Formation of conserved charges at the de Sitter space

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Plan

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1. Conserved charges and nubmers in Kaluza-Klein-like theories

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2. Apple-like extra space models with U(1)-symmetry

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6. Conclusion

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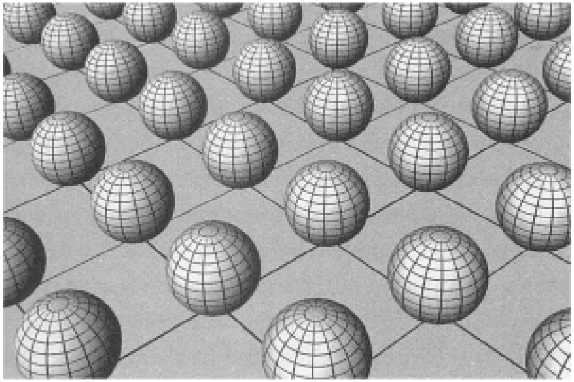

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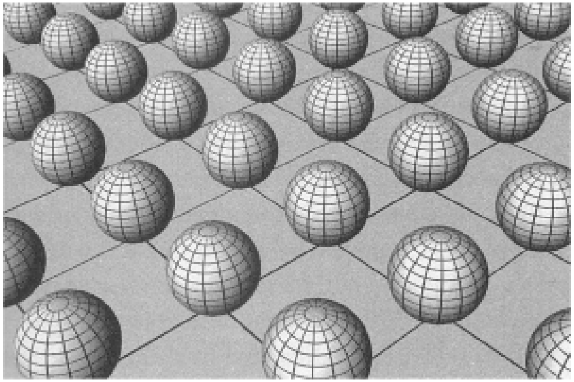
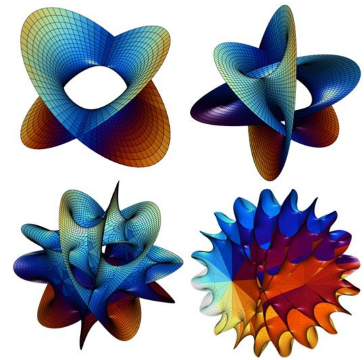


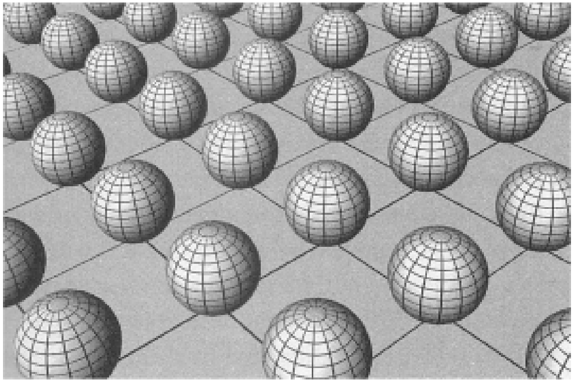


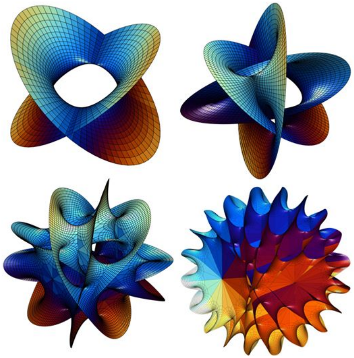
Spatial isometries of extra space

$$ds^2 = g \quad (x)dx \;\; dx \;\; + k_{m\,n}(y)dy^m dy^n \, ; \tag{1}$$

$$r_{a \;\; b} \quad r_{b \;\; a} = 0 : \tag{2}$$

Conserved charges and nubmers in Kaluza-Klein-like theories





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Neother's current and charge (number)

$$J^a = \frac{@L_{\mathrm{m}}(\;\;)}{@(@_a \;\;)} \; {}^{b}@_b \qquad {}^{a}L_{\mathrm{m}}(\;\;) ; \tag{3}$$

