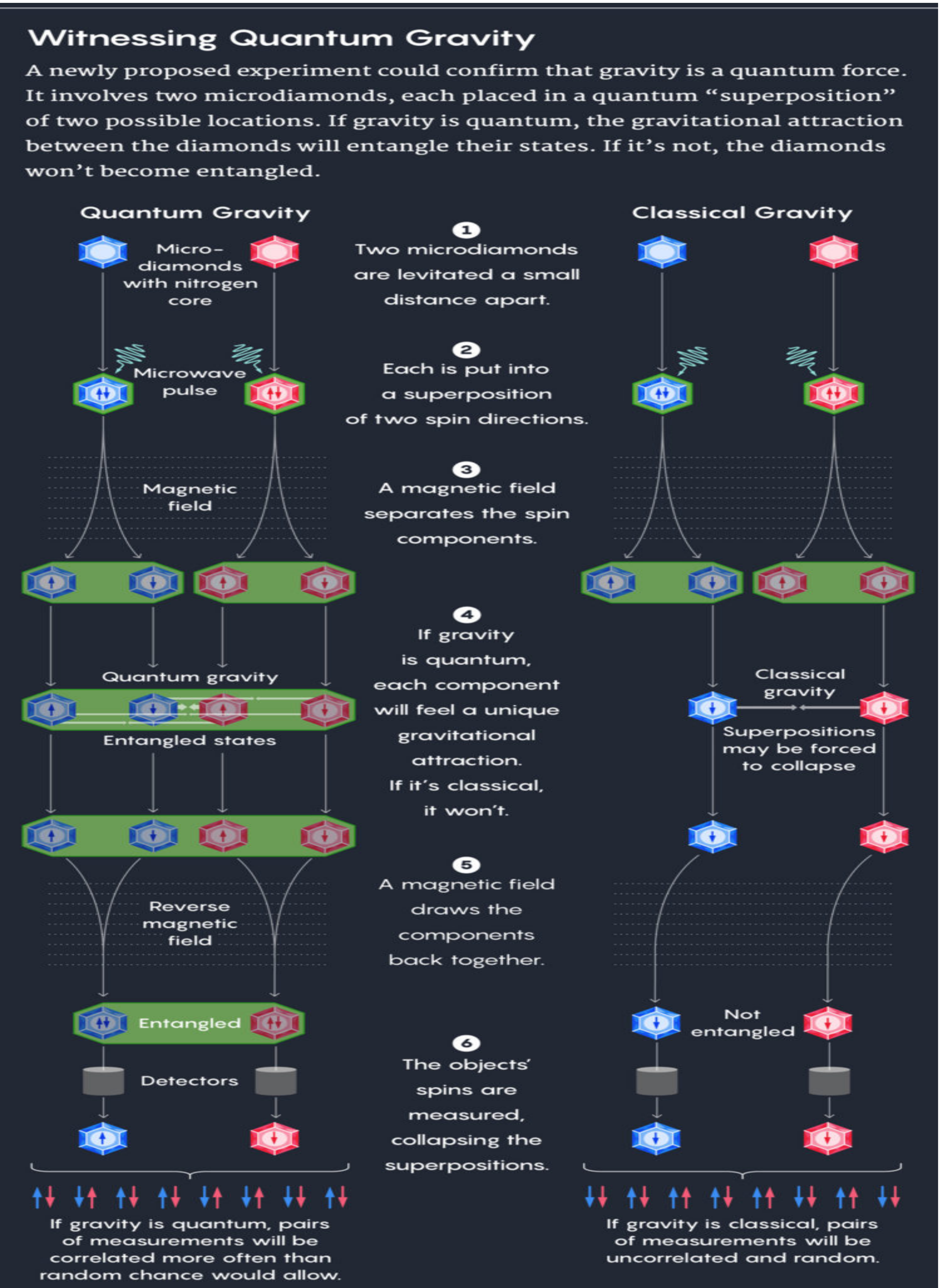
Warren Siegel, Tirthabir Biswas, Robert Brandenberger, Alexey Koshelev, Joao Marto, Tomi Koivisto Luca Buoninfante….

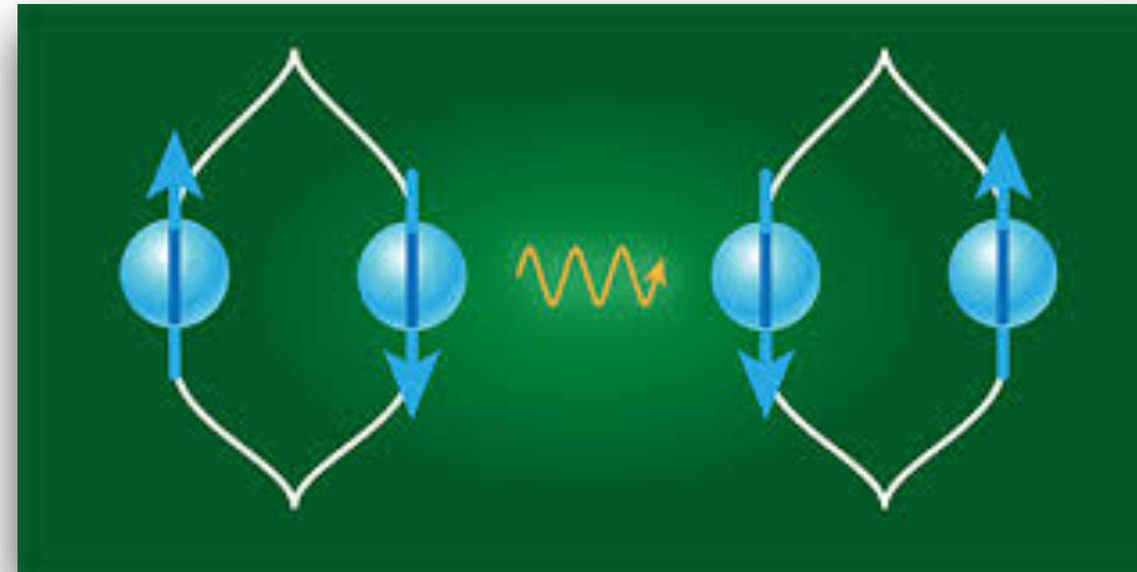
Hot topics in modern cosmology-2018

van swinderen institute for particle physics and gravity

rijksuniversiteit groningen

Witnessing Quantum Gravity





Witnessing the spin-correlation

Bose, AM, Morley, Ulbricht,Toros, Paternostro, Geraci, Barker, Kim, Milburn

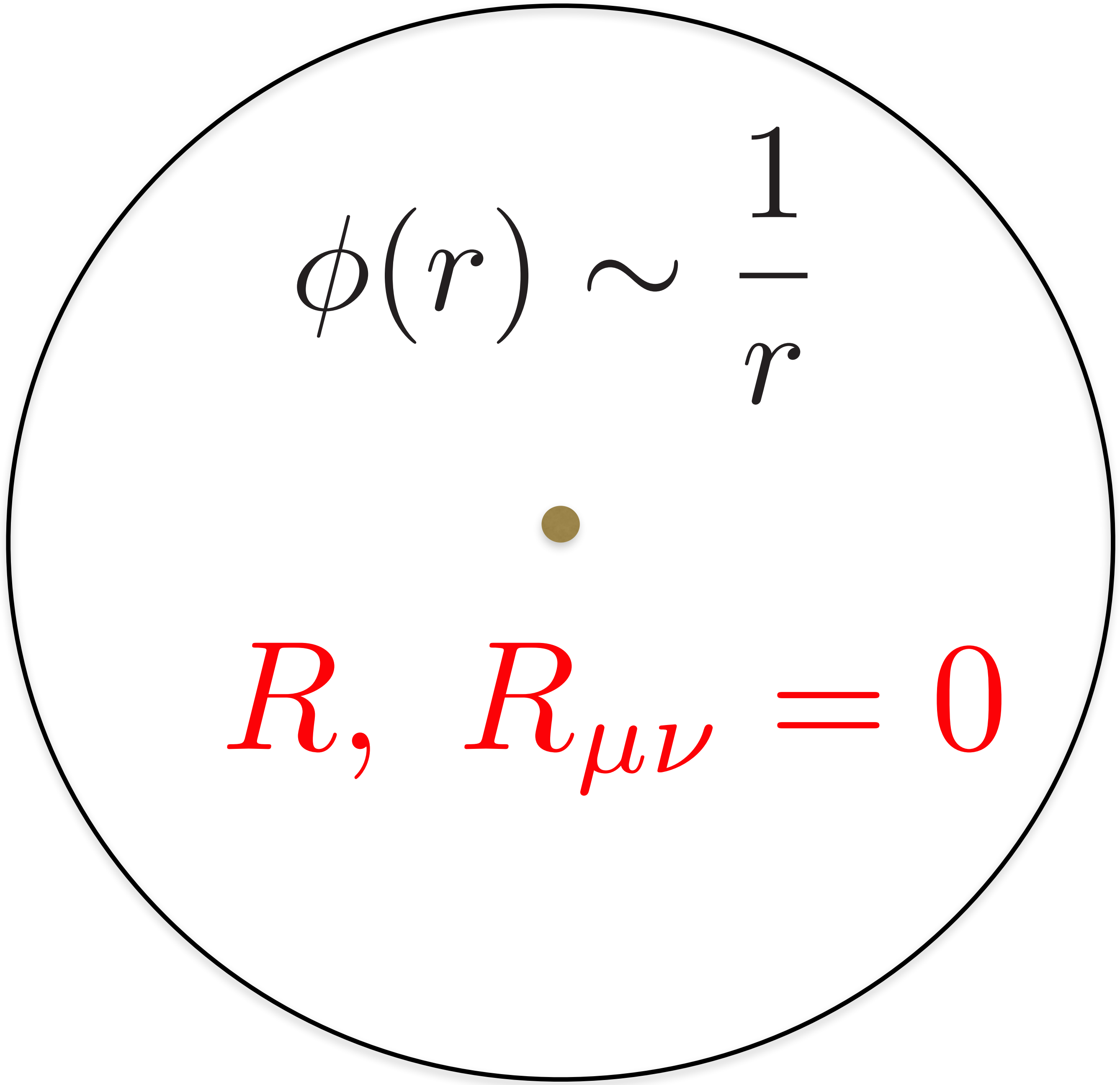
Phys. Rev. Lett. 119 (2017) no.24, 240401

1707.06050 [quant-ph]

Einstein’s Gravity

- Extremely successful theory in the IR. By IR, we mean - at large distances, large time scales, and weak metric potential
- In the UV (short distances, small time scales) the theory has problems at a classical and at a quantum level
- In UV there are many theories, typically there are two classes; one where you have perturbative approach, and second non-perturbative approach to begin with. Both have “pros-and-cons”.
- In this talk we will have similar approaches but as you will see, we would need perhaps both perturbative and non-perturbative arguments to understand the nature of spacetime.

