Induced Wald Charge on Magnetized Kerr Black Hole

ICRANet

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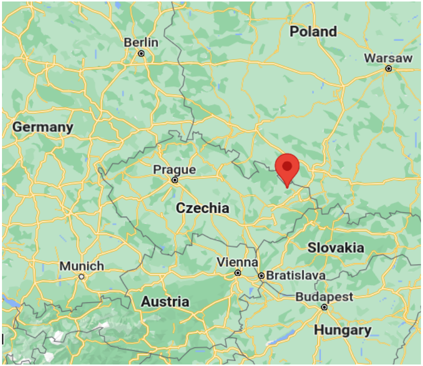
The 6th Zeldovich meeting, Jul 13-17, 2026 ICRANet, Pescara

Institute of Physics, Silesian University in Opava (CZ)

- Institute of Physics: $\sim$ 50 people (Z.Stuchlík, R.Konoplya, A.Zhidenko, G.Török ...)
- Research centres: Theoretical Physics and Astrophysics; Computational Physics and Data Processing; Educational Centre
- **Annual relativistic conference RAGtime28: Nov 2-6, 2026 – you are welcome!**

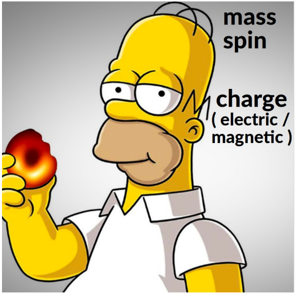
https://ragtime.physics.cz/



Black hole magnetosphere

pulsar magnetosphere = rotating dipole; black hole = ?

A) Black hole is alone – BH's own EM field



- BH no-hair theorem – black holes have only three hairs: mass, spin, monopole (electric/~~magnetic~~) charge

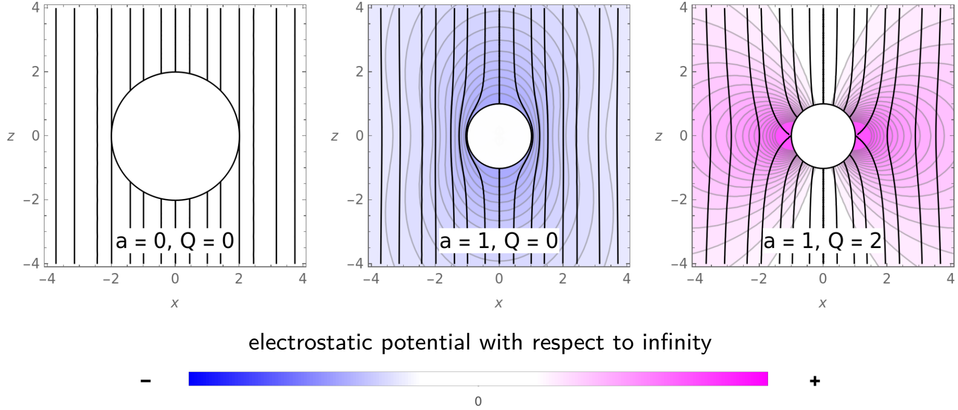
$\Longrightarrow$ there can be induced monopole electric charge on rotating black hole in magnetic field

B) Plasma presence around BH
– electromagnetic field around the BH generated by moving plasma

0) Maxwell Equations	1) Force-Free Electrodynamics	2) Magnetohydrody-namics	3) Kinetic Approach: Particle-In-Cell
linear eqn; J^μ	$B^2 \gg \rho c^2$	fluid description	charged particles

Rotating BH immersed in uniform magnetic field

$\Longrightarrow$ the induced electric field cannot be screened by any choice of el. charge Q on BH; el.potential along z-axis $\varphi_{\mathrm{H}} - \varphi_{\infty} = (Q - Q_{\mathrm{W}})/2M$ where $Q_{\mathrm{W}} = 2aMB$ is Wald charge