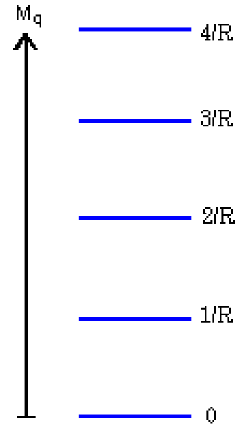
$$Q = \int J^0 \, \mathrm{p}\overline{jgj} \, \mathrm{p}\overline{jkj} \, d^3x \, d^dy = \mathrm{const} : \tag{4}$$

Transition to effective 4-dim theory

$$\phi(x;y) = \sum_{q=0}^{\infty} \phi_q(x) Y_q(y); \qquad \Box_d Y_q(y) = M_q^2 Y_q(y); \quad M_q \sim q/R; \quad q \in \mathbb{N}. \tag{5}$$

$$S \simeq \int d^4x d^d y \sqrt{|g|}\sqrt{|k|}\,\frac{1}{2}\Big[\partial_A \phi\, \partial^A \phi - m^2 \phi^2\Big] = \tag{6}$$

$$= \int d^4x \sqrt{|g|} \sum_{q=0}^{\infty} \frac{1}{2}\left((\partial \phi_q)^2 - (M_q^2 + m^2)\phi_q^2 \right).$$



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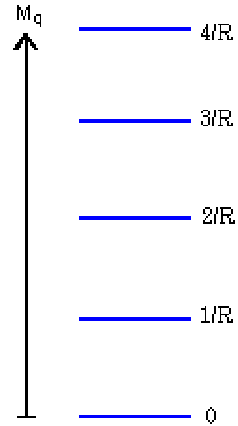

Effective 4-dim Neother's current and charge (number)

$$j \;\; = \frac{\partial L_4}{\partial(\partial \;\; {}^n)}(t)^n_m \;\; {}^m\,; \qquad (t_i)^n_m = \int Y_n \;\; {}^a\partial_a Y_m \sqrt{|k|}\,d^dy \qquad (7)$$

$$Q = \int j^0 \sqrt{|g|}\,d^3x = \text{const}\,. \qquad (8)$$

Apple-like extra space models with U(1)-symmetry

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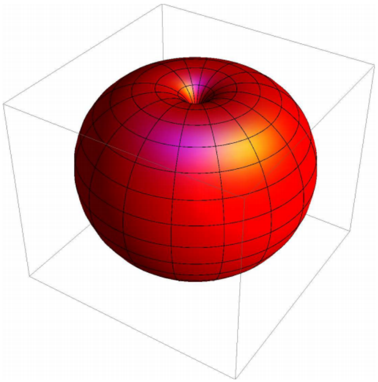

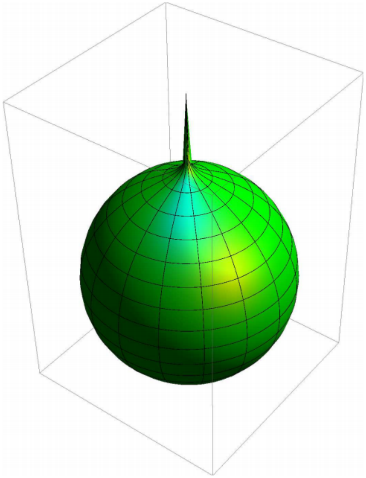

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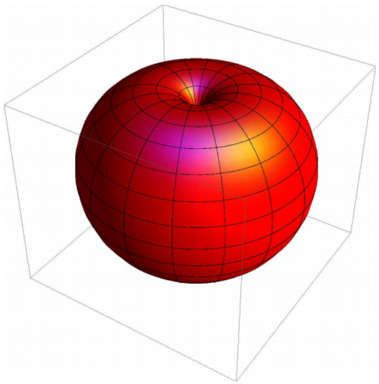

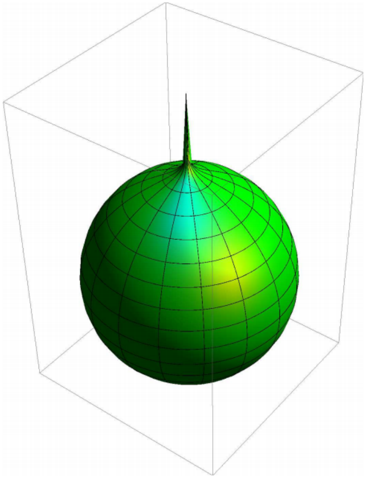

- Compact 2-dim apple-like manifold have U(1)–symmetry associated with polar rotational isometry.