Schwarzschild Metric

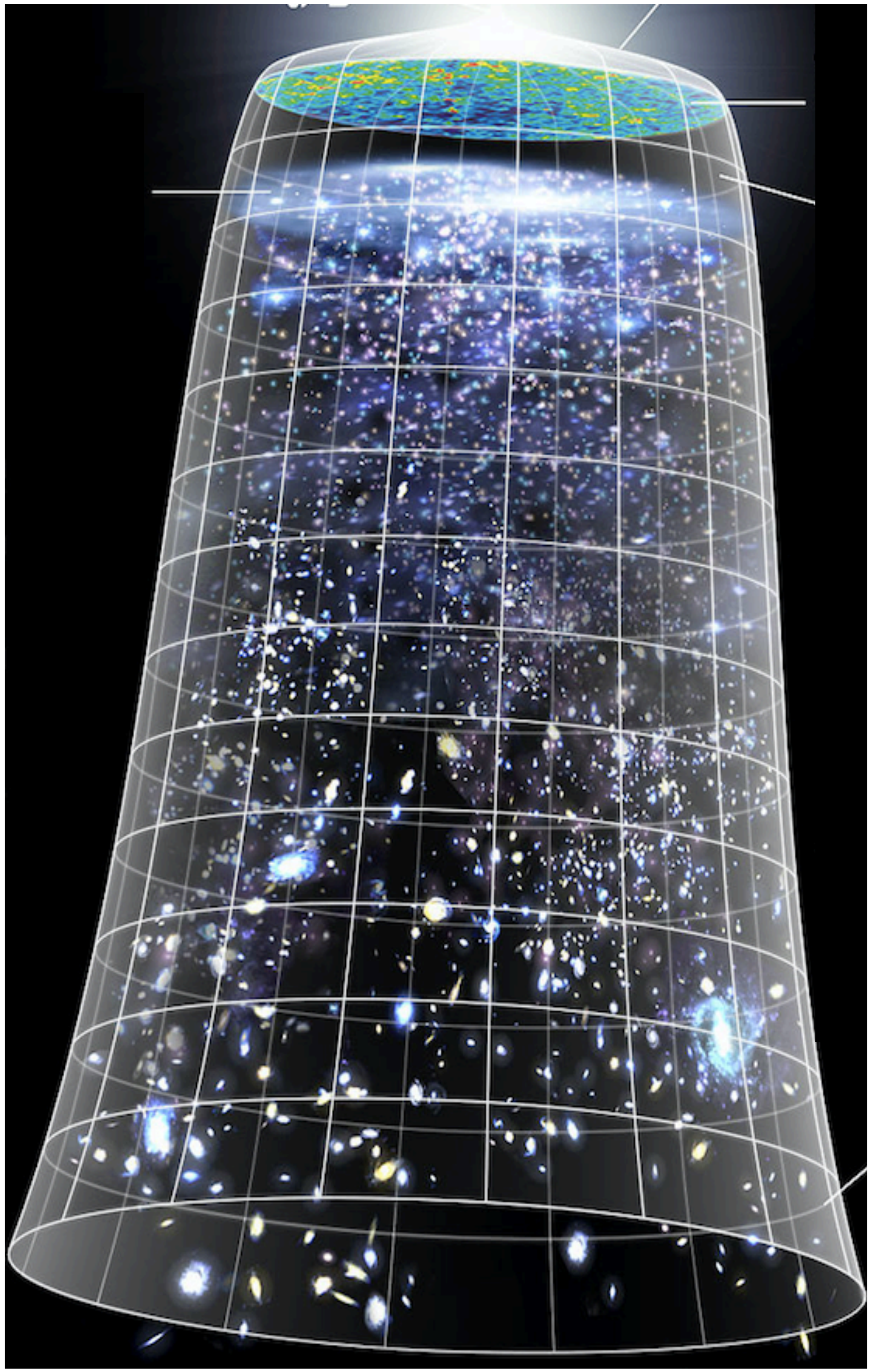


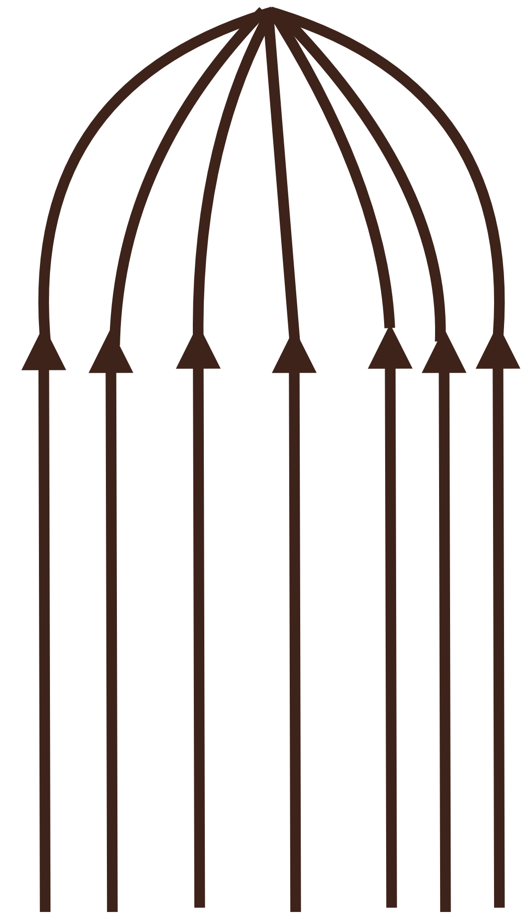
$$\phi(r) \sim \frac{1}{r}$$

$$R, \; R_{\mu\nu} = 0$$

$$R_{\mu\nu\lambda\sigma} \neq 0$$

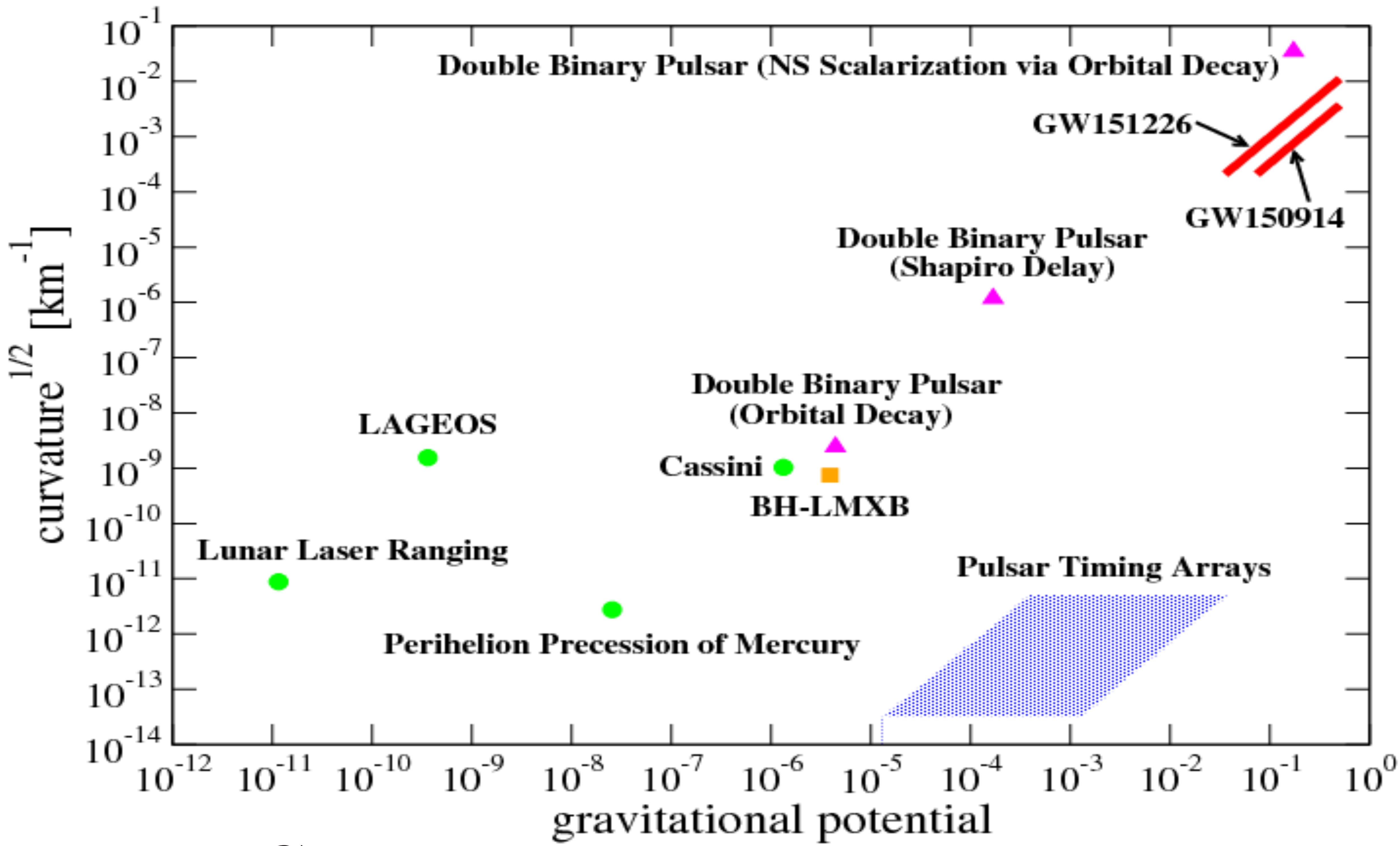
Cosmological Singularity in Einstein's GR





Focusing of Null-Rays
Hawking-Penrose Theorem via
Raychaudhury equation

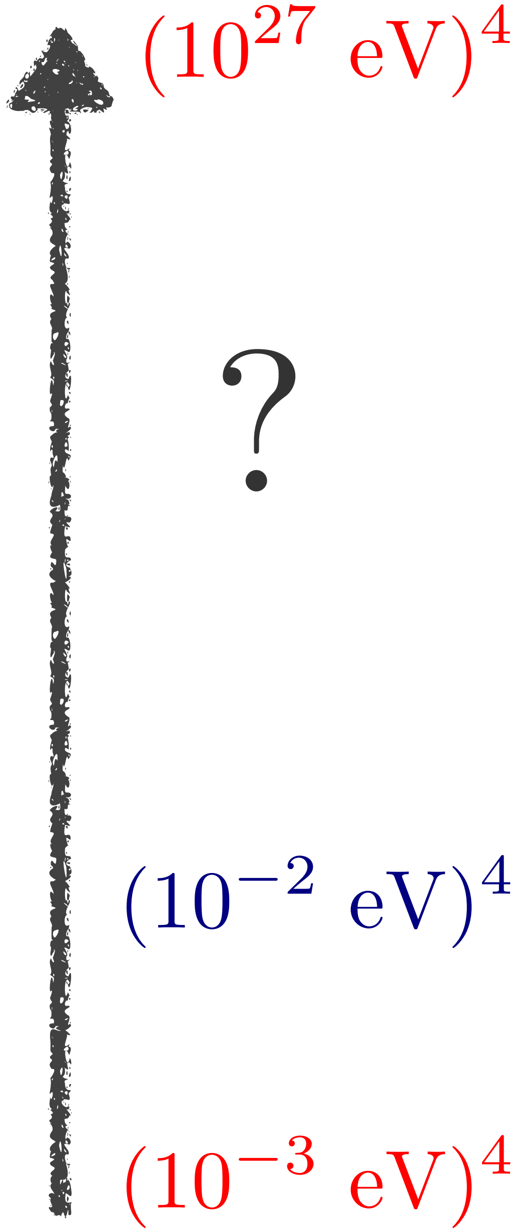
Testing Einstein's Gravity in the UV?

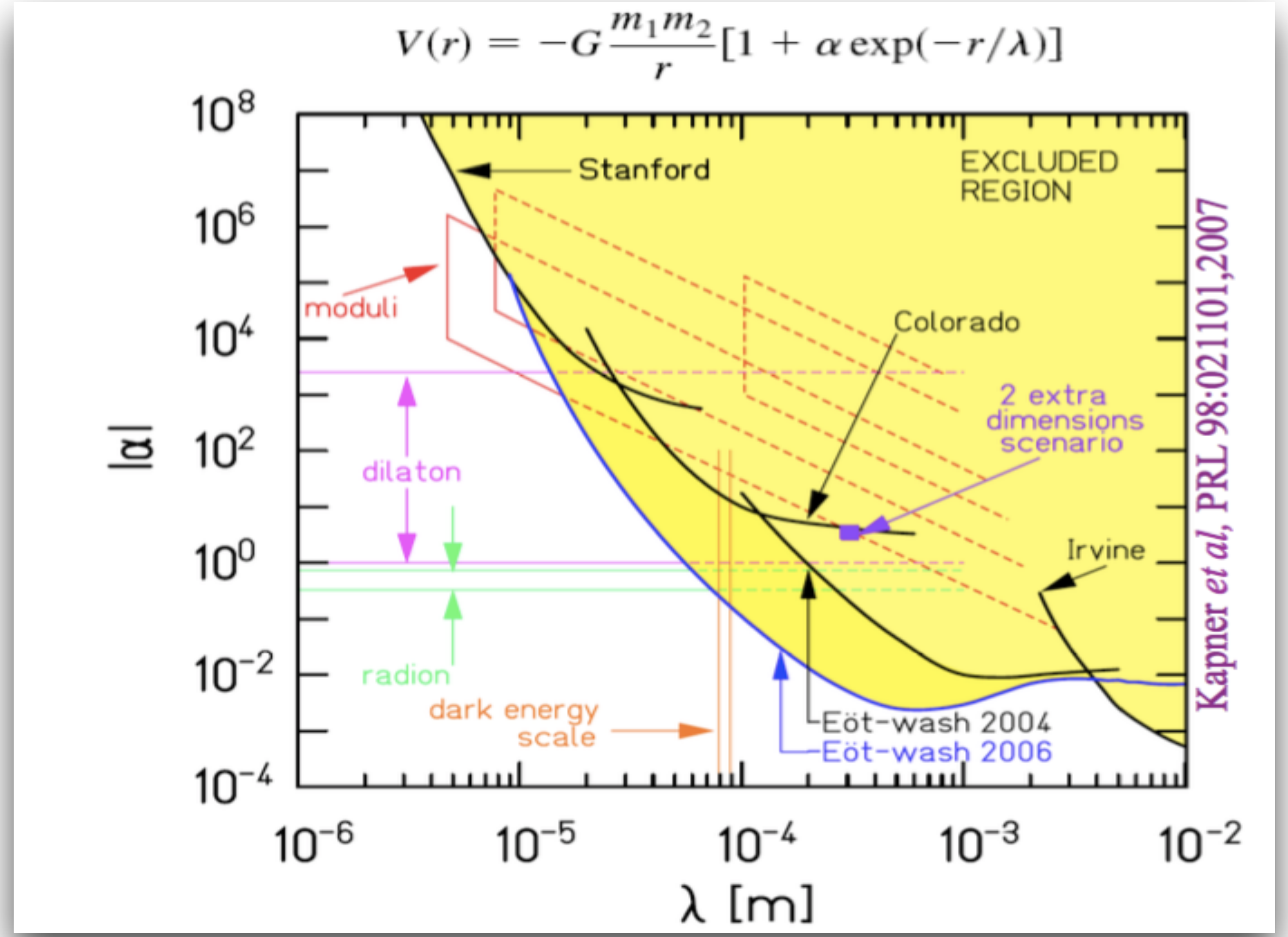


$$\Phi \sim \frac{GM}{r}$$

Yagi-kent et.al 1608.02582

Gravity : Least Known Interaction





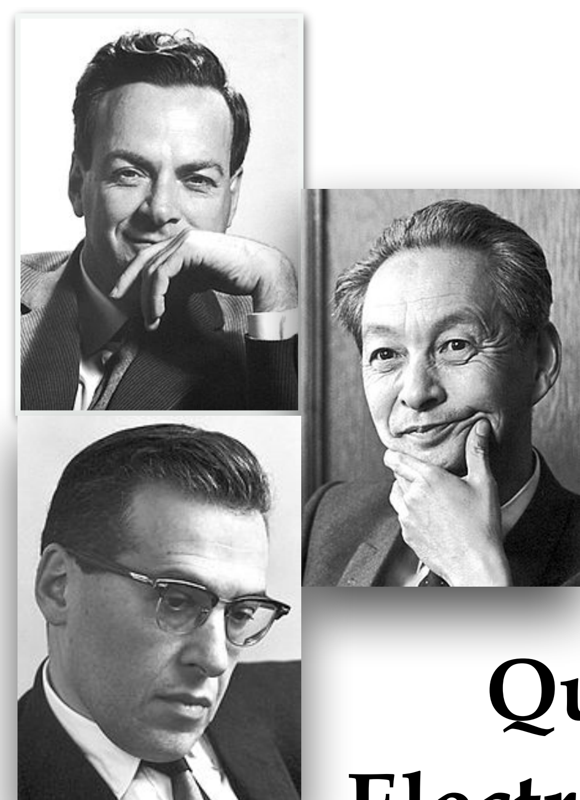
$$10^{-5}\ \mathrm{m} \sim 100\ (\mathrm{eV})^{-1}$$

$$\text{or,}\ \ M \sim 10^{-2}\ \mathrm{eV}$$

Maxwell’s Electromagnetism

Self energy of an electron is Infinite in Maxwell’s theory

1/r-fall of Coulomb’s Potential



Quantum Electrodynamics

Classical approach: Born-Infeld

Born-Infeld Resolves Singularity

$$\mathcal{L}_{\text{Born-Infeld}} = b^2 \left[1 - \sqrt{1 - (\boldsymbol{E}^2 - \boldsymbol{B}^2)/b^2 - (\boldsymbol{E}\cdot\boldsymbol{B})^2/b^4} \right]$$

$$b \to \infty \qquad \mathcal{L}_{\text{Born-Infeld}} \to \mathcal{L}_{\text{Maxwell}}$$