- Robert M. Wald: Black hole in a uniform magnetic field, hysical Review D, 10 (1974)
- Serguei S. Komissarov: Electrically-charged black holes and the Blandford-Znajek mechanism, MNRAS, 512/2 [`arxiv.org/abs/2108.08161`] (2022)

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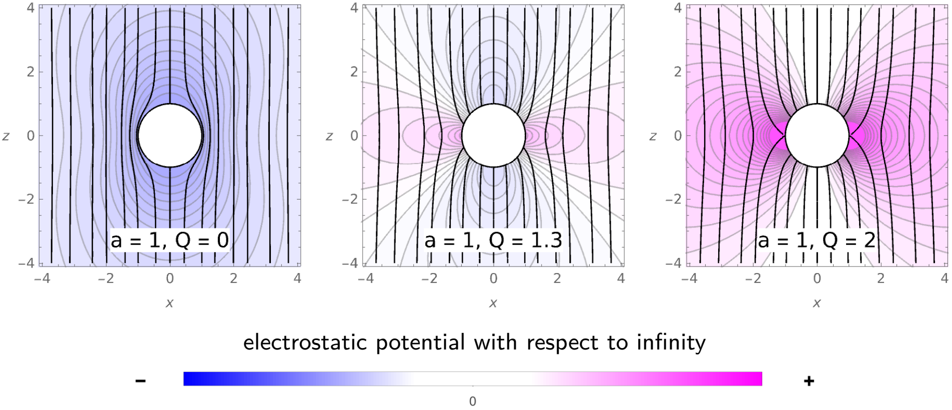

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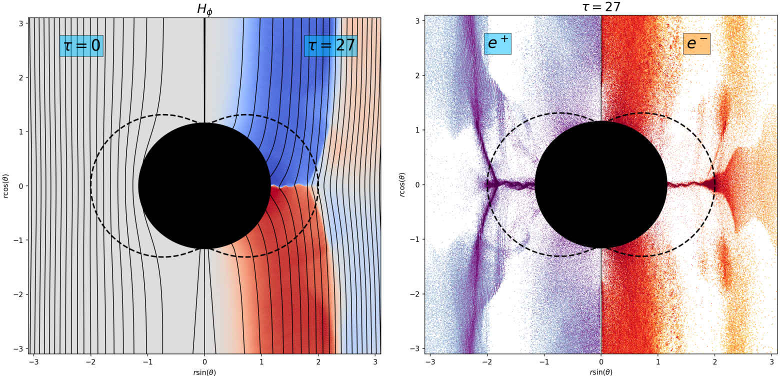
General Relativistic Particle-in-Cell (GRPIC) setup

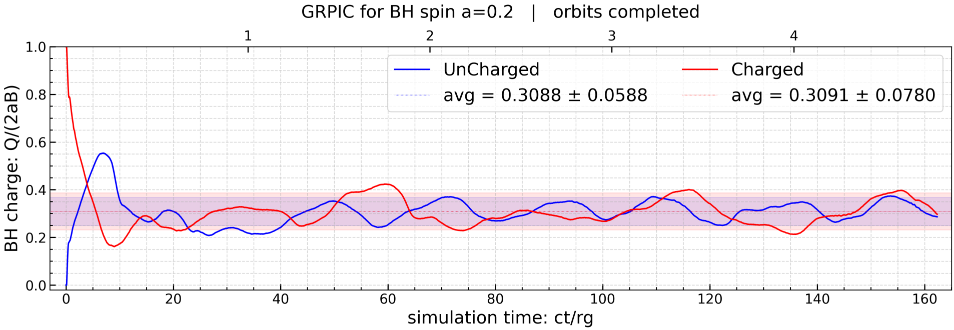
The GRPIC simulation is modeling plasma by tracking many individual charged "macro-particles" as they move through a spatial grid. At each step, the particles charges and currents are deposited onto the grid, the EM fields are solved, and then interpolated back to push the particle forward

. • Benjamin Crinquand: Particle acceleration in Kerr black-hole magnetospheres, PhD thesis (2016)



Our setup: uniform external magnetic field, fixed on the outer boundary. Particle pairs e^-/e^+ created that fill the space around the BH and change the structure of the initial EM field.