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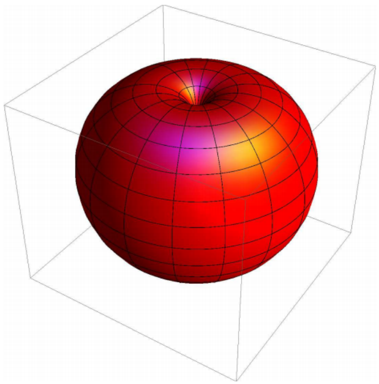
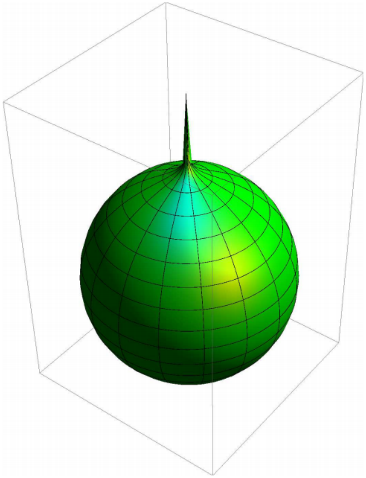
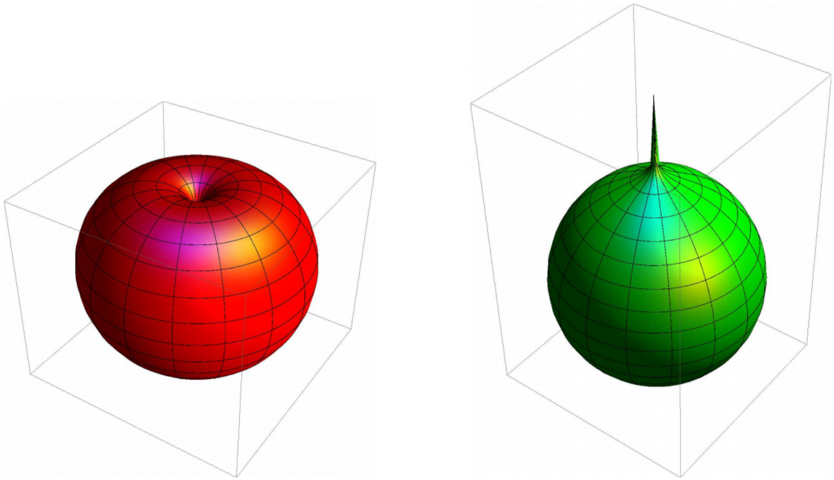




- Compact 2-dim apple-like manifold have U(1)–symmetry associated with polar rotational isometry.
- Unlike the one-dimensional compact extra space, a 2-dim manifold has a non-zero Ricci scalar and can be perturbed.

Apple-like extra space models with U(1)-symmetry



- Compact 2-dim apple-like manifold have U(1)–symmetry associated with polar rotational isometry.
- Unlike the one-dimensional compact extra space, a 2-dim manifold has a non-zero Ricci scalar and can be perturbed.
- Considered in the framework of warped extra dimensions. It is developed in different works: arxiv:0706.0676, arxiv:1511.01869, arxiv:hep-th/0302067, etc.