Maxwell	**Born-Infeld**
$E_{\text{tot}} = \frac{1}{2}\int (E.D + B.H) d^3r$ $D = e\hat{r}/4\pi r^2, \quad E = e\hat{r}/4\pi\epsilon r^2, \quad B = H = 0$ $E_{\text{tot}} = \frac{1}{32\pi^2}\int_0^\infty \frac{e^2}{r^4} 4\pi r^2 dr = \infty$	$\boldsymbol{\nabla}\cdot D = e\delta^{(3)}(\boldsymbol{r}) \qquad \boldsymbol{B} = 0$ $\boldsymbol{D} = \frac{e\boldsymbol{r}}{4\pi\|\boldsymbol{r}\|^3} \qquad \boldsymbol{D}^2/b^2 = \frac{q^2}{r^4}$ $E_{\text{tot}} = 4\pi b^2 \int_0^\infty dr\, r^2 \left(\sqrt{1+q^2/r^4} - 1\right)$ $= \frac{4\Gamma^2(5/4)\sqrt{e^3 b}}{3\pi} = 1.2361\sqrt{e^3 b}$

4th Derivative Gravity & Ghosts

$$I = \int d^4x \sqrt{g} \left[\lambda_0 + k\,R + a\,R_{\mu\nu}R^{\mu\nu} - \frac{1}{3}\,(b+a)R^2 \right]$$

$$D \propto \frac{1}{k^4 + Ak^2} = \frac{1}{A}\left(\frac{1}{k^2} - \frac{1}{k^2 + A}\right)$$

Massless Spin-0 & Massive Spin-2 (Ghost) Stelle (1977)

Utiyama, De Witt (1961), Stelle (1977)

Modification of Einstein's GR

Modification of Graviton Propagator

Extra propagating degree of freedom (dof)

Challenge: to get rid of the extra dof

Infinite Derivative Gravity

GR is a good approximation in InfraRed

Corrections in UltraViolet becomes important

$M \to \infty$(Theory reduces to GR)

$$S_q = \int d^4x \sqrt{-g} R_{\mu_1\nu_1\lambda_1\sigma_1} \mathcal{O}^{\mu_1\nu_1\lambda_1\sigma_1}_{\mu_2\nu_2\lambda_2\sigma_2} R^{\mu_2\nu_2\lambda_2\sigma_2}$$

Biswas, AM, Siegel (2006), Biswas, Gerwick, Koivisto, AM (2011)
Biswas, Koshelev, AM (2015)

Effective Field Theory: Towards UV

$$S = \int d^4x \; \phi\Box(\Box + m^2)\phi \Rightarrow \Box(\Box + m^2)\phi = 0$$

$$\Delta(p^2) = \frac{1}{p^2(p^2+m^2)} \sim \frac{1}{p^2} - \frac{1}{(p^2+m^2)}$$

$$S = \int d^4x \phi e^{\Box/M_s^2}(\Box + m^2)\phi$$

$$e^{\Box/M_s^2}(\Box + m^2)\phi = 0$$

Woodard (1991), Moffat (1991),
Tomboulis (1997),
Tseytlin (1997), Siegel (2003),
Biswas, Grisaru, Siegel (2004),
Biswas, Mazumdar, Siegel (2006)

No new poles.

No new dof. Retains original dof.

Perturbative Unitarity is maintained

Beyond the New Scale, interactions become non-local

Infinite Derivative Gravity

$$S_q = \int d^4x \sqrt{-g} R_{\mu_1\nu_1\lambda_1\sigma_1} \mathcal{O}^{\mu_1\nu_1\lambda_1\sigma_1}_{\mu_2\nu_2\lambda_2\sigma_2} R^{\mu_2\nu_2\lambda_2\sigma_2}$$

$$S = \int d^4x \sqrt{-g} \left[\frac{R}{16\pi G} + R\mathcal{F}_1\left(\frac{\Box}{M^2}\right) R + R_{\mu\nu}\mathcal{F}_2\left(\frac{\Box}{M^2}\right) R^{\mu\nu} + R_{\mu\nu\lambda\sigma}\mathcal{F}_3\left(\frac{\Box}{M^2}\right) R^{\mu\nu\lambda\sigma} \right]$$

Infrared (IR)

Ultra Violet (UV)

$M \to \infty$(Theory reduces to GR)

Biswas, AM, Siegel, JCAP, 2006, hep-th/0508194

Biswas, Gerwick, Koivisto, AM, Phys. Rev. Lett 2012, gr-qc/1110.5249

Biswas, Koshelev, AM, 2016, PRD (extension for de Sitter & Anti-deSitter),

arXiv:1602.08475 , arXiv:1606.01250,

Infinite Derivative Gravity: Non-perturbative statement

$$S = S_{EH} + S_q$$
$$= \frac{1}{16\pi G}\int d^4x\sqrt{-g}\,[\mathcal{R} + \alpha_c\left(\mathcal{R}\mathcal{F}_1(\Box_s)\mathcal{R} + \mathcal{R}_{\mu\nu}\mathcal{F}_2(\Box_s)\mathcal{R}^{\mu\nu} + \mathcal{C}_{\mu\nu\rho\sigma}\mathcal{F}_3(\Box_s)\mathcal{C}^{\mu\nu\rho\sigma}\right)]$$

$$S_{EH} \sim M_p^2\int d^4x\sqrt{-g}\mathcal{R} \sim M_p^2 L^2$$

$$S_q \sim M_p^2\int d^4x\sqrt{-g}\;\alpha_c\,[\mathcal{R}\mathcal{F}_1(\Box_s)\mathcal{R} + \cdots] \sim \frac{M_p^2}{M_s^2}$$

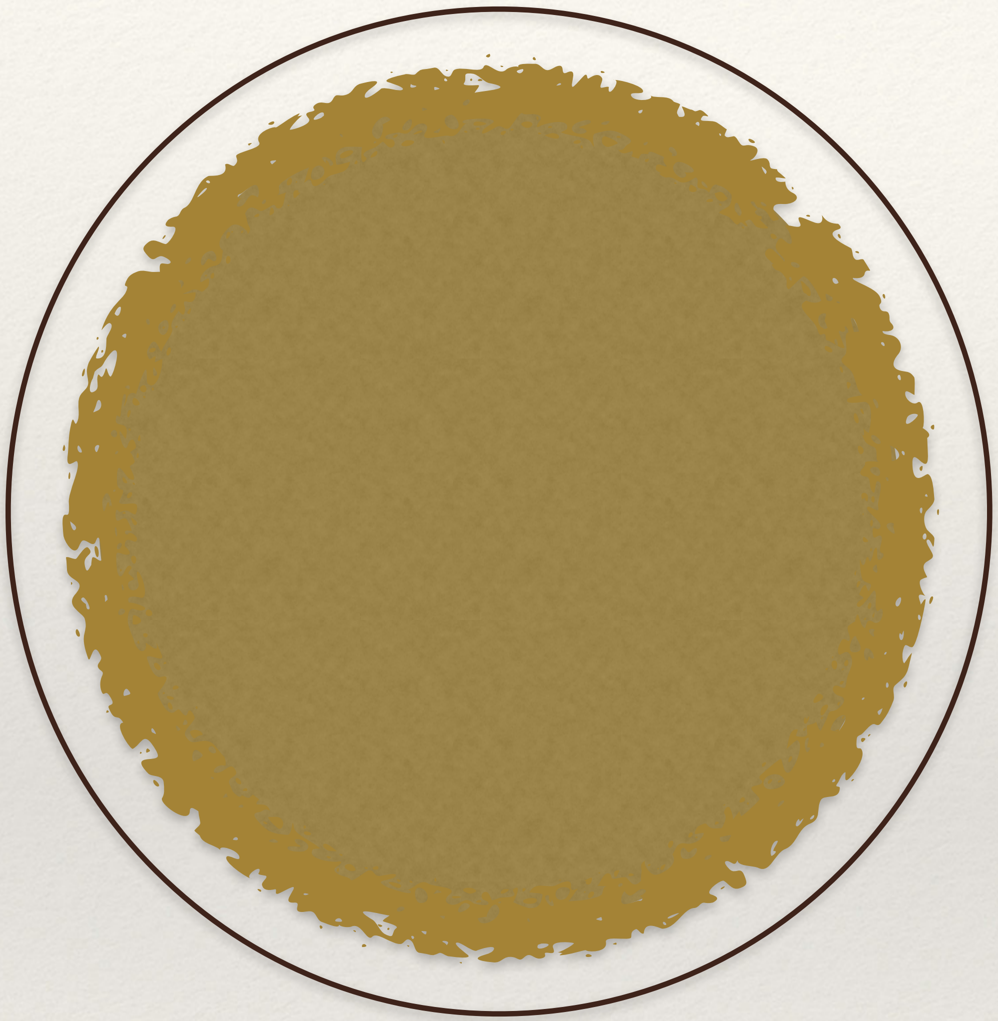
$$S \sim M_p^2 L^2 + \frac{M_p^2}{M_s^2} = M_p^2 L^2\left(1 + \frac{1}{M_s^2 L^2}\right)$$

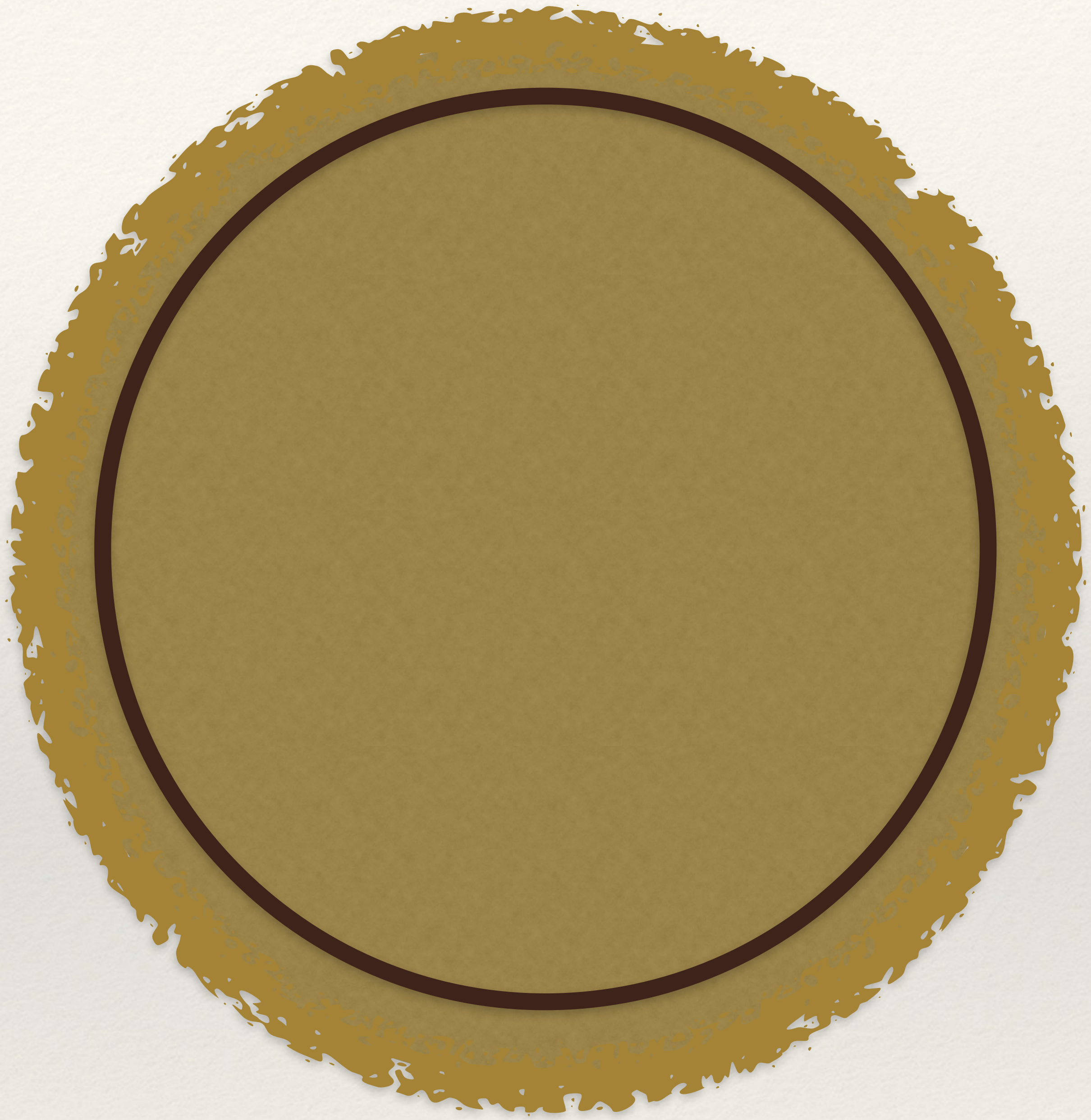
$$S \sim \frac{4m^2}{M_p^2}\left(1 + \frac{M_p^4}{4M_s^2 m^2}\right)$$

$$L \sim 2Gm$$

$$2mM_s < M_p^2 \Longleftrightarrow r_{\rm sch} < \frac{2}{M_s}$$

Local vs. Infinite Derivative Gravity





$$S_{EH} > S_q \qquad\qquad S_{EH} < S_q$$

Graviton Propagator

Massless graviton (transverse & traveless dof)

$$\Pi = \frac{P^2}{ak^2} + \frac{P_s^0}{(a-3c)k^2}$$

$$a(\Box) = c(\Box) \Rightarrow 2\mathcal{F}_1(\Box) + \mathcal{F}_2(\Box) + 2\mathcal{F}_3(\Box) = 0$$

