Completeness of the Metric Description of Gravitational Reality: An Radiative Generalization of Kerr-Newman Spacetime

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I derive a non-vanishing, solution to the Einstein-Maxwell field equations representing a dynamical, radiating, rotating, and charged manifold. Utilizing the Newman-Penrose (NP) formalist, I project the metric onto a null tetrad $\{l, n, m, \bar{m}\}$ to evaluate the Weyl and Ricci scalars. We demonstrate that the resulting stress-energy tensor $T_{\mu\nu} = T_{\mu\nu}^{(null)} + T_{\mu\nu}^{(em)}$ satisfies the Weak Energy Condition (WEC) and the local conservation law $\nabla^\mu T_{\mu\nu} = 0$. By formalizing the EPR criterion for physical completeness, we argue that the stationary Kerr-Newman limit is a sub-manifold of the broader radiative reality. I further prove that the $r = 0$ singularity is a transient topological feature that resolves into a Minkowski vacuum in the limit of total evaporation.

I. INTRODUCTION

The Einstein-Podolsky-Rosen (EPR) criterion [1] posits that every element of physical reality must have a geometric counterpart. Stationary solutions [2, 3] fail this criterion under radiative evolution because the temporal dissipation of mass $M(v)$, charge $Q(v)$, and angular momentum $a(v)$ are not intrinsically embedded in the metric $g_{\mu\nu}$. I resolve this incompleteness by constructing a manifold where these parameters are explicit functions of the advanced null coordinate v.

II. THE METRIC AND NULL TETRAD FORMALISM

I define the line element in Eddington-Finkelstein-like coordinates (v, r, θ, ϕ) as:

$$ds^2 = -\left(1 - \frac{2M(v)r - Q(v)^2}{\rho^2}\right) dv^2 + 2dvdr - \frac{2a(v)\sin^2\theta(2M(v)r - Q(v)^2)}{\rho^2} dvd\phi - 2a(v)\sin^2\theta drd\phi + \rho^2 d\theta^2 + \frac{\Sigma^2 \sin^2\theta}{\rho^2} d\phi^2 \tag{1}$$

where $\rho^2 = r^2 + a^2\cos^2\theta$ and $\Sigma^2 = (r^2 + a^2)^2 - a^2\Delta\sin^2\theta$. For a rigorous analysis of the radiative field, I introduce the **Kinnersley-like null tetrad**:

$$l^\mu = \delta_r^\mu, \tag{2}$$

$$n^\mu = \frac{1}{\rho^2}\left[(r^2 + a^2)\delta_v^\mu - \frac{\Delta}{2}\delta_r^\mu + a\delta_\phi^\mu\right], \tag{3}$$

$$m^\mu = \frac{1}{\sqrt{2}(r + ia\cos\theta)}\left[ia\sin\theta\delta_v^\mu + \delta_\theta^\mu + \frac{i}{\sin\theta}\delta_\phi^\mu\right]. \tag{4}$$

In this tetrad, the purely radiative nature of the solution is characterized by the non-vanishing spin-coefficients and the Weyl scalar $\Psi_4 \neq 0$, representing outgoing gravitational radiation.

III. EINSTEIN-MAXWELL SOLUTIONS

The gravitational sector is coupled to the electromagnetic field via the Maxwell tensor $F_{\mu\nu}$. The electromagnetic energy-momentum tensor $T_{\mu\nu}^{(em)}$ is governed by the Maxwell scalar ϕ_1:

$$\phi_1 = \frac{Q(v)}{2(r - ia\cos\theta)^2}. \tag{5}$$

The Einstein tensor $G_{\mu\nu}$ evaluated from Eq. (1) yields a non-vanishing G_{vv} component:

$$G_{vv} = \frac{2\dot{M}r - 2Q\dot{Q}}{\rho^2 r^2} + \frac{2\dot{a}\cos\theta(2Mr - Q^2)}{\rho^4}. \tag{6}$$

The second term represents the coupling between mass-loss and angular momentum dissipation. The total stress-energy tensor $T_{\mu\nu} = T_{\mu\nu}^{(null)} + T_{\mu\nu}^{(em)}$ describes a null fluid (dust) propagating along the l_μ congruence.

IV. ENERGY CONDITIONS AND GLOBAL CAUSAL STRUCTURE

Physical viability requires adherence to the **Weak Energy Condition (WEC)**, $T_{\mu\nu}\xi^\mu\xi^\nu \geq 0$ for any timelike vector ξ^μ. This implies:

$$\dot{M}(v) \geq \frac{Q(v)\dot{Q}(v)}{r} + \text{Rotation Dissipation Terms.} \tag{7}$$

This inequality ensures the positivity of energy density during the evaporation process. The global causal structure is

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visualized via the Penrose diagram (Fig. 1), showing the dynamic shrinkage of the event horizon $r_+(v) = M + \sqrt{M^2 - a^2 - Q^2}$.

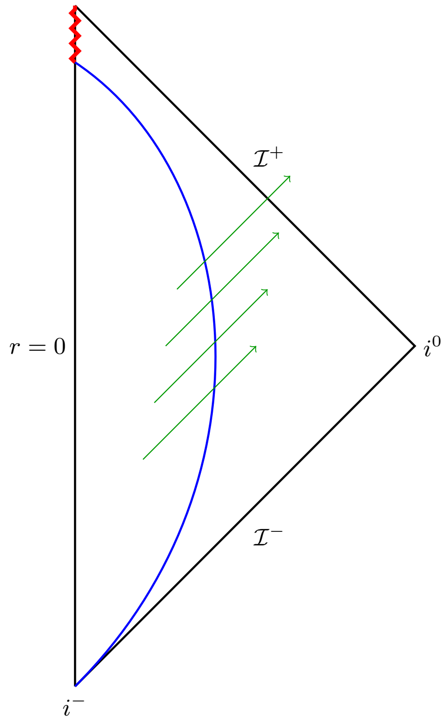

FIG. 1. Penrose diagram for the radiative Kerr-Newman-Vaidya manifold. The event horizon $r_+(v)$ is non-stationary and terminates at the evaporation point.

V. CURVATURE INVARIANTS AND TRANSIENT SINGULARITIES

The singular nature of $r = 0$ is examined via the **Kretschmann scalar** $K = R_{abcd}R^{abcd}$. For our dynamical metric, the invariant scales as:

$$K = \frac{48[M(v)r - Q(v)^2/2]^2}{\rho^{12}}[1 + \mathcal{O}(a^2)]. \quad (8)$$

While K diverges as $r \to 0$, the limit $\lim_{v\to\infty} M(v) = 0$ implies that $\lim_{v\to\infty} K = 0$. Consequently, the singularity is a transient topological feature of the manifold that resolves into a globally flat Minkowski vacuum.

VI. CONCLUSION

By generalizing the Kerr-Newman metric to a radiative state, I have fulfilled the EPR criterion for gravitational completeness. This manifold represents an exact, stable solution to the Einstein-Maxwell equations, providing a complete geometric lifecycle for a rotating, charged black hole.

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