Space-time setting

$$S = \frac{m_D^{D-2}}{2}\int d^D X \sqrt{|G|}\,[f(R) + L_{\rm m}]\,; \quad f(R) = aR^2 + R + c. \tag{9}$$

$$ds^2 = G_{MN}dX^M dX^N = g_{\mu\nu}(x)dx^\mu dx^\nu + k_{mn}(x,y)dy^m dy^n\,; \tag{10}$$

$$g_{\mu\nu} = diag(1, -e^{2Ht}, -e^{2Ht}, -e^{2Ht})\,; \tag{11}$$

$$k_{mn}(x,y) \xrightarrow{t\to\infty} k^{\rm st}_{mn}(y) \tag{12}$$

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Extra space configuration

$$k_{mn}(x,y) = r(\ ,\ ,t)^2(d\ ^2 + \sin\ \ d\ ^2) \xrightarrow{t\to\infty} \tag{13}$$

$$\xrightarrow{t\to\infty} \quad k^{\rm st}_{mn}(y) = r_0(\ )^2(d\ ^2 + \sin\ \ d\ ^2)\,; \tag{14}$$

$$r(\ ,\ ,t) = r_0(\ )\,e^{\ \ (\ ,\ ,t)} = r_0\,e^{\ (\ )+\ \ (\ ,\ ,t)} \tag{15}$$

Inflationary extra space relaxation in the presence of (scalar) field

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Matter content

$$L_{\mathrm{m}} = \frac{1}{2} G^{MN} \partial_M \phi \, \partial_N \phi - V(\phi); \quad V(\phi) = \frac{1}{2} m^2 \phi^2 . \tag{16}$$

$$T_{MN} = -2 \frac{\partial L_{\mathrm{m}}}{\partial G^{MN}} + G_{MN} L_{\mathrm{m}} . \tag{17}$$

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Dinamical equations

$$R_{MN} f' \quad \frac{1}{2} f(R) k^{\mathrm{st}}_{MN} + \nabla_M \nabla_N f' \quad k^{\mathrm{st}}_{MN} \quad f' = \frac{1}{m_D^{D \ \ 2}} T_{MN} . \tag{18}$$

$$_d \ = \ V'(\ ); \tag{19}$$

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- To reduce the order of the PDEs system, we take the standard equation for the connection of Ricci scalar with the metric as the third equation. We also compute the trace of Einstein's equations to simplify. As a result we obtain a second order system of 3 equations for 3 unknown functions: $(t; \ ; \ )$, $R(t; \ ; \ )$, $(t; \ ; \ )$.

Stationary symmetrical equations for metric $k^{st}_{mn}(y)$: $_{st}(\ )$, $R_{st}(\ )$, $_{st}(\ )$

$$e^2 \ r^2 \ 3 \ aR^2 + c + R \quad 6H^2 \ 2aR + 1 \quad 3 \ m^2 \ ^2 \ + 4 \ 2aR + 1 \quad \cot \ +$$

$$+4 \ 2aR + 1 \quad 8a \ \cot \ R \ + R \quad + 4 \ 2aR + 1 \ + \ ^2 = 0\,; \tag{20}$$

$$e^2 \ r^2 \ 12H^2 \quad R \quad 2 \quad \cot \ + \quad 1 \ = 0\,; \tag{21}$$

$$e^2 \ m^2 r^2 \quad \cot \ + \quad = 0\,; \tag{22}$$

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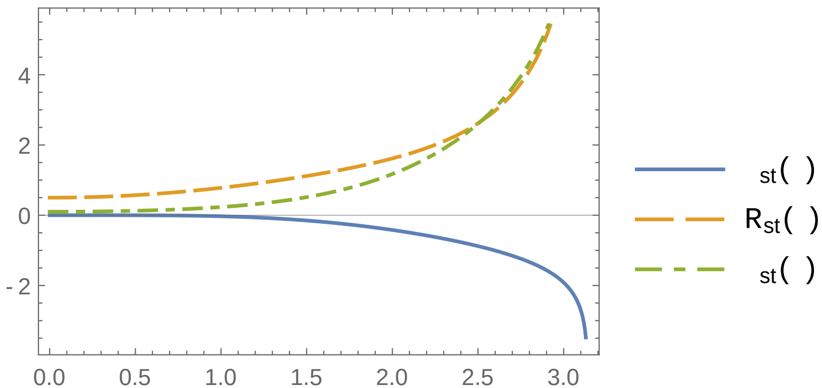