(Around Minkowski spacetime)

$$a(\Box) = e^{\gamma(\Box)}; \qquad \gamma = \text{Entire Function}$$

For dS and AdS backgrounds, see:

Biswas, Koshelev, AM, 2016, PRD (extension for de Sitter & Anti-deSitter),
arXiv:1602.08475 , arXiv:1606.01250,

Complete Equations of Motion

2.3. The Complete Field Equations

Following from this we find the equation of motion for the full action S in (1) to be a combination of S_0, S_1, S_2 and S_3 above

$$\begin{aligned} P^{\alpha\beta} = {} & G^{\alpha\beta} + 4G^{\alpha\beta}\mathcal{F}_1(\Box)R + g^{\alpha\beta}R\mathcal{F}_1(\Box)R - 4\left(\nabla^\alpha\nabla^\beta - g^{\alpha\beta}\Box\right)\mathcal{F}_1(\Box)R \\ & - 2\Omega_1^{\alpha\beta} + g^{\alpha\beta}(\Omega_{1\sigma}^{\sigma} + \bar{\Omega}_1) + 4R_\mu^\alpha\mathcal{F}_2(\Box)R^{\mu\beta} \\ & - g^{\alpha\beta}R_\nu^\mu\mathcal{F}_2(\Box)R_\mu^\nu - 4\nabla_\mu\nabla^\beta(\mathcal{F}_2(\Box)R^{\mu\alpha}) + 2\Box(\mathcal{F}_2(\Box)R^{\alpha\beta}) \\ & + 2g^{\alpha\beta}\nabla_\mu\nabla_\nu(\mathcal{F}_2(\Box)R^{\mu\nu}) - 2\Omega_2^{\alpha\beta} + g^{\alpha\beta}(\Omega_{2\sigma}^{\sigma} + \bar{\Omega}_2) - 4\Delta_2^{\alpha\beta} \\ & - g^{\alpha\beta}C^{\mu\nu\lambda\sigma}\mathcal{F}_3(\Box)C_{\mu\nu\lambda\sigma} + 4C^{\alpha}_{\ \mu\nu\sigma}\mathcal{F}_3(\Box)C^{\beta\mu\nu\sigma} \\ & - 4(R_{\mu\nu} + 2\nabla_\mu\nabla_\nu)(\mathcal{F}_3(\Box)C^{\beta\mu\nu\alpha}) - 2\Omega_3^{\alpha\beta} + g^{\alpha\beta}(\Omega_{3\gamma}^{\gamma} + \bar{\Omega}_3) - 8\Delta_3^{\alpha\beta} \\ & = T^{\alpha\beta}\,, \end{aligned} \tag{52}$$

where $T^{\alpha\beta}$ is the stress energy tensor for the matter components in the universe and we have defined the following symmetric tensors:

$$\Omega_1^{\alpha\beta} = \sum_{n=1}^{\infty} f_{1_n} \sum_{l=0}^{n-1} \nabla^\alpha R^{(l)} \nabla^\beta R^{(n-l-1)}, \quad \bar{\Omega}_1 = \sum_{n=1}^{\infty} f_{1_n} \sum_{l=0}^{n-1} R^{(l)} R^{(n-l)}, \tag{53}$$

$$\Omega_2^{\alpha\beta} = \sum_{n=1}^{\infty} f_{2_n} \sum_{l=0}^{n-1} R_\nu^{\mu;\alpha(l)} R_\mu^{\nu;\beta(n-l-1)}, \quad \bar{\Omega}_2 = \sum_{n=1}^{\infty} f_{2_n} \sum_{l=0}^{n-1} R_\nu^{\mu(l)} R_\mu^{\nu(n-l)}\,, \tag{54}$$

$$\Delta_2^{\alpha\beta} = \frac{1}{2}\sum_{n=1}^{\infty} f_{2_n} \sum_{l=0}^{n-1} [R_\sigma^{\nu(l)} R^{(\beta|\sigma|;\alpha)(n-l-1)} - R_\sigma^{\nu;(\alpha(l)} R^{\beta)\sigma(n-l-1)}]_{;\nu}\,, \tag{55}$$

$$\Omega_3^{\alpha\beta} = \sum_{n=1}^{\infty} f_{3_n} \sum_{l=0}^{n-1} C^{\mu;\alpha(l)}_{\ \nu\lambda\sigma} C_\mu^{\ \nu\lambda\sigma;\beta(n-l-1)}, \ \bar{\Omega}_3 = \sum_{n=1}^{\infty} f_{3_n} \sum_{l=0}^{n-1} C^{\mu(l)}_{\ \nu\lambda\sigma} C_\mu^{\ \nu\lambda\sigma(n-l)}\,, \tag{56}$$

$$\Delta_3^{\alpha\beta} = \frac{1}{2}\sum_{n=1}^{\infty} f_{3_n} \sum_{l=0}^{n-1} [C^{\lambda\nu(l)}_{\ \ \sigma\mu} C_\lambda^{\ (\beta|\sigma\mu|;\alpha)(n-l-1)} - C^{\lambda\nu\ \ ;(\alpha(l)}_{\ \ \sigma\mu} C_\lambda^{\ \beta)\sigma\mu(n-l-1)}]_{;\nu}\,. \tag{57}$$

The trace equation is often particularly useful and below we provide it for the general action (1):

$$\begin{aligned} P = {} & -R + 12\Box\mathcal{F}_1(\Box)R + 2\Box(\mathcal{F}_2(\Box)R) + 4\nabla_\mu\nabla_\nu(\mathcal{F}_2(\Box)R^{\mu\nu}) \\ & + 2(\Omega_{1\sigma}^{\sigma} + 2\bar{\Omega}_1) + 2(\Omega_{2\sigma}^{\sigma} + 2\bar{\Omega}_2) + 2(\Omega_{3\sigma}^{\sigma} + 2\bar{\Omega}_3) - 4\Delta_{2\sigma}^{\sigma} - 8\Delta_{3\sigma}^{\sigma} \\ & = T \equiv g_{\alpha\beta}T^{\alpha\beta}\,. \end{aligned} \tag{58}$$

It is worth noting that we have checked special cases of our result against previous work in sixth order gravity given in [24] and found them to be equivalent at least to the cubic order (see Appendix C for details).

$$R^{(m)} \equiv \Box^m R$$

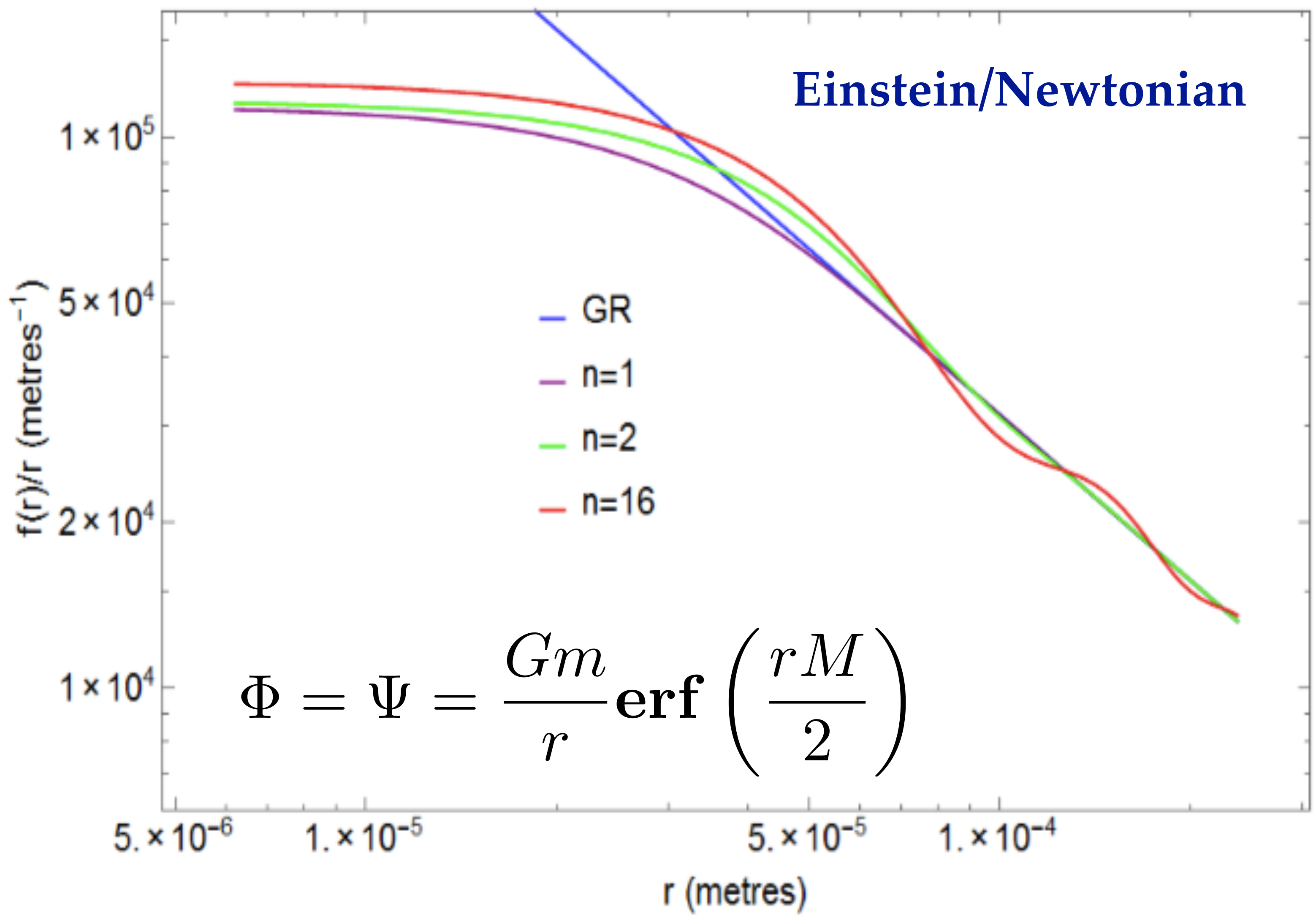
Biswas, Conroy, Koshelev, Mazumdar
1308.2319, Class.Quant. Grav. (2014)

