Topological Protection of Black Hole's Baryon/Skyrmion Hair and Observable Manifestations

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based on

- Gia Dvali and Alexander Gußmann: "Skyrmion black hole hair: Conservation of baryon number by black holes and Observable manifestations" (hep-th 1605.00543, 02.05.2016)
- Gia Dvali and Alexander Gußmann: "Topological protection of black hole's baryon/skyrmion hair" (to appear)
- Alexander Gußmann: "Scattering of massless scalar waves by magnetically charged black holes in Einstein-Yang-Mills-Higgs theory" (hep-th 1608.00552, 02.08.2016)

Overview

- Historical introduction
- Review: Skyrmions and black holes with classical skyrmion hair
- Answer 3 Questions

Historical introduction

- 1971: "no hair" conjecture (Wheeler, Ruffini)
- 1972: first "no hair" theorems (Bekenstein, Teitelboim, Hartle)
- 1989: discovery of first black holes which were interpreted as black holes with classical primary hair (Volkov, Galtsov)
  - stability issue: topology seems to be necessary condition for Lyapunov-stability in spherically-symmetric asymptotically-flat case
  - "horizon inside classical lump"

Skyrmions (in flat spacetime) (Skyrme 1961/1962, Witten 1983)

Classical skyrmions identifiable with baryons for large N_C (in a world with only pions and no other meson degrees of freedom)

$$\mathcal{L}_{sky} = -\frac{F_\pi^2}{4} Tr(U^+ \partial_\mu U U^+ \partial^\mu U) + \frac{1}{32e^2} Tr([\partial_\mu U U^+, \partial_\nu U U^+]^2)$$

Here: massless pions, two quark flavors

$$U = e^{\frac{i}{F_\pi}\pi_a \sigma_a}$$

$$[F_\pi] = \sqrt{\frac{[mass]}{[length]}},\ [e] = \frac{1}{\sqrt{[mass][length]}}$$

Solitonic configurations:

$$E = \int d^3x \mathcal{H}_{sky}$$

$$\frac{\pi_a}{F_\pi} = F(r) n_a,\ F(0) = B\pi,\ F(\infty) = 0$$

$$L = \frac{1}{F_\pi e},\ M_S = \frac{F_\pi}{e}$$

Black holes with skyrmion hair (Luckock, Moss, Droz, Heusler, Straumann, Bizon, Chmaj, Shiiki, Sawado, ...)

$$G_{\mu\nu} = 8\pi G_N T_{\mu\nu}$$

$$T_{\mu\nu} = \frac{2}{\sqrt{(-g)}} \frac{\delta \mathcal{L}_{sky}}{\delta g^{\mu\nu}}$$

$$ds^2 = N^2(r)\left(1 - \frac{2M(r)G}{r}\right) dt^2 - \frac{1}{1 - \frac{2M(r)G}{r}} dr^2 - r^2 d\Omega^2$$

2 classes of numerical solutions:

gravitating skyrmions: no r_h such that $\left(1 - \frac{2M(r_h)G}{r_h}\right) = 0$

hairy black hole: there is an r_h such that $\left(1 - \frac{2M(r_h)G}{r_h}\right) = 0$

Parameter space of (black hole) solutions:

- skyrmion not itself a black holes
- event hoizon r_h located inside the soliton core

Skyrmion black holes - mass functions for several examples

$$\alpha = 4\pi G_N F_\pi^2,\ x_h = eF_\pi r_h,\ m(x) = eF_\pi G_N M(r)$$

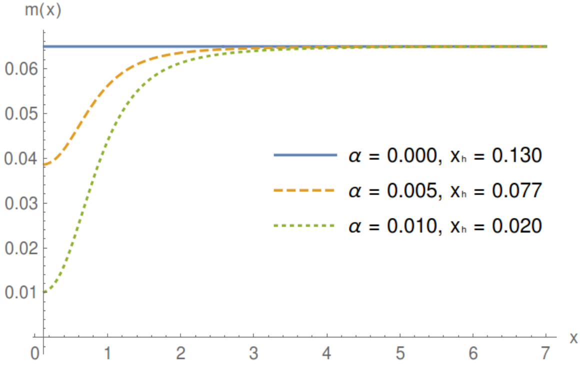


Figure: $m(x)$ for the case $m_{ADM} = 0.065$

3 Questions

- 1) Are there experiments which allow to distinguish skyrmion black holes classically from Schwarzschild BHs with same ADM mass?
Yes, e.g. scattering experiments
- 2) Can black holes of arbitrary size also carry skyrmion/baryon hair? What would be experiments in such a case? Yes, but the hair is quantum. Aharonov-Bohm type experiments
- Can baryon number be conserved by semi-classical black holes? probably yes, at least for large-N_C QCD

1) Classical scattering

Consider external probe scalar field Φ, minimally coupled; can be generalized to higher spin fields

let Φ scatter by given skyrmon black hole (for simplicity - and other reasons - neglect possible non-gravitational interactions between Φ and skyrmion)

Compare obtained scattering cross sections with scattering cross sections of same scalar field scattered by Schwarzschild black holes with same ADM mass

(analogous cross sections for other hairy black hole example: A.G. hep-th 1608.00552)