Inflationary extra space relaxation in the presence of (scalar) field

Small pertribations approximation

$$
\begin{aligned}
(t;\ ;\ ) &= {}_{\mathrm{st}}(\ ) + \ (t;\ ;\ ); \qquad (t;\ ;\ ) \qquad {}_{\mathrm{st}}(\ ); \\
R(t;\ ;\ ) &= R_{\mathrm{st}}(\ ) + R(t;\ ;\ ); \qquad R(t;\ ;\ ) \qquad R_{\mathrm{st}}(\ ); \\
(t;\ ;\ ) &= {}_{\mathrm{st}}(\ ) + \ (t;\ ;\ ); \qquad (t;\ ;\ ) \qquad {}_{\mathrm{st}}(\ ):
\end{aligned}
\tag{23}
$$

Inflationary extra space relaxation in the presence of (scalar) field

Small pertribations approximation

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\end{aligned} \tag{23}$$

Linearized equations

$$\begin{aligned}
& e^2 \ r^2 \ 3 \ R \ 4aH^2 \ 2aR \ 1 + 8a \ R \ \csc^2 \ 8a \ R \ \cot \ + \ 1 \ + \\
& +2 \ 3 \ m^2 \ 3 \ R \ 4aH^2 + aR + 1 + c \ 2H^2 \ m^2 \ {}^2 \ 12aHR \ {}_t + \\
& +4 \ 2aR + 1 \ {}_{tt} + 18aH \ R_t \ 4a \ R_{tt} + 6H \ {}_t \ + 8a \ R \ \cot \ 4 \\
& 4 \ 2aR + 1 \ \csc^2 \ 4 \ 2aR + 1 \ \cot \ + 8a \ R \ R \ + 2 \ = 0;
\end{aligned} \tag{24}$$

$$e^2 \ r^2 \ 24H^2 \ 2R \ +4 \ 3H \ {}_t + \ {}_{tt} \ R \ 2 \ \cot \ + \ \csc^2 \ + \ = 0; \tag{25}$$

$$e^2 \ r^2 \ m^2 \ 2 \ + \ + 3H \ {}_t + \ {}_{tt} \ \cot \ \csc^2 \ = 0: \tag{26}$$

Initial conditions (for example random traveling wave in n=2 mode)

$$(t; \; ; \quad) = \quad {}_2(t; \quad) \sin(2 \quad) + \quad {}_2 \; t + \frac{n}{2}; \quad \cos(2 \;) \; ;$$

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$$(t;\ ;\ ) = \ _2(t;\ )\sin(2\ ) + \ _2\ t + \frac{n}{2};\ \cos(2\ ): \quad (27)$$

Accumulation of U(1)-number initial asymmetry

E ective 4-dim U(1)-number before the relaxation ends

$$Q(t) = \int \partial^{0} \partial \quad r^{2} e^{2} \quad \sin \; d \, d \quad =$$

$$= \int \partial^{0} \quad (t; \; ; \quad) \partial \quad (t; \; ; \quad) \, r^{2} e^{2 \quad st(\quad)+ \quad (t; \; ; \quad)} \sin \; d \, d \; : \qquad (28)$$

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Problem of charge (number) transfer to the lowest KK-mode

The total charge of the KK-tower

$$
\begin{aligned}
Q &= \int J^0 \sqrt{|g|}\sqrt{|k|}\, d^3x\, d^d y \\
&= \int \sum_{n=0}^{\infty} n \; {}_n \partial^0 \; {}_n \sqrt{|g|}\, d^3x = \qquad (29) \\
&= \int \sum_{n=\infty}^{\infty} n \; {}_n \partial^0 \; {}_n \sqrt{|g|}\, d^3x\,.
\end{aligned}
$$

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&\int \sum_{n=0}^{\infty} \ldots_n \ldots_n \partial^0 \ldots_n \sqrt{|g|}\, d^3x = \qquad (29) \\
&= \int \sum_{n=1}^{\infty} \ldots_n \ldots_n \partial^0 \ldots_n \sqrt{|g|}\, d^3x .
\end{aligned}
$$

- The lower level of the KK-tower does not contribute to the total charge. The charge of its particles is zero - therefore, the massive KK-modes cannot decay into known particles (which should be located at the lower level of the KK-towers).