Newtonian Potential

$$ds^2 = -(1-2\Phi)dt^2 + (1+2\Psi)dr^2$$

$$a(\Box) = e^{\gamma(\Box)}$$

$$\gamma(\Box) = -\frac{\Box}{M^2} - \sum_N a_N \left(\frac{\Box}{M^2}\right)^N$$



$$mM < M_p^2 \Longrightarrow \frac{2m}{M_p^2} < \frac{2}{M_s}$$

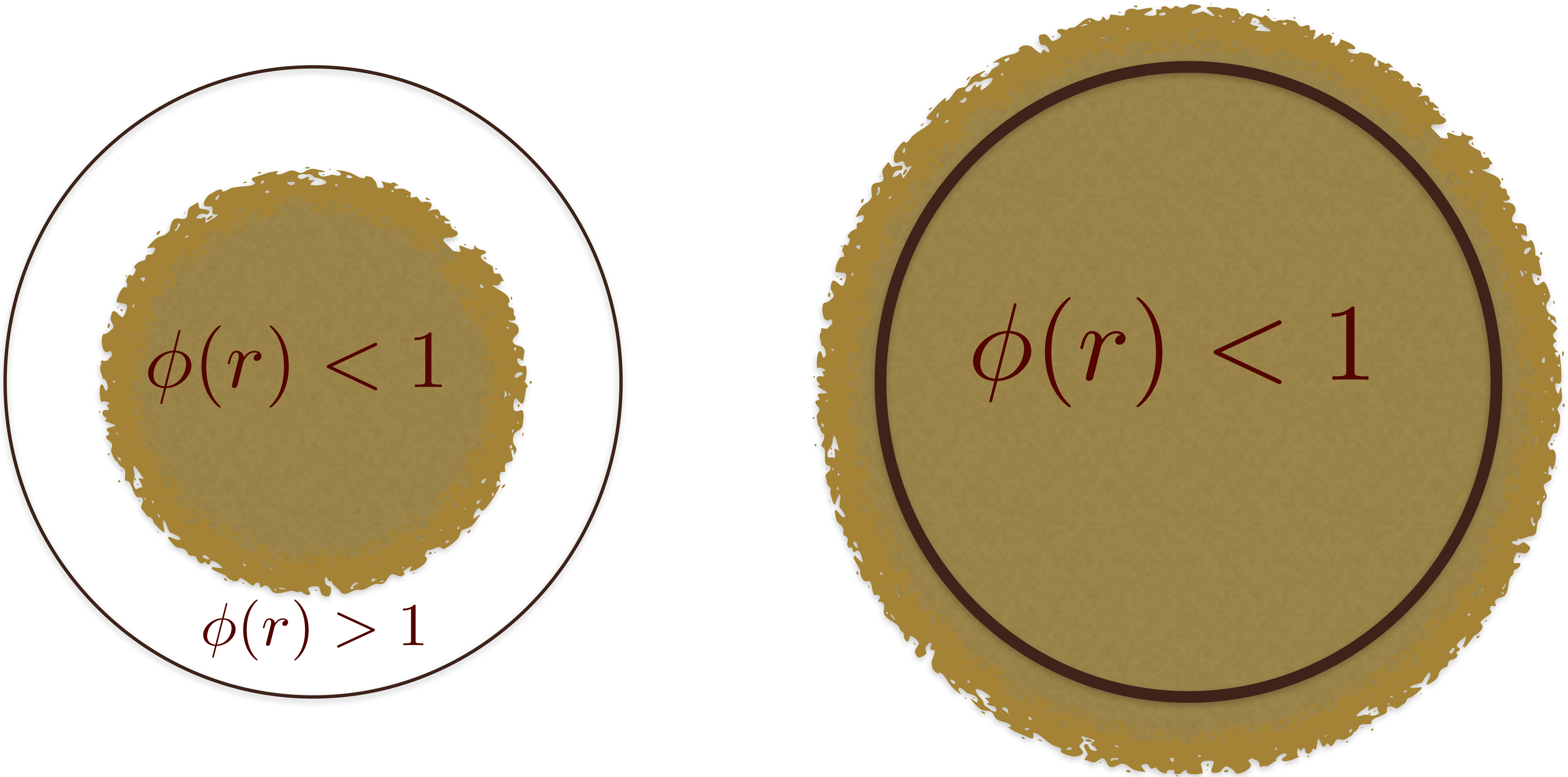
$$r_{sch} < r_{NL} \sim \frac{2}{M_s}$$

Gravitational Force Vanishes $r \to 0$

Biswas, Gerwick, Koivisto, AM (2012), Edholm, Koshelev, AM (2016), Frolov & Zelnikov (2015, 2016)

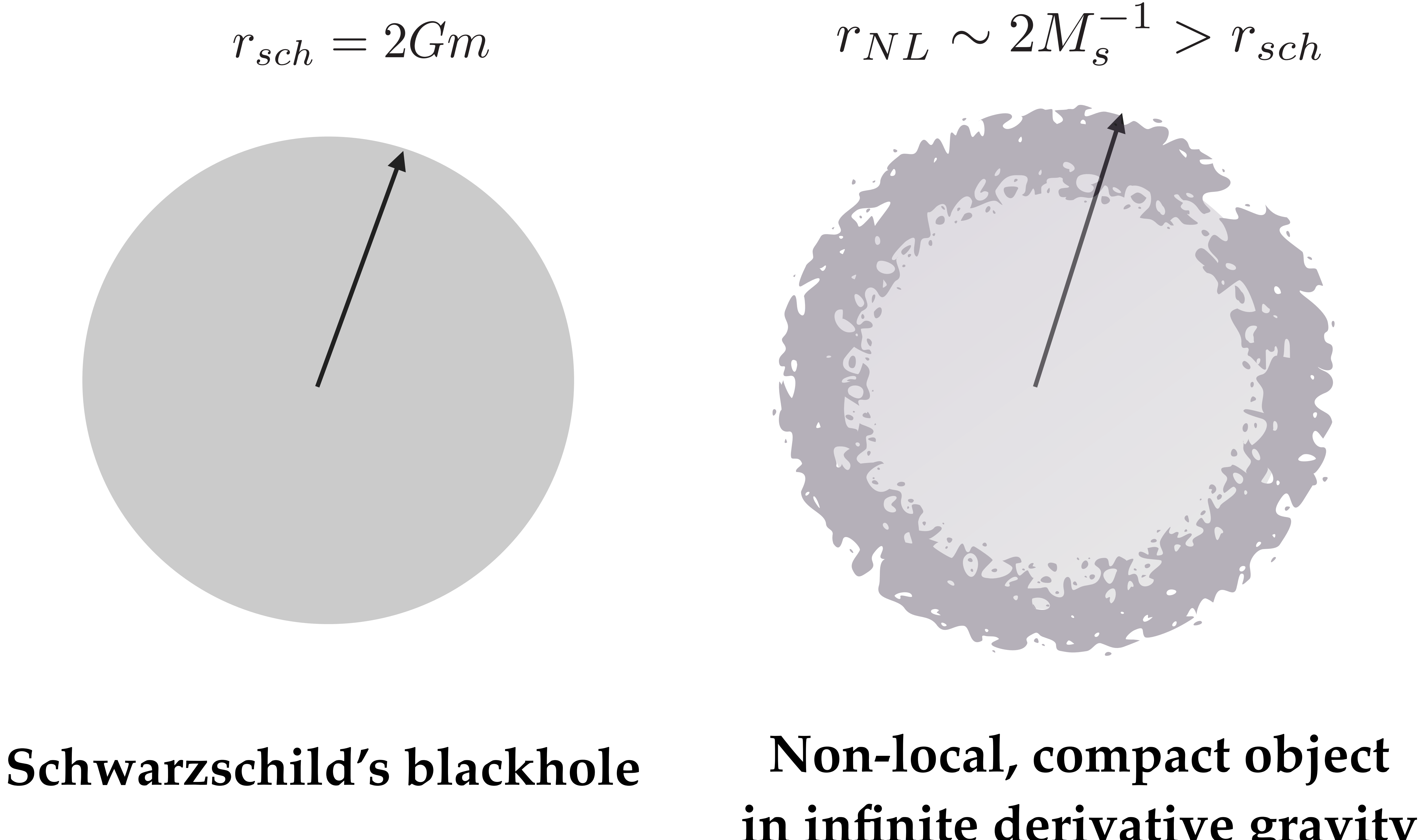
Non-Singular Static Compact Object

$\phi(r) < 1$ $\phi(r) < 1$



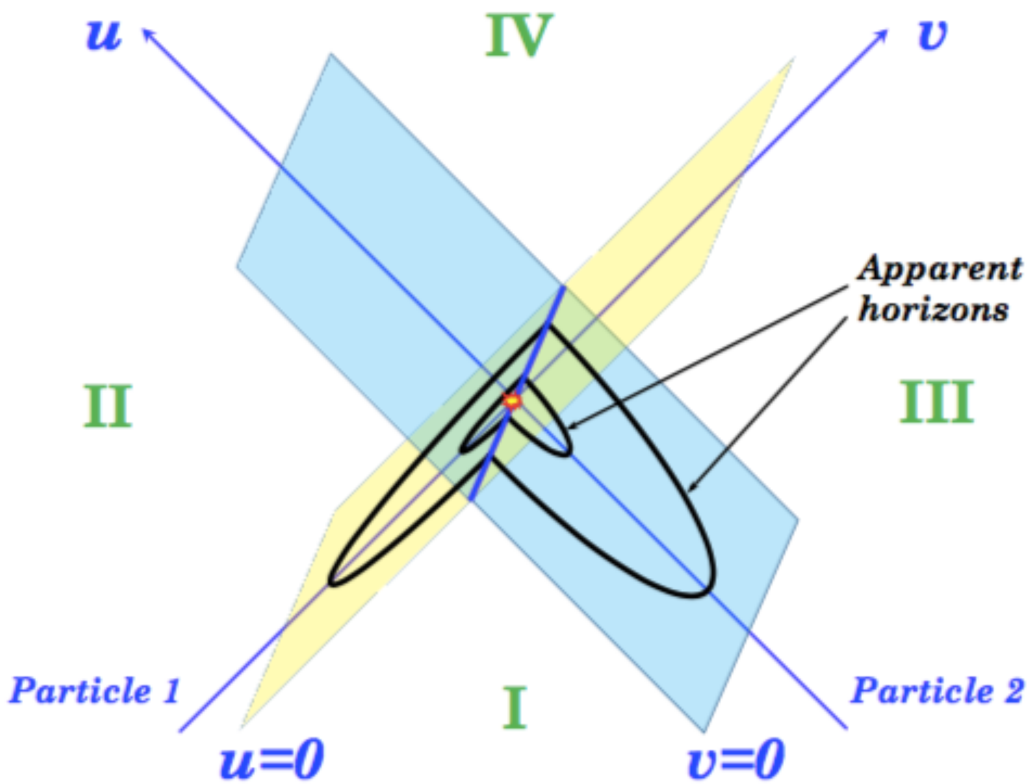
$S_{EH} > S_q$ $S_{EH} < S_q$

Buoninfante, Koshelev, Lambiase, AM arXiv:1802.00399



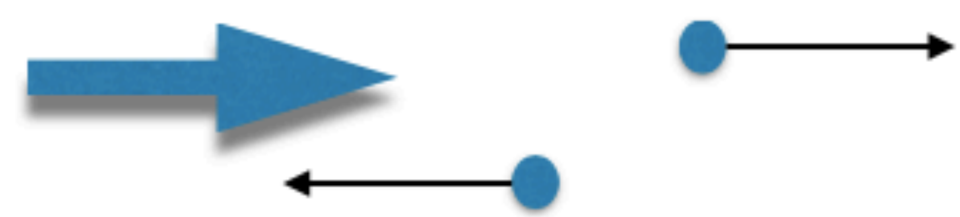
$r_{sch} = 2Gm$
$r_{NL} \sim 2M_s^{-1} > r_{sch}$
Schwarzschild’s blackhole
Non-local, compact object
in infinite derivative gravity