Induced charge on the BH using GRPIC simulation



- We started with two initial configurations:
  - uncharged BH ($Q = 0$, blue)
  - charged BH ($Q = Q_\mathrm{W}$, red)
- in both cases dynamical equilibrium is quickly reached
- for BH spin $a = 0.2$ we got charge $Q \sim 0.3\,Q_\mathrm{W}$; for spin $a = 0.9$ charge $Q \sim 0.2\,Q_\mathrm{W}$

Simulations done by Farukh Abdulkhamidov using GRZeltron GRRPIC code (Benoit Cerutti).

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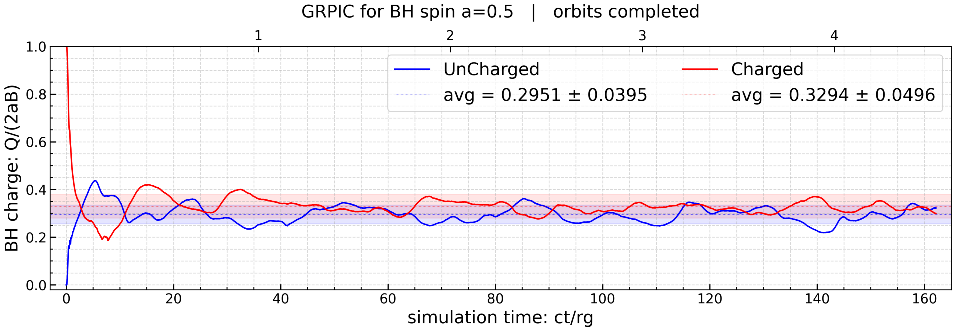

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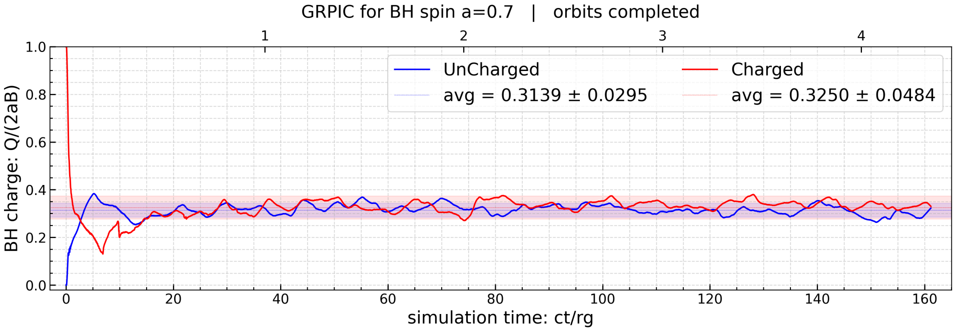

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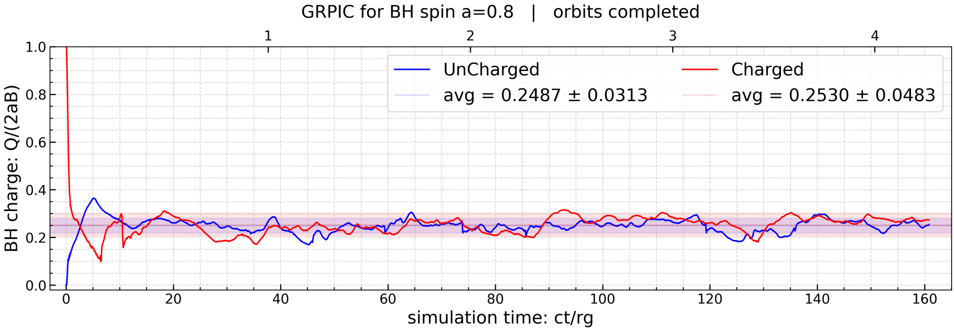