Fermion splitting in extra space with angle profuse

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Angle profuse extra space

$$ds^2 = g \quad (x \quad) dx \quad dx \qquad r_0^2 \quad d \quad ^2 + b^2 \sin^2 \quad d' \quad ^2 \quad ; \tag{30}$$

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Higher-dimentional fermionic action

$$S \quad = \int d^6 x \sqrt{|G|}\; i \;\bar{}\; h^B_{\tilde{A}} \;\; ^{\tilde{A}} r \;\; _B \quad ; \qquad (31)$$

where $^{\tilde{A}}$ is at gamma matrices

$$= \begin{pmatrix} & 0 \\ 0 & \end{pmatrix} ; \quad = \begin{pmatrix} 0 & 1 \\ 1 & 0 \end{pmatrix} ; \quad ' = \begin{pmatrix} 0 & i \\ i & 0 \end{pmatrix} ; \qquad (32)$$

and $h^B_{\tilde{A}}$ is the frame eld:

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- You can nd a detailed derivation of fermion splitting in the paper arxiv: 0706.0676.

Kaluza-Klein decomposition of lowest level

$$x^{A} = \sum_{l} Y_{l}(\ ; ' \ ) \ _{l}(x) = \sum_{l} \frac{e^{il'}}{\sqrt{2}} \begin{pmatrix} _{l}(\ ) \ _{l}(x) \\ _{l}(\ ) \ _{l}(x) \end{pmatrix} ; \qquad (34)$$

where the form of $_l(\ )$ and $_l(\ )$ are computed from extra metric. E ective fermions $_l$ and $_l$ are indistinguishable for the massles KK-level.

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where the form of ${}_l(\;)$ and ${}_l(\;)$ are computed from extra metric. E ective fermions ${}_l$ and ${}_l$ are indistinguishable for the massles KK-level.

Massles e ective 4-dim modes

$$S = \int d^6X \sqrt{|G|}\, i\,\bar{\;}\, h^B_{\tilde{A}}\;{}^{\tilde{A}}\, r_B\; = \int \sqrt{g}\, d^4x \sum_l i\,\bar{\;}_l\;\partial\;{}_l; \qquad l = \;d\;\lfloor\;/2\rceil;\ldots;0;\ldots;+\lfloor\;/2\rfloor: \qquad (35)$$

Limitation of mode number comes from the normalization condition:

$$\int d^6X \sqrt{|G|} = \int d^4x \sqrt{|g|} \sum_l \;{}_l\;{}_l + \;{}_l\;{}_l\;: \qquad (36)$$

Fermion splitting in extra space with angle profuse

Correspandence of currents

$$J^m = \frac{\partial L}{\partial(\partial_m \Psi)} \partial_{\varphi} \Psi = i\bar{\Psi} h^m_{\tilde{A}} \Gamma^{\tilde{A}} \partial_{\varphi} \Psi \quad \Longrightarrow$$

$$j^{\mu} = \frac{\partial L_4}{\partial(\partial_{\mu} \psi_l)} t_{ll'} \psi_{l'} = i \sum_l l \bar{\psi}_l \gamma^{\mu} \psi_l ; \qquad t_{ll'} = \int Y_l \partial_{\varphi} Y_{l'} \sqrt{k}\, d^2 y = i l \delta_{ll'} ; \tag{37}$$

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$$J^m = \frac{\partial L}{\partial(\partial_m \Psi)}\partial_\phi \Psi = i\bar{\Psi} h^m_{\tilde{A}} \Gamma^{\tilde{A}} \partial_\phi \Psi \quad \Longrightarrow$$

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U(1)-number

Take the angle profuse parameter $b = 4$ for example.
Then we have triplet splitting: $l = -1; 0; +1$.

$$Q = \int J^0 \sqrt{|G|}\, d^3x d^2y = \int j^0 \sqrt{|g|}\, d^3x =$$
$$= \int i(\psi^\dagger_{+1}\psi_{+1} - \psi^\dagger_{-1}\psi_{-1}) d^3x = N_{+1} - N_{-1} = \text{const}. \qquad (38)$$

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Thanks for you attention!

Any questions?