Collapsing Shell in Infinite Derivative Gravity



Einstein's GR

NO formation
of trapped surface
due to weakness in
gravitational interaction

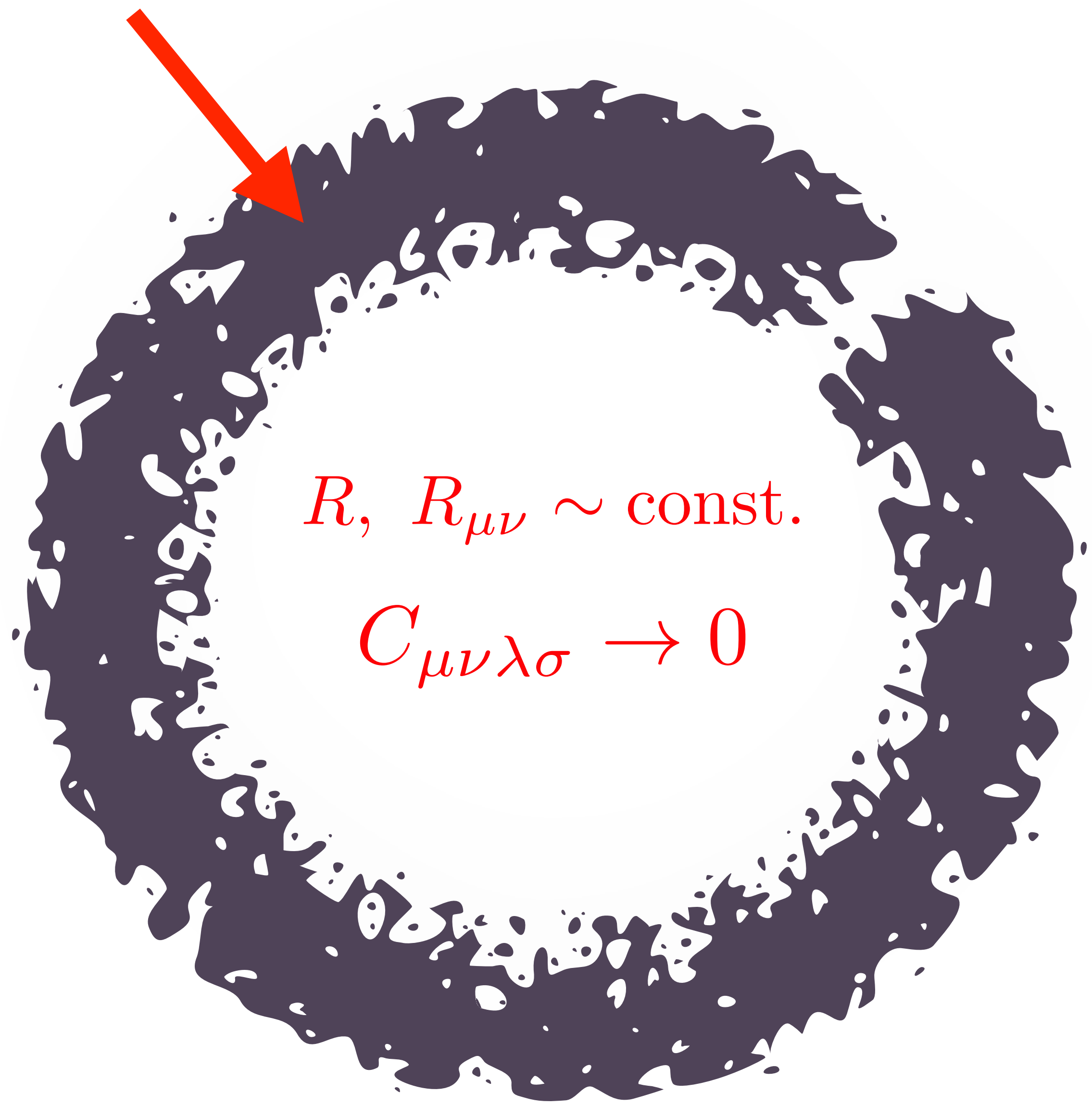


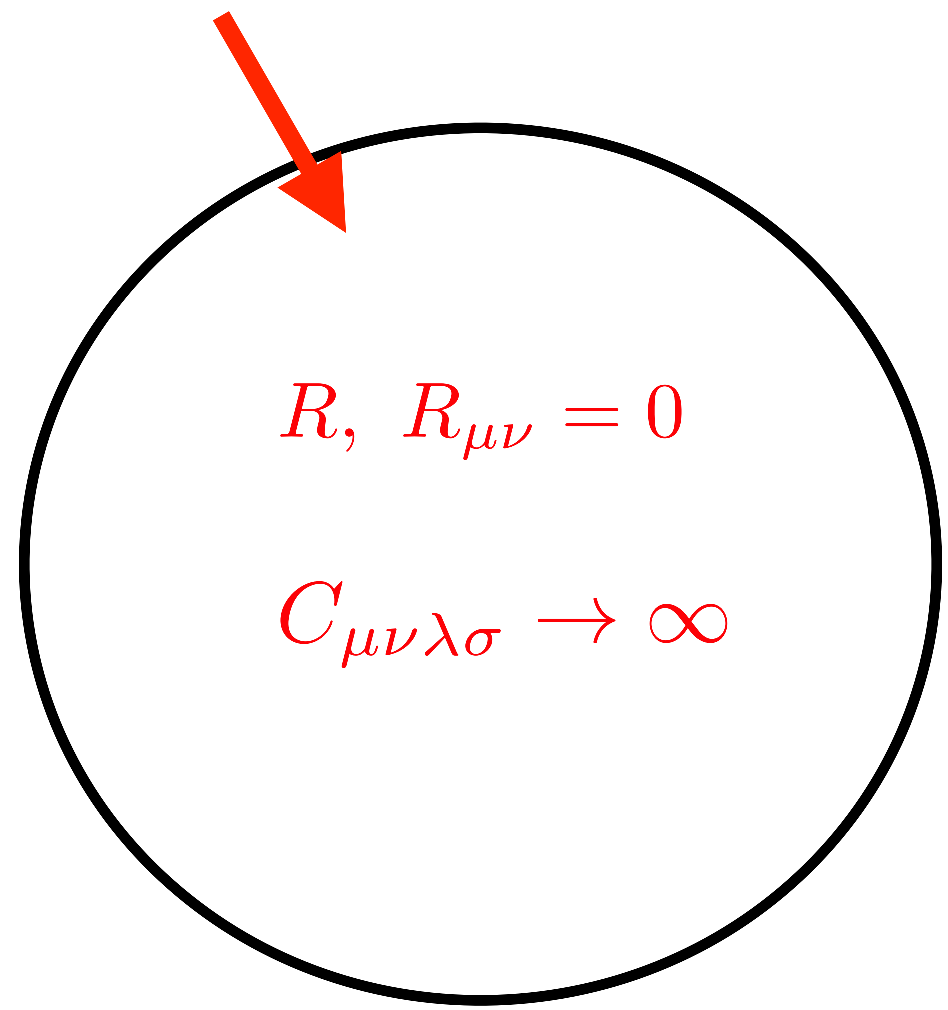
No blackhole

A proposed diagram of scattering of ultra high energy particles/gravitons (2 blobs are made up of **N-particles/gravitons** states) in *Ghost free IDG*; the scattering amplitude will be exponentially suppressed as the centre of mass energy exceeds that of the scale of non-locality, and no trapped surface is ever formed, hence no blackhole formation.

Valeri Frolov & Andrei Zelnikov (2015, 2016), Talaganis, AM, (2016)

Non-linear solutions



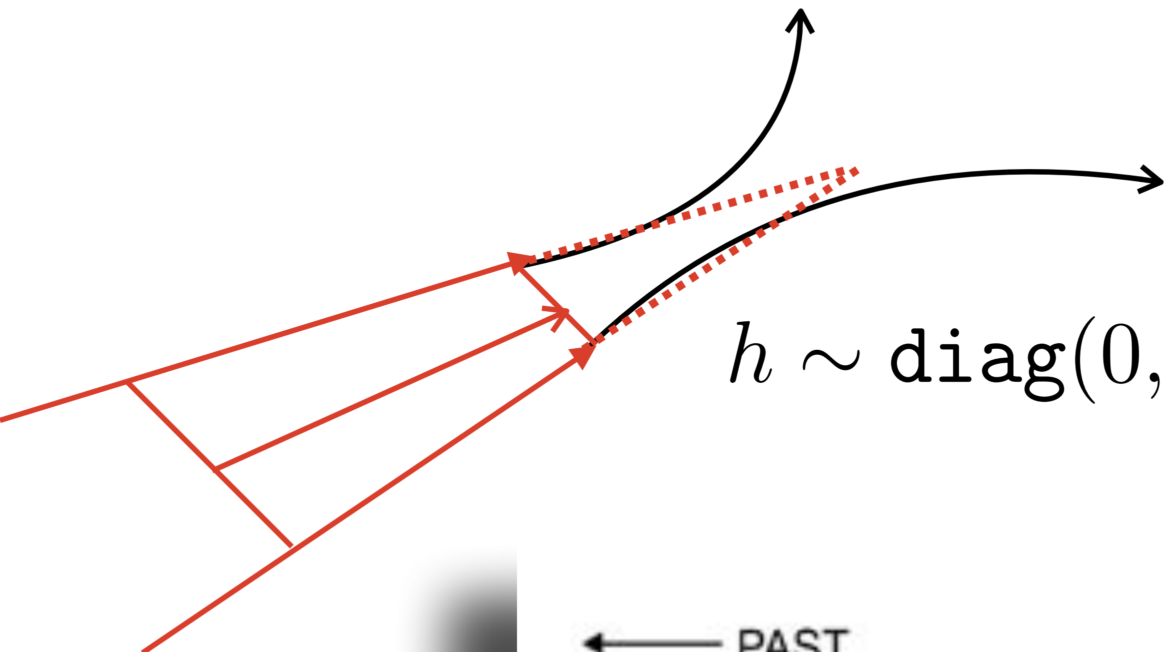


Infinite Derivative Gravity **Einstein's Gravity**

No 1/r -like solution in the static context

Both the systems are very good absorbers

Universe as a Soliton



$$h \sim \texttt{diag}(0, A\sin\lambda t, A\sin\lambda t, A\sin\lambda t) \text{ with } A \ll 1$$

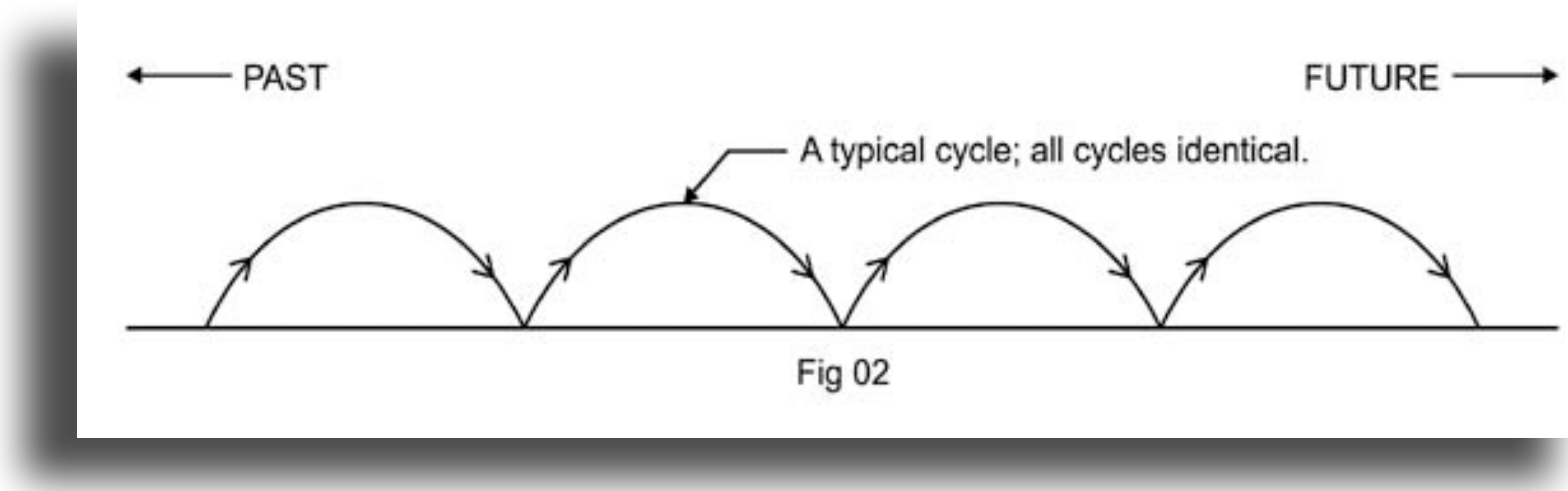


Fig 02

$$a(t) = \cosh\left(\sqrt{\frac{r_1}{2}}t\right)$$

As $t \to 0$, Conformally flat metric

Biswas, Gerwick, Koivisto, Mazumdar, Phys. Rev. Lett. (gr-qc/1110.5249)

Towards non-singular metric solution in infinite derivative gravity

Alexey S. Koshelev[1,2,3,4], João Marto[1,2], Anupam Mazumdar[5,6]
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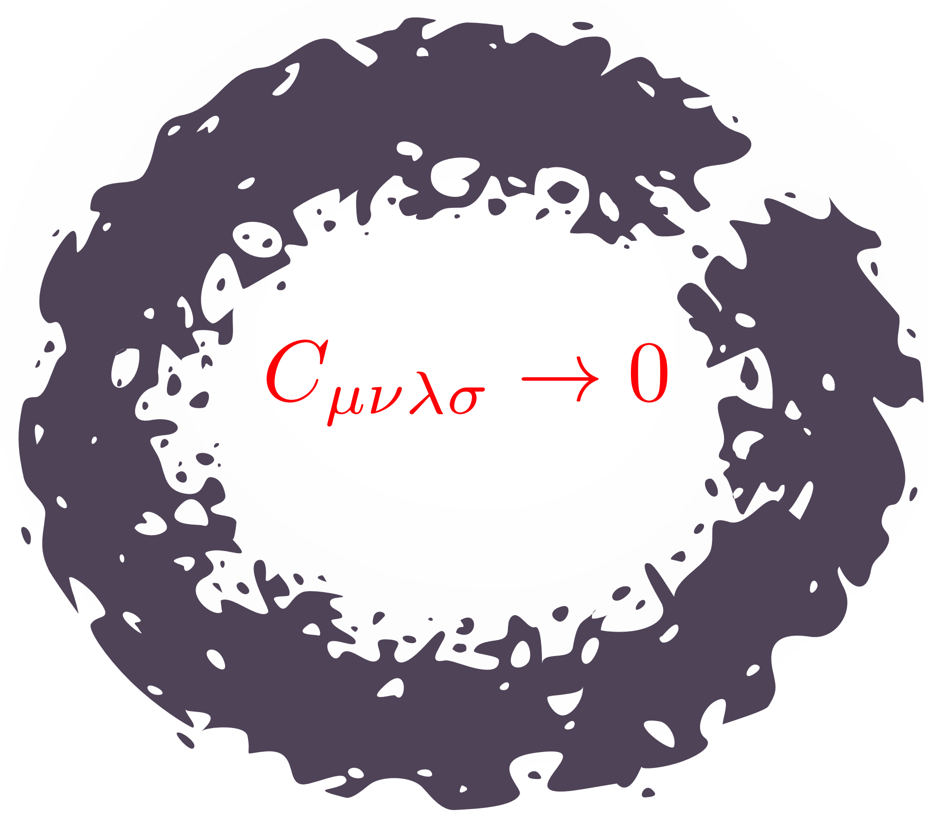
[5] *Van Swinderen Institute, University of Groningen, 9747 AG, Groningen, The Netherlands and*
[6] *Kapteyn Astronomical Institute, University of Groningen, 9700 AV Groningen, The Netherlands.*
(Dated: March 13, 2018)

In this paper, we will argue that in the infinite derivative gravity, within the scale of non-locality, $1/r$-type singular solution is not *permissible*. Therefore, Schwarzschild-like vacuum solution which is a prediction in Einstein-Hilbert gravity will *not* persist in the infinite derivative gravity.



$$C_{\mu\nu\lambda\sigma} \neq 0$$

Towards resolution of anisotropic cosmological singularity in infinite derivative gravity