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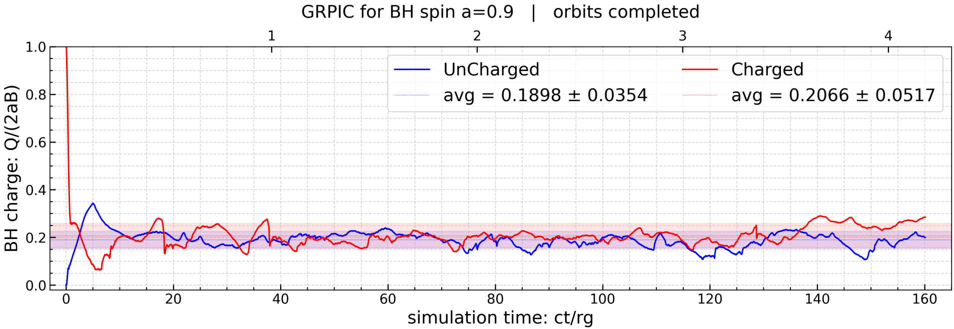

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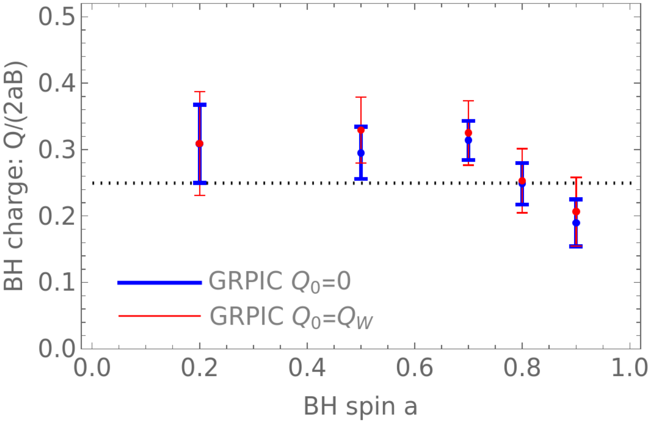
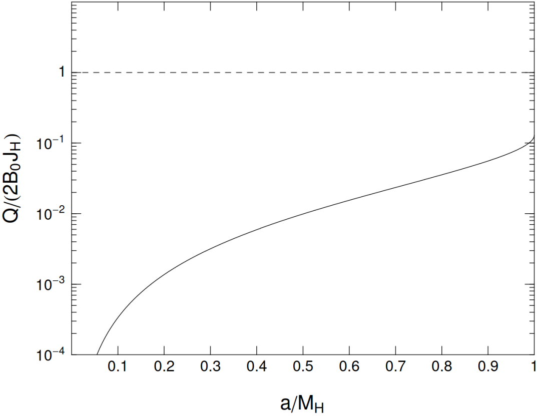
Black hole charge Q as a function of BH spin a



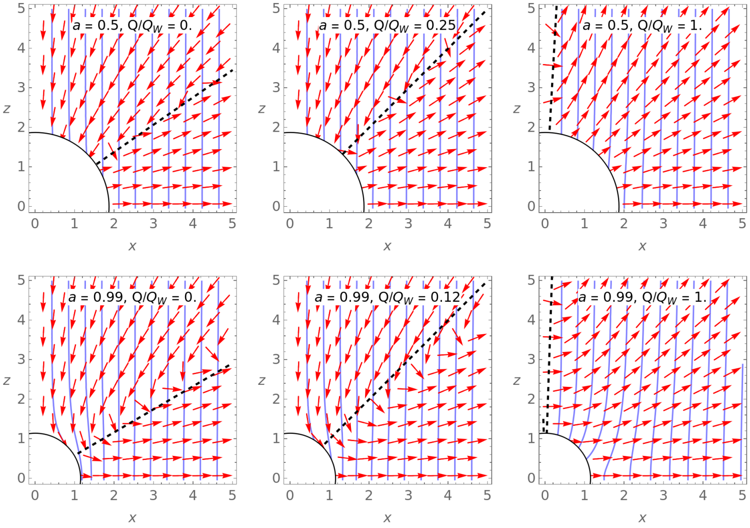
- The charged induced on BH in GRPIC simulation is changing with BH spin.
- BH charge can be approximated as $Q \sim 0.25\,Q_{\mathrm{Wald}} = 0.25(2aB) = 0.5aB$.
- BH charge drops down for larger BH spins.

