Rethinking baryon number conservation by black holes

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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)

Overview

- Review: Skyrmions and black holes with classical skyrmion hair
- Is baryon number conservation compatible with semi-classical black hole physics?

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

There exists a branch of black holes with skyrmion hair which are dynamically stable against linear perturbations

Skyrmion black holes - mass functions for several examples

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

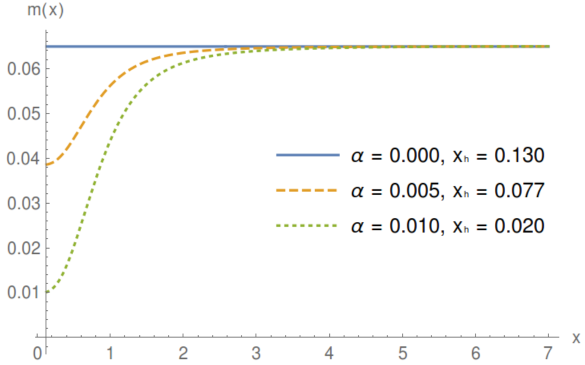


Figure: $m(x)$ for the case $m_{ADM} = 0.065$

Conservation of baryon number by semi-classical black holes?

Black hole folk theorems: Global charges such as baryon number are incompatible with semi-classical black hole physics

Thought experiment: One skyrmion/baryon is swallowed by a (large) black hole

Assumptions of folk theorems:

- No semi-classical black hole hair $\rightarrow$ Schwarzschild (or Kerr) metric
- Thermal Hawking evaporation of the black hole $\rightarrow$ black hole shrinks

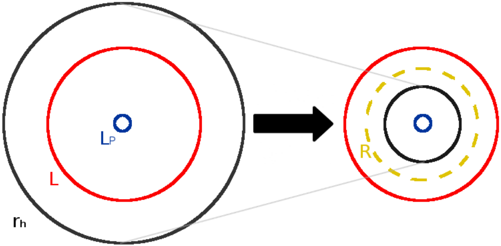
Conclusions:

- Black hole shrinks down to the Planck size without returning baryon number (due to thermality)
- Baryon number is lost or is carried by Planck size remnants

Conservation of baryon number - Gedankenexperiments

Loophole: No hair assumption is wrong since skyrmion black hole hair exists (due to baryon/skyrmion correspondence it is a baryon black hole hair from the point of view of a high energy observer)!

$\rightarrow$ logical possibility that skyrmion hair of a black hole which swallowed a baryon emerges at a scale L



Question: Is this (only) a logical possiblity or is it a must?

Evidence in favor of baryon number conservation: 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: $\int d^3x J_0 = \int_{S_2} dx^\mu \wedge dx^\nu S_{\mu\nu}$

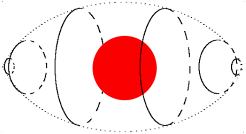
$\longrightarrow$ charge can be defined at infinity, since it is conserved this charge remains even if we insert baryon/skyrmion in a black hole

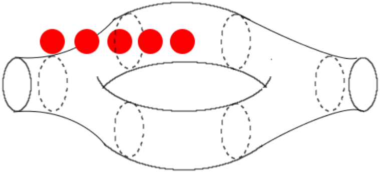
Question: Can we measure this charge at infinity?

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)

Consequences and Outlook

- Classical scattering on black holes with classical skyrmion hair (hep-th 1605.00543)
- Consequences for weak-gravity conjecture (hep-th 1605.00543)
- 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)