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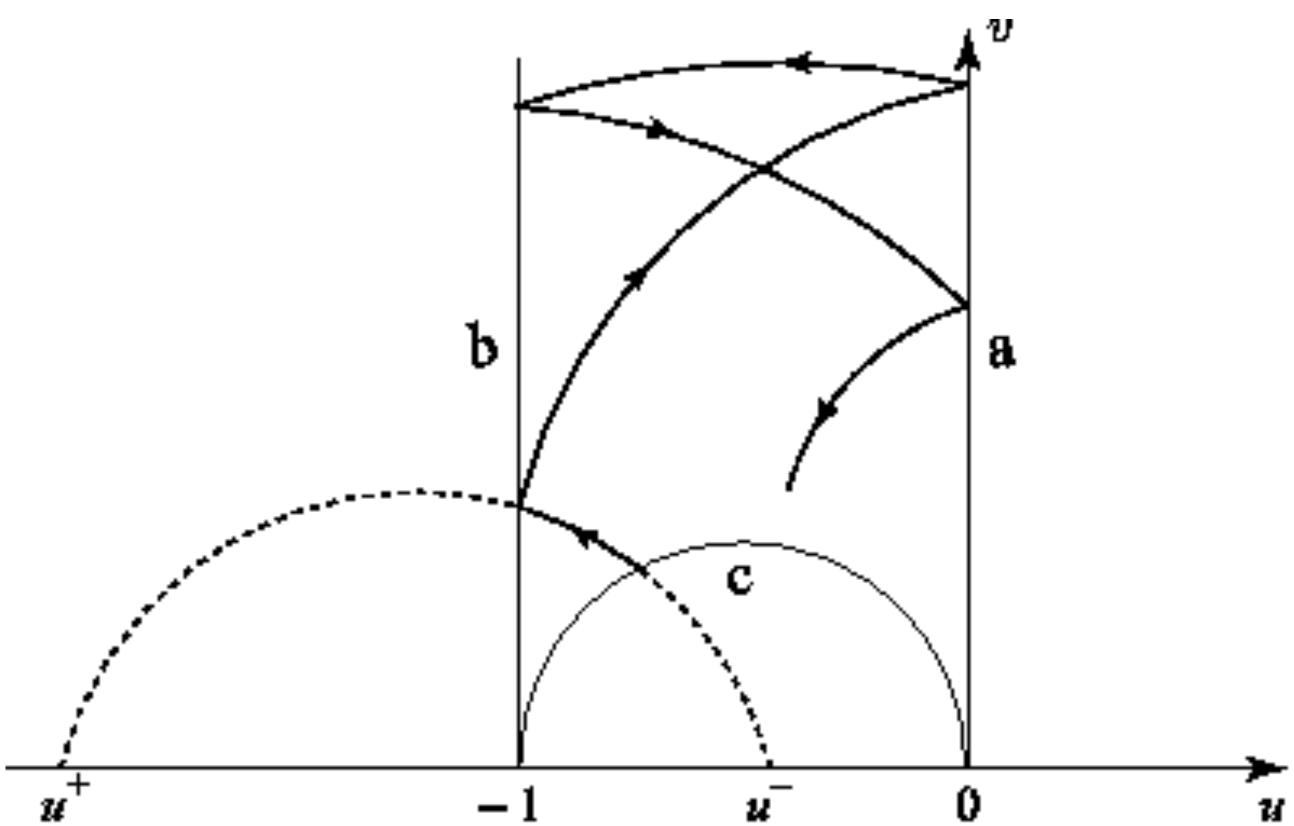
[5] *Van Swinderen Institute, University of Groningen, 9747 AG, Groningen, The Netherlands and*
[6] *Kapteyn Astronomical Institute, University of Groningen, 9700 AV Groningen, The Netherlands.*
(Dated: March 21, 2018)

arXiv:1803.07072 [gr-qc]

In this paper, we will show that the equations of motion of the quadratic in curvature, *ghost free*, infinite derivative theory of gravity will not *permit* an anisotropic collapse of a homogeneous Universe for a Kasner-type vacuum solution.



GR

Infinite derivative gravity
its not a solution

Quantum Aspects

arXiv:1412.3467v1 [hep-th] 10 Dec 2014

Towards understanding the ultraviolet behavior of quantum loops in infinite-derivative theories of gravity

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[c] *Département de Physique Théorique, Université de Genéve, 24, Quai E Ansermet, 1211 Genéve 4, Switzerland*

Abstract

In this paper we will consider quantum aspects of a non-local, infinite derivative scalar field theory - a *toy model* depiction of a covariant infinite derivative, non-local extension of Einstein's general relativity which has previously been shown to be free from ghosts around the Minkowski background. The graviton propagator in this theory gets an exponential suppression making it *asymptotically free*, thus providing strong prospects of resolving various classical and quantum divergences. In particular, we will find that at 1-loop, the 2-point function is still divergent, but once this amplitude is renormalized by adding appropriate counter terms, the ultraviolet (UV) behavior of all other 1-loop diagrams as well as the 2-loop, 2-point function remains well under control. We will go on to discuss how one may be able to generalize our computations and arguments to arbitrary loops.

arXiv:1603.03440v1 [hep-th] 10 Mar 2016

High-Energy Scatterings in Infinite-Derivative Field Theory and Ghost-Free Gravity

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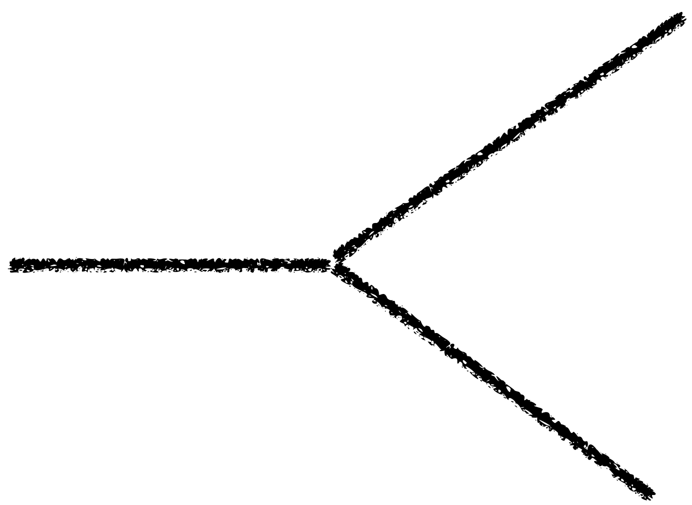
Abstract

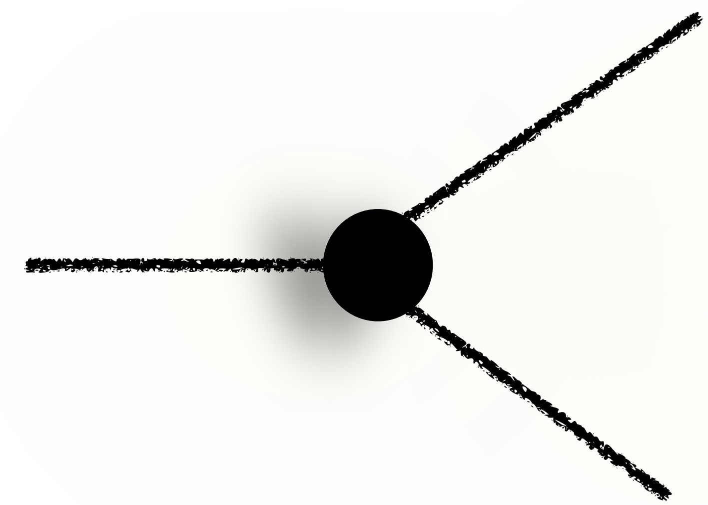
In this paper, we will consider scattering diagrams in the context of infinite-derivative theories. First, we examine a finite-order higher-derivative scalar field theory and find that we cannot eliminate the external momentum divergences of scattering diagrams in the regime of large external momenta. Then, we employ an infinite-derivative scalar toy model and obtain that the external momentum dependence of scattering diagrams is convergent as the external momenta become very large. In order to eliminate the external momentum divergences, one has to dress the bare vertices of the scattering diagrams by considering renormalised propagator and vertex loop corrections to the bare vertices. Finally, we investigate scattering diagrams in the context of a scalar toy model which is inspired by a *ghost-free* and *singularity-free* infinite-derivative theory of gravity, where we conclude that infinite derivatives can eliminate the external momentum divergences of scattering diagrams and make the scattering diagrams convergent in the ultraviolet.

Ultra - high energy scatterings do not form Blackhole

Local vs. Non-local Interaction



$$P^2 < M^2$$



$$P^2 \geq M^2$$

Scale of non-locality: $t,\ r \sim M^{-1}$

Hint towards Super-renormalizable Gravity

$$S = \int d^4x\sqrt{-g}\left[\frac{R}{16\pi G} + R\mathcal{F}_1\left(\frac{\Box}{M^2}\right)R + R_{\mu\nu}\mathcal{F}_2\left(\frac{\Box}{M^2}\right)R^{\mu\nu} + R_{\mu\nu\lambda\sigma}\mathcal{F}_3\left(\frac{\Box}{M^2}\right)R^{\mu\nu\lambda\sigma}\right]$$

- **Superficial degree of divergence goes as**

$$E = V - I. \ \text{Use Topological relation}: \ L = 1 + I - V$$

$$E = 1 - L \qquad\qquad E < 0, \ \text{for} \ L > 1$$

- **At 1-loop, the theory requires <u>Local Counter</u> term**
- **At 2-loops, the theory does not give rise to additional divergences, the UV behavior becomes finite, at large external momentum, where dressed propagators gives rise to more suppression than the vertex factors**

Scalar Graviton

Around Minkowski space the e.o.m are invariant under:

$$\text{GR e.o.m}: \quad g_{\mu\nu} \to \Omega\, g_{\mu\nu}$$

$$h_{\mu\nu} \to (1+\epsilon) h_{\mu\nu} + \epsilon \eta_{\mu\nu}$$

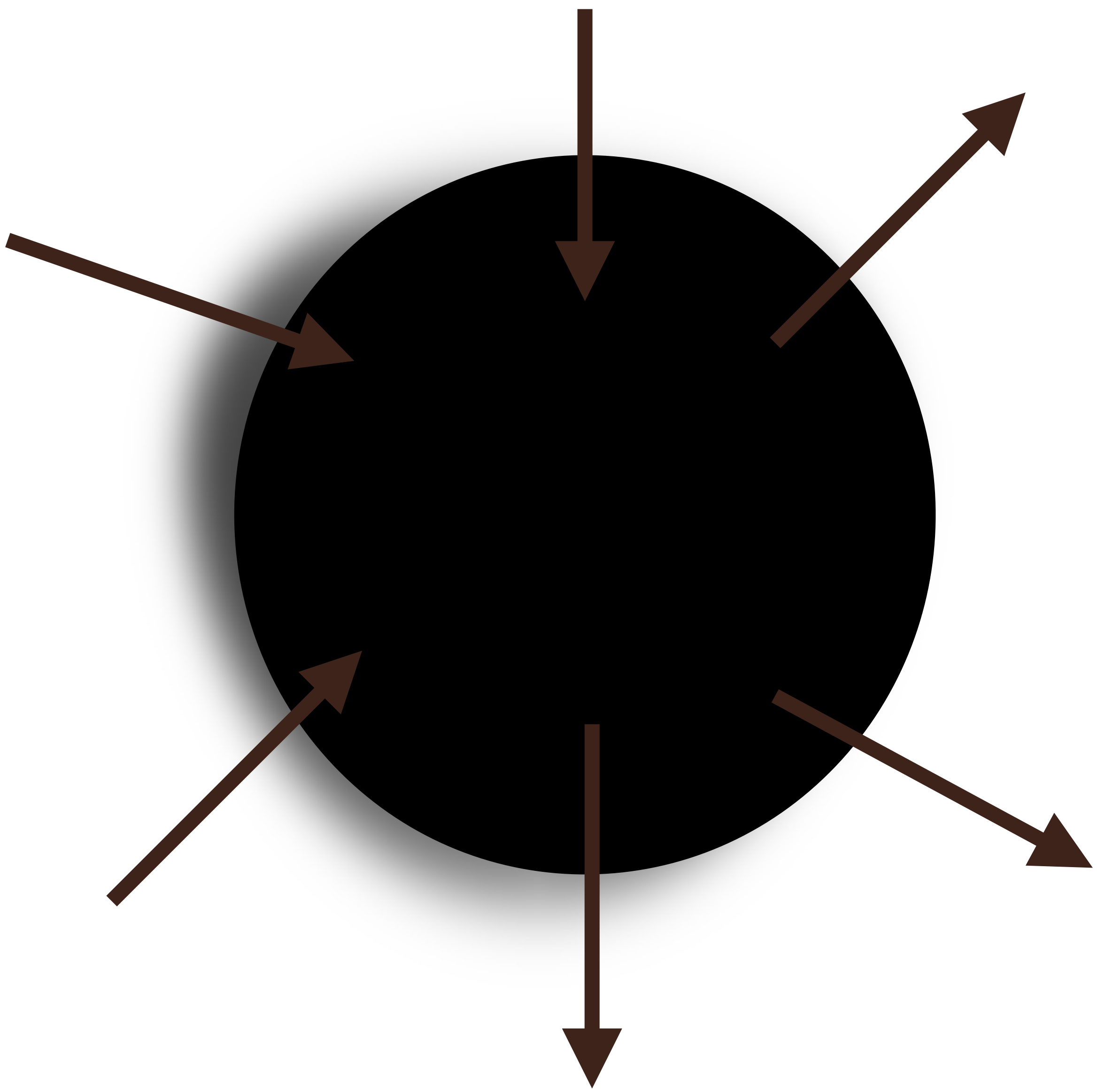
$$\phi \to (1+\epsilon)\phi + \epsilon$$

$$S_{free} = \frac{1}{2}\int d^4x (\phi \Box a(\Box)\phi) \qquad a(\Box) = e^{-\Box/M^2}$$