Explaining data: configuration with the lowest energy



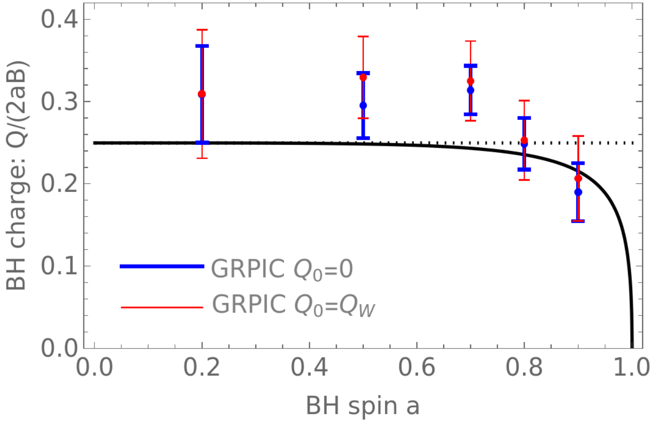
Total energy of EM field around BH should be the lowest:
(!) Wald charge is increasing with BH spin;
(!) gives too low value - max $Q = 0.13\,Q_{\mathrm{W}}$ for $a \to 1$
• Li-Xin Li. Electromagnetic energy for a charged Kerr black hole in a uniform magnetic field. Phys. Rev. D, 61(8):084033 (2000)

We assume selective accretion for charged particles



- Jorge A. Rueda and Remo Ruffini. Kerr black hole energy extraction, irreducible mass feedback, and the effect of captured particles charge. *Eur. Phys. J. C*, 84(11):1166 (2024)

Selective accretion - preliminary 45° formula



- To fit GRPIC data we assume the same flux of electric field in/from BH (45° formula).
- BH spin is increasing linearly as $Q = 0.25\, Q_{\rm Wald} = 0.5aB$ (dotted) and then drop down for larger BH spins (thick black curve): $Q(a) = \frac{-a^4-3\sqrt{1-a^2}a^2-7a^2+8\sqrt{1-a^2}+8}{-12\sqrt{1-a^2}a^2-28a^2+32\sqrt{1-a^2}+32}$.

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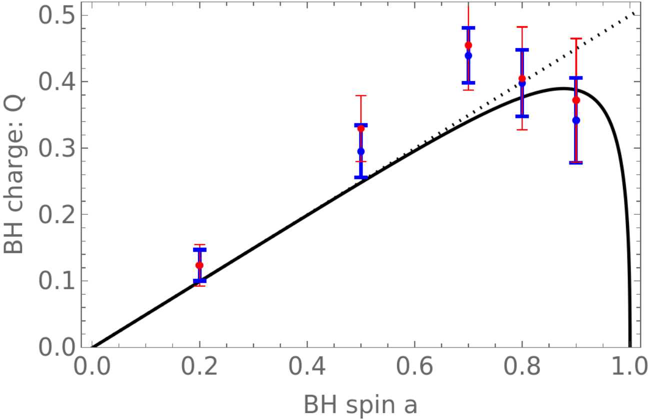

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Summary, problems & future plans

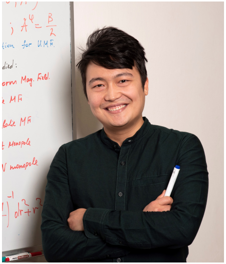
- The charged induced on BH in GRPIC simulation is changing with BH spin; $Q \sim 0.25\, Q_{\mathrm{Wald}}$ and then gets down for larger BH spins.

- Problem with axisymmetric 2.5D and full 3D GRPIC simulation; problem with proper analytic formula explaining the data

- GRPIC simulations for large BH spins are still in progress; more computation time.

Thank you for your attention and do not hesitate to contact us for discussion!



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