Classical scattering cross sections for one example

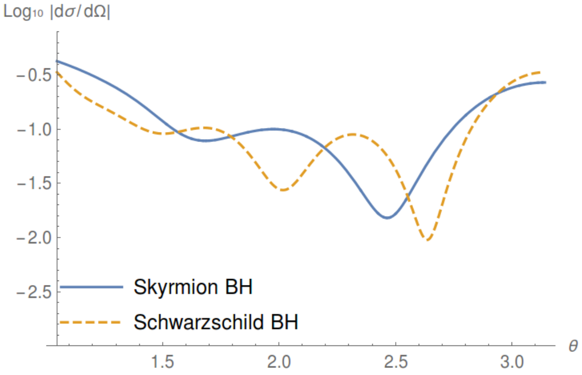


Figure: differential scattering cross section for $m_{ADM} = 0.111$, $\omega = 8$

2) Skyrmion/baryon hair for black holes of arbitrary size

Remember: Baryon/skyrmion correspondence in large-N_C QCD, in particular $U_B(1)$ currents:

high energies: $J_\mu = \frac{1}{N_C}\bar{q}\gamma_\mu q$

low energies: $J_\mu = \epsilon_{\mu\nu\alpha\beta} Tr \left(U^{-1}\partial^\nu U U^{-1}\partial^\alpha U U^{-1}\partial^\beta U \right)$

Notice: On the hedgehog ansatz $J_0 = \star dS$ where for $B = 1$
$S_{\mu\nu} = -\left(F(r) - \frac{1}{2} sin(2F(r)) - \pi \right) \partial_{[\mu} cos\theta \partial_{\nu]}\phi$

Thus: $\int d^3x J_0 = \int_{S_2} dx^\mu \wedge dx^\nu S_{\mu\nu}$

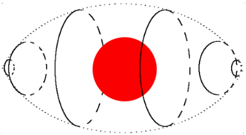
$\longrightarrow$ charge can be defined at infinity, since it is conserved this charge remains even if we insert baryon/skyrmion in a black hole

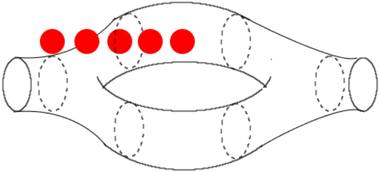
Question: Can we measure this charge at infinity?

Skyrmion/baryon hair for black holes of arbitrary size

Couple the two-form to a probe string
$S = g \int dx^{\mu} \wedge dx^{\nu} S_{\mu\nu}$

Phase shift $\Delta\phi = 2\pi g$ in Aharanov-Bohm type experiments





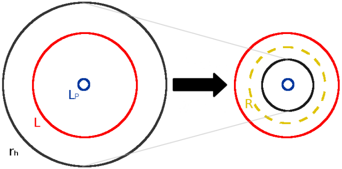
(similar to massive spin 2 hair (G. Dvali, 2006) and discrete Aharonov-Bohm type quantum hair considered by Coleman, Preskill, Wilczek 1992)

3) Conservation of baryon number - Gedankenexperiments

Standard folklore of folk theorems: Global charges such as baryon number are incompatible with sem-classical black hole physics

- Assumption: No hair
- Thermal evaporation of a black hole which initially swallowed a baryon/skyrmion down to Planck size

Loophole: Skyrmion/Baryon hair exists! $\rightarrow$ logical possibility that skyrmion hair of a black hole which swallowed a baryon emerges



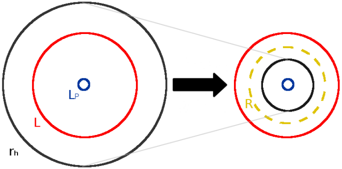
With existence of Aharonov Bohm type hair favors this possibility: Measure Baryon number at beginning, since it is conserved and since it corresponds to a classical object with size L it is natural that this object is returned when black hole shrinks down to size L in form of known black hole with skyrmion hair

3) Conservation of baryon number - Gedankenexperiments

Argument in favor of "weak-gravity conjecture": Weakly gauged baryon number is incompatible with semi-classical black holes

- Assumption: No hair
- Thermal evaporation of a black hole which initially swallowed a baryon/skyrmion down to Planck size

Loophole: Skyrmion/Baryon hair exists! $\rightarrow$ logical possibility that skyrmion hair of a black hole which swallowed a baryon emerges



With existence of gauge field this possiblity is favored: (In principle) the gauge field is measurable at infinity. Since it is conserved and since it corresponds to a classical object with size L it is natural that this object is returned when black hole shrinks down to size L in form of known black hole with skyrmion hair

Consequences and Outlook

- Astrophysical consequences, testing no-hair conjecture
- Similar analysis for different kinds of hair
- Similar analysis for magnetic monpoles instead of skyrmions (see also Lee, Nair, Weinberg, 1992)

Classical scattering cross sections for one example of a magnetic monpole black hole with frozen vacuum expectation value (hep-th 1608.00552)

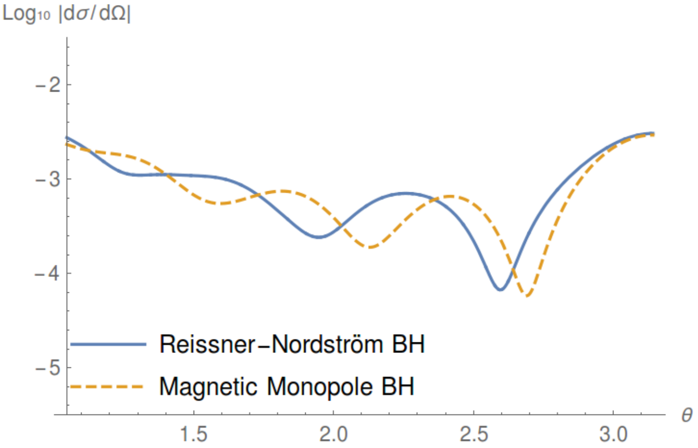


Figure: differential scattering cross section for $m_{ADM} = 0.0102$, $\omega = 8$