$$S_{int} = \frac{1}{M_p}\int d^4x \left(\frac{1}{4}\phi\partial_\mu\phi\partial^\mu\phi + \frac{1}{4}\phi\Box\phi a(\Box)\phi - \frac{1}{4}\phi\partial_\mu\phi a(\Box)\partial^\mu\phi\right)$$

$$\Pi(k^2) = -\frac{i}{k^2 e^{\bar{k}^2}}$$

Scattering Amplitude



Quantum Object

Inside the Non-Local region
we need to dress Propagator
& Vertices

$$\mathcal{M} \sim e^{N E_{\rm cm}^2 / M_s^2}$$

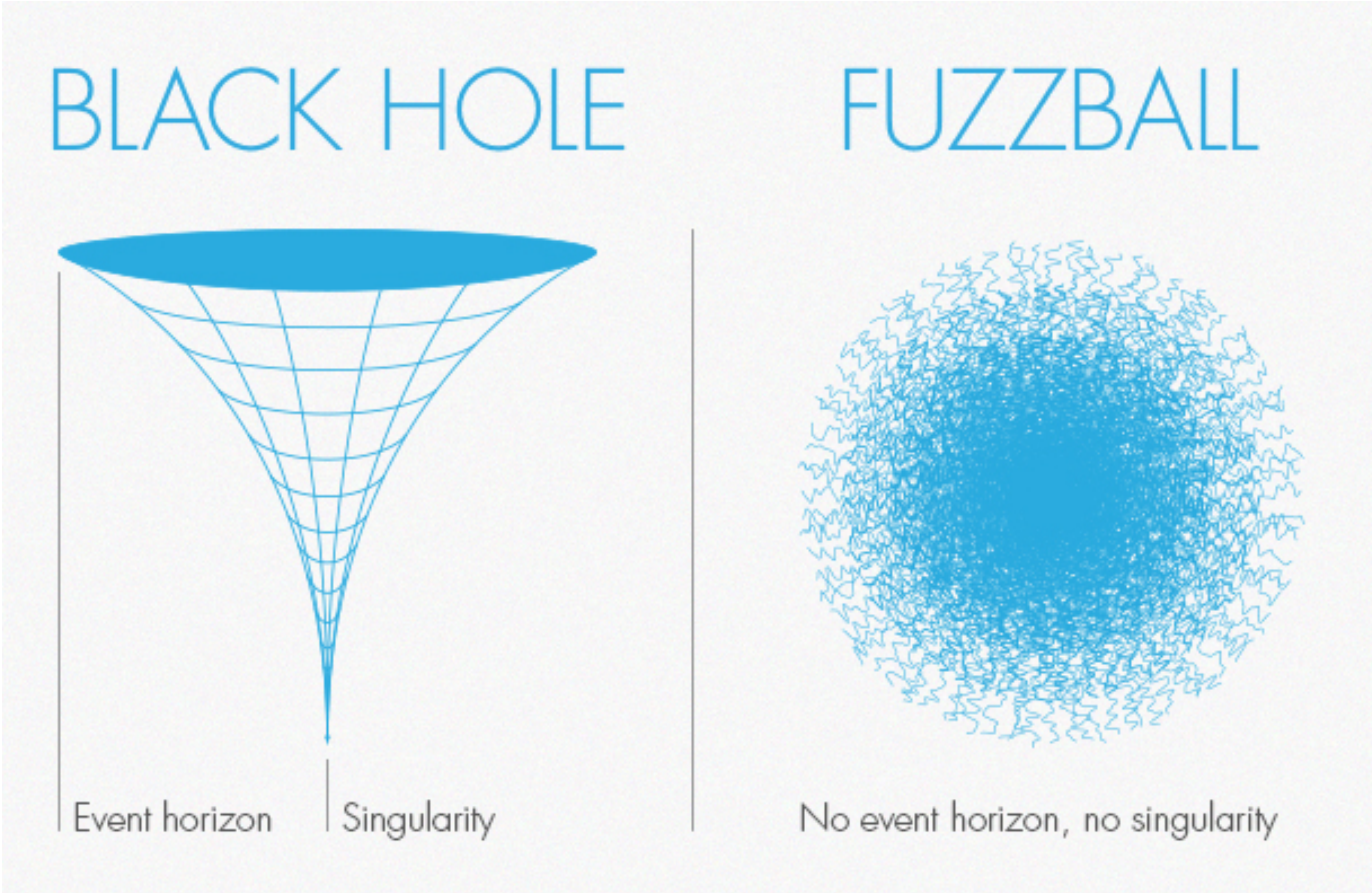
$$M_{eff} \sim M_s/\sqrt{N}$$

Probing the Non-Local region

Buoninfante, Lambiase, AM, 1805.03559

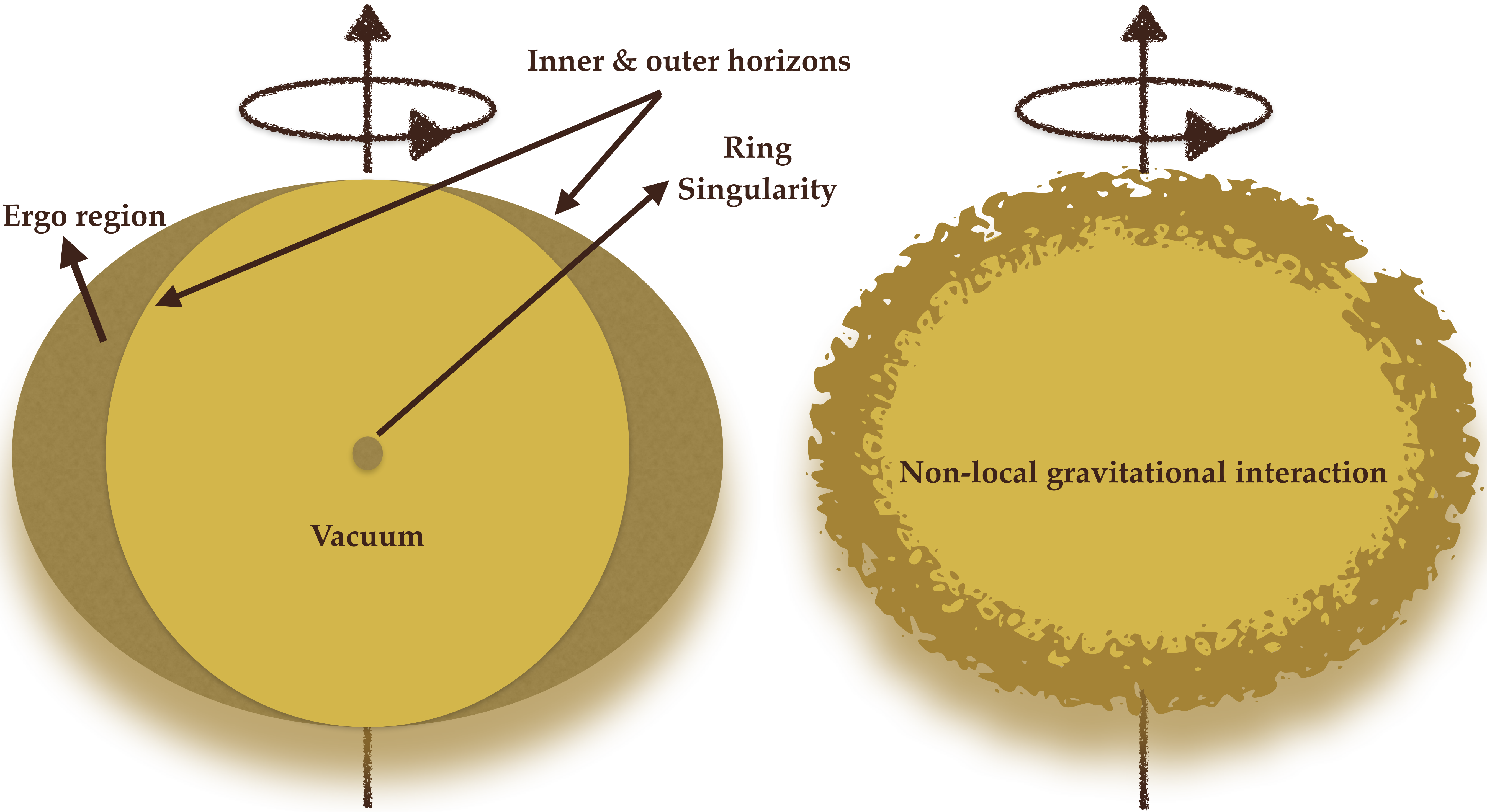
Conclusions

- We have constructed a Infinite Derivative Theory of Gravity (Ghost free & Singularity free).
- Studying singularity theorems, Information-loss paradox, Non-Singular Bouncing Cosmology , ..., many interesting problems have been studied in this framework.
- Event Horizon & BBO will play significant role in testing Event-Horizon hypothesis (Future for Gravitational Astronomy)
- Quantum computations also show that Infinite Derivative Gravity can ameliorate UV behaviour. Ultra-High energy graviton scatterings do not blow up.
- Quantum effects can be seen on Macroscopic scale.



In String Theory there are attempts to resolve the Event-Horizon

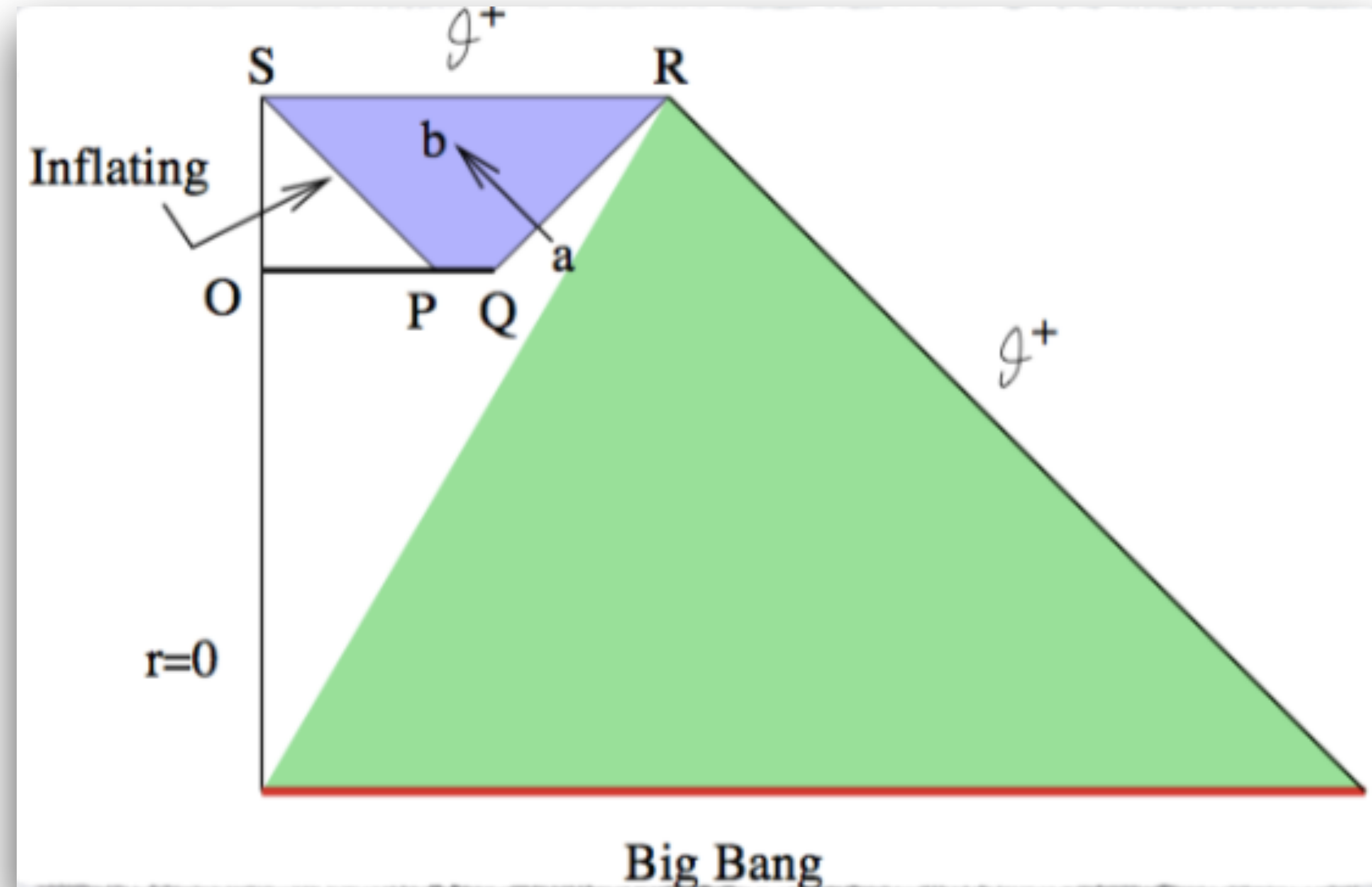
Samir Mathur, and many others. **For a review: hep-th/0502050**



Kerr-metric in Einstein's gravity

Rotating metric in Ghost free & Singularity free Infinite derivative gravity

Inflation is Fine-Tuned in Einstein's GR



- Minkowski spacetime for example is a "Normal region"
- Inside the Schwarzschild radius the region is "Trapped"
- Inflationary Hubble patch is "Anti-trapped"
- GR prevents: Geodesics traversing from "normal" or "trapped" region to "anti-trapped" region as long as "Weak Energy Condition" is preserved