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Static, equipotential photon surfaces have no hair

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The Schwarzschild spacetime of positive mass is well-known to possess a unique “photon sphere” – meaning a cylindrical, timelike hypersurface P such that any null geodesic initially tangent to P remains tangent to P – in all dimensions. We will show that it also possesses a rich family of spatially spherically symmetric “photon surfaces” – general timelike hypersurfaces P such that any null geodesic initially tangent to P remains tangent to P. This generalizes a result of Foertsch, Hasse, and Perlick from $2+1$ to higher dimensions. Furthermore, we will discuss how these photon surfaces behave across the black hole horizon and towards infinity in the Kruskal–Szekeres extension.

Similar results can be obtained in a large class of static, spherically symmetric spacetimes, including for example sub-extremal Reissner–Nordström spacetimes, but also other relevant examples. We show that they are (almost) necessarily rotationally symmetric and give concrete ODEs for their radial profile, including a solvability analysis of said ODEs.

We will also present a general theorem that implies that any static, vacuum, asymptotically flat spacetime possessing a so-called “equipotential” photon surface must already be the Schwarzschild spacetime. The proof of the theorem uses and extends Riemannian geometry arguments first introduced by Bunting and Masood-ul-Alam in their proof of static black hole uniqueness. It holds in all dimensions $n+1 \geq 3+1$ and naturally generalizes to electro-vacuum.

Parts of this work are joint with Gregory J. Galloway, with Sophia Jahns and Olivia Vicanek Martinez, and with Markus Wolff.

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