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New Study Sheds Light on the Penrose Process and Energy Extraction from Kerr Black Holes

Pescara, Italy – March 13, 2025

A groundbreaking study published in Physical Review Letters explores the long-debated Penrose process, shedding new light on the extraction of rotational energy from Kerr black holes. Led by a team of international researchers from ICRANet and other global institutions, the study provides novel insights into the fundamental physics of energy extraction of astrophysical black holes.

The research, titled "Single versus the Repetitive Penrose Process in a Kerr Black Hole," revisits the original Penrose process, a theoretical model proposed by Roger Penrose in 1969. The study examines how a single decay event of a massive particle into two particles inside the ergosphere of a rotating black hole can result in energy extraction. The team successfully demonstrated that, contrary to earlier criticisms, the single-event Penrose process is indeed capable of extracting significant energy efficiently, with an upper efficiency of 14.5% for a maximally rotating Kerr black hole.

A key aspect of the study also explores the possibility of a repetitive Penrose process, first suggested by Misner, Thorne, and Wheeler in Gravitation (1973). The researchers theoretically analyzed an iterative sequence of decay processes, which, if naively implemented, would appear to extract 100% of the rotational energy of a black hole. However, their findings highlight a crucial limitation: such a linear repetitive process would violate energy conservation laws. The team highlights that this inconsistency can be solved by properly incorporating the nonlinearity introduced by the increase of the irreducible mass of the black hole during the process, which is the subject of an accompanying publication in Physical Review Research. These results laid the groundwork for a revised energy extraction mechanism that obeys fundamental conservation principles.

"Our study clarifies the feasibility of the Penrose process as a mechanism for energy extraction from Kerr black holes," said Professor Remo Ruffini, first author of the paper. "We have demonstrated that a single Penrose process is indeed effective, no modifications are needed as previously assumed. The authors have also uncovered the key limitations of a naive repetitive approach and, in the specific examples provided, evidenced significant mass defect constraints. This research provides a necessary step toward a more complete understanding of black hole energetics."

These findings have broad implications for astrophysics, including the study of high-energy cosmic phenomena such as gamma-ray bursts and active galactic nuclei, where black hole rotational energy may play a critical role. Future research will aim to expand on these results, further refining our understanding of black hole dynamics and potential astrophysical applications.

The paper published in Physical Review Letters can be accessed here:
https://doi.org/10.1103/PhysRevLett.134.081403

The accompanying paper published in Physical Review Research can be accessed here:
https://doi.org/10.1103/PhysRevResearch.7.013203

About the Research Team

This study was conducted by researchers from ICRANet, ICRA, INAF, Al-Farab Kazakh National University, the University of Science and Technology of China, the Universidad Nacional Autónoma de México, and other institutions. Their work builds on decades of theoretical advancements in black hole physics, combining classical general relativity with modern astrophysical insights.

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Roger Penrose to Remo Ruffini, February 23, 2025

Roger Penrose <rpenroad@gmail.com>

23 febbraio 2025 alle ore 00:15

A: Remo Ruffini <ruffini@icra.it>

Dear Remo,

Thank you in bringing me up to date with regard to so much of the new work on energy extraction from the accessible rotational energy of a Kerr black hole. I am afraid that I have not been able to keep with thongs these days, with my attention being distracted by many other matters.

On the energy extraction issue, I had from decades ago, been most particularly intrigued the issue of quasars, and how it could be that so much energy could be transmitted (in electro-magnetic form), so precisely along the axis if rotation in both (opposite) directions. I had assumed that, after so many years, some conventional explanation of this very striking observed phenomenon could be understood. Is there a "standard" explanation that people are satisfied with? In my ignorance I had formulated my own (very incomplete) viewpoint that it had to do with the "Penrose process" (henceforth PP) in a rather exotic situation . (At root, it HAS to be some form of PP since that is really the only way of harnessing the rotational energy of a black hole.) In detail, I wouldn't have any detailed picture (which I am supposing somebody else would have worked out). But the key issue has to be that the source of the energy release involved would be the black Hole's rotation.

Since it is clear that electromagnetism is crucially involved, we need to be looking at a Kerr-Newman solution, rather than just a Kerr solution (which you had referred to in your previous e-mail), and I was assuming that the reason that the energy was emitted very closely along the rotation axis is that the angular momentum is not carried away by the emission only when it comes out along the axis. That way the energy in the rotation of the hole can be harnessed by converting it inti energy ("PP") which comes out only along the axis of rotation because that way the energy can come out without I carrying away any angular momentum—a very efficient way of employing a PP.

I would appreciate it if you can fill me in on how quasars are explained I current understanding and whether or not the essential role o the general idea o the PP must be involved (although not with individual particles, just an "ergosphere" phenomenon in your and Wheeler's terminology.

Let me know the sort of thing that you now have in mind.

All best wishes—Roger

Remo Ruffini to Roger Penrose, February 26, 2025

Remo Ruffini <ruffini@icra.it> 26 febbraio 2025 alle ore 11:19
A: Roger Penrose <rpenroad@gmail.com>

Dear Roger,
I respond to your kind mail (see below).The typing of your article in MGXVII proceedings is being completed.

Today the first of our papers appeared in PRL
(Link: https://doi.org/10.1103/PhysRevLett.134.081403), to be followed by the second paper in PRR in a few days. We may enjoy explaining these results in light of our initial intuitions and review the new perspectives in Physics Today or Science .I will take this occasion to modify two figures in the original article in Physics Today, with printing mistakes.

Yes, as you say, you are completely correct. The role of the Kerr-Newmann is indeed essential, as well as the concept of an "effective charge" , a most innovative concept we introduced in 2020 . I enclose four papers on the electrodynamical process. The power law observed in the GeV emission in GRBs clearly points to an almost reversibility in the electrodynamic PP, so overcoming the highly irreversible gravitational ones in PRL and PRR.

Turning now to the Quasars: Yes we can jointly attempt a successful model along the lines you have indicated and our above results. In these hours we are completing a fundamental article, with Vereschagin, addressing the Quasar's fundamental parameter: their mass in the range 10+8 10+9 Solar Masses. We infer from the observations of the red-dots, recently discovered by Luis Ho and his group, that the mass of the Quasars originates mainly from Dark Matter!

In Estonia, June 2- 4, we celebrate the entrance of the University of Tartu we are calling an international meeting : your presence and the one by Luis Ho, in person or in remote, will be appreciated

Looking forward to receive your comments in this very exciting scientific moment: we have a good chance to explain the nature of Quasars!
Greetings,
Remo