Domain Walls As Probes of Gravity

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Summary

- Gravitational effect of a domain wall in large distance modified gravity seems puzzling
- Solution can be exactly found in DGP model
- Solution is dramatically different than in 4D GR
- Domain walls can be short distance probe of large distance modified gravity

DGP Model

Dvali, Gabadadze, Porrati (2000)

- Infinite-volume extra dimension. Brane-induced gravity

$$S_{\rm DGP} = \frac{M_*^3}{2}\int d^4x \int_{-\infty}^{+\infty} dy \sqrt{G} R_5 \;+\; \frac{M_{\rm Pl}^2}{2}\int d^4x \sqrt{g}\, R_4$$

$\uparrow$ 5D Piece (first term) $\qquad$ $\uparrow$ 4D Piece (second term)

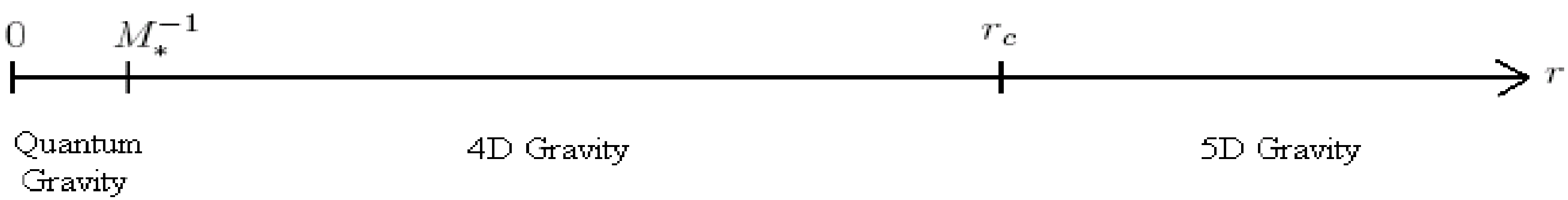
- Gibbons-Hawking surface term containing extrinsic curvature *K*
- Model contains one parameter: $r_c \equiv \dfrac{M_{\rm Pl}^2}{2M_*^3}$
- Large distance modification of gravity with $r_c \sim H_0^{-1} \sim 10^{28}$ cm.

Facts about DGP

- Gravition propagates extra degrees of freedom But **no vDVZ** due to nonlinear interactions!
- Metastable 4D graviton with width ~ m_c = $1/r_c$

$$G^{(4)}_{\mu\nu} + m_c(K_{\mu\nu} - g_{\mu\nu}K) = 8\pi G_N T_{\mu\nu} ,$$

- $r \ll r_c$: 4D Newtonian gravity + small correction



- $r \gg r_c$: 5D gravity

Domain Wall in 4D

$$T_{\mu\nu} = \sigma\,\delta(z)\ \mathrm{diag}(1,-1,-1,0)\ ,$$

Vilenkin (`83), Ipser, Sikivie (`84)

$$ds^2 = (1 - H|z|)^2\left(-dt^2 + e^{2Ht}(dx^2+dy^2)\right) + dz^2\,,$$

- Observer living on the domain was sees de Sitter expansion with Hubble rate $H = 2\pi G_N \sigma.$
- Freely falling observer outside is repelled from the wall
- **The metric is <u>not</u> static; no time-like Killing vector.**

Codimension-2 Object in 5D

- This is similar to a cosmic string in 4D, … …

$$ds^2 = (1+h)(dx_5^2 + dz^2) - dt^2 + dx^2 + dy^2 \ ,$$

With $h = -\frac{1}{2\pi}\frac{\sigma}{M_*^3}\log\left[(z^2+x_5^2)\mu^2\right] \ ,$

- This can be written in a locally flat form

$$ds^2 = d\rho^2 + \rho^2 d\theta^2 - dt^2 + dx^2 + dy^2 \ ,$$

But $0 \leq \theta < 2\pi - \delta$ with $\delta = \frac{\sigma}{M_*^3} \, .$

- **Spacetime is <u>static</u>**, conically flat with a deficit angle.
- Minkowski to an observer living at $x_5 = 0$

Puzzle with DGP Domain Wall

- At short distances: Nonstatic solution!
- At large distances: Static solution!
- How can one smoothly interpolate between static and nonstatic patches????
- What is the fate of a domain wall in DGP????

The Solution

- Exact solution was obtained (Here I mention only about the case with positive *K*, i. e., conventional branch).
- The solutions fall into two different classes depending on the relative values of σ and $2\pi M_*^3$
- 1. **Subcritical DW**, $\sigma < 2\pi M_*^3$: Domain wall does **not** inflate at all! 5D codimension-2 behavior seen at any distance scale! DW tension is completely screened by the curvature term!! 4D observer does not see gravitational effect whatsoever.
- 2. **Supercritical DW**, $\sigma > 2\pi M_*^3$: Deficit angle has already been saturated to *2*π*.* The dimension transverse to the domain wall is compactified to the thickness of the DW itself. DW starts to inflate with rate $H = 2\pi G_N(\sigma - 2\pi M_*^3)$.

Short Distance Probe of DGP

- In DGP subcritical domain walls do <u>not</u> gravitate at all. They only way to see them is nongravitationally.
- Therefore, they are potential short-distance probe of gravity!
- Schwarzschild type sources also produce short distance corrections on top of Einsteinian GR. But it is extremely tiny. They are potentially detectable in Lunar Ranging Experiments.

Generic IR Modified Gravity

- DGP is just an example of more generic set of theories, which are ghost-free, unitary and may have sensible nonlinear completion.

$$\mathcal{E}^{\alpha\beta}_{\mu\nu} h_{\alpha\beta} - m^2(\Box)\left(h_{\mu\nu} - \eta_{\mu\nu} h\right) = -16\pi G_N T_{\mu\nu} , \quad m^2(\Box) = r_c^{-2(1-\alpha)} \Box^\alpha ,$$

$$\mathcal{E}^{\alpha\beta}_{\mu\nu} h_{\alpha\beta} = \Box h_{\mu\nu} - \Box \eta_{\mu\nu} h - \partial^\alpha \partial_\mu h_{\alpha\nu} - \partial^\alpha \partial_\nu h_{\alpha\mu} + \eta_{\mu\nu} \partial^\alpha \partial^\beta h_{\alpha\beta} + \partial_\mu \partial_\nu h , \quad 0 \le \alpha < 1$$

- Properties of domain walls are dramatically different in **any** large distance modified gravity than in ordinary GR (α = *0*)

- Generic treatment is based only on perturbative analysis, because DGP (α = *1/2*) is the only such theory for which the full nonlinear theory is known.

- DW can easily tell apart ordinary GR from modified gravity.