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Static, equipotential photon surfaces have no hair

Abstract

The Schwarzschild spacetime 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 *F* 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.

By Lorentzian geometry arguments, one can in fact show that all photon surfaces in the Schwarzschild spacetime must be spherically symmetric and in particular members of the family *F* or partial radial planes.

We will also present a general theorem that implies that any static, vacuum, asymptotically flat spacetime possessing a possibly disconnected, suitably defined photon sphere must already be the Schwarzschild spacetime. Moreover, the theorem helps to prove that any static, vacuum, asymptotically flat spacetime that possesses a possibly disconnected, 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 $n+1>3$.

Part of this work is joint with Gregory Galloway.