ICRA – ICRANet Press release

New Research Unveils the Role of Irreducible Mass in Energy Extraction from Kerr Black Holes

Pescara, Italy – March 13.03.2025
A new study published in Physical Review Research offers a major breakthrough in our understanding of the Penrose process, refining our knowledge of energy extraction from Kerr black holes. Building on a previous study in Physical Review Letters, this work clarifies the limitations of the repetitive Penrose process and establishes the central role of irreducible mass in black hole dynamics.

The study, titled "Role of the Irreducible Mass in Repetitive Penrose Energy Extraction Processes in a Kerr Black Hole," highlights the highly nonlinear nature of energy extraction from a rotating black hole. The research team, led by scientists from ICRANet and global institutions, demonstrates that the increase in a black hole's irreducible mass significantly limits the efficiency of repetitive Penrose processes, debunking prior assumptions about the feasibility of extracting the entirety of a black hole's rotational energy.

"Our findings show that, contrary to previous expectations, the Penrose process is far from a linear, scale-invariant mechanism," said Professor Remo Ruffini, one of the study's lead authors. "Instead, the irreducible mass increases much more than the extracted energy, ultimately halting the process after a finite number of iterations."

Key results of the study include:

Nonlinear limitations: The research demonstrates that each successive decay event in the ergosphere of a Kerr black hole leads to an increase in irreducible mass, which quickly outweighs the extracted energy.

Finite energy extraction: The iterative Penrose process stops well before a black hole can be fully stripped of its rotational energy. The latter amounts to a maximum of 29% of the black hole mass if it is at maximal rotation. For selected decay radii inside the black hole's ergosphere and a decaying particle mass of 1% of the mass of a maximally rotating black hole, the paper shows that energy extraction ceases after as few as 8 or as many as 34 iterations, extracting at most 1% and 0.4% of the black hole's mass, while reducing the rotational energy by 17% and 50%.

Breakdown of naive repetition models: The above implies that the work corrects prior assumptions that a sufficiently large number of iterations could extract 100% of a black hole's rotational energy. Instead, the process is self-limiting, as rotational energy in the process is primarily converted into black hole's irreducible mass rather than released to infinity.

An animation showing an example of repetitive Penrose process in a maximally rotating black hole examined in the paper, can be found in the videos of the repetitive Penrose process:
www.icranet.org/documents/video_dot1.mp4
www.icranet.org/documents/video_dot2.mp4
www.icranet.org/documents/video_dot3.mp4

These findings have profound implications for astrophysical models involving black hole energy extraction well identified in gamma-ray bursts GRB's and other high-energy cosmic events.

This study serves as a complementary extension to the team's previous work, "*Single versus the Repetitive Penrose Process in a Kerr Black Hole"*, published in Physical Review Letters. Together, these studies provide a comprehensive revision of the Penrose process and its constraints, implying the need for alternative processes to extract the black hole's energy keeping the irreducible mass increase as small as possible. In this line, electro dynamical processes appear as a promising path as shown by recent works of the team.

The publication of the original results goes back fifty years and has been followed for many decades of thinking and progress reaching the final form in these days: it is fortunate that the main contributors : Roger Penrose and Remo Ruffini) have enjoyed sharing and discussing these results and indicate further developments (see Enclosure 1 *"Roger Penrose to Remo Ruffini, February 23, 2025"* and Enclosure 2 *"Remo Ruffini to Roger Penrose, February 26, 2025"*).

An essential point to address is the objective scientific urgency of addressing these results: since the first discovery of a BH in Cygnus X1 in a binary X-ray source (Ruffini , N.Y. Texas Meeting 1972), the largest observational effort in developing observatories from the ground and from space have reached the scope: "Identify BHs all over the Universe" : from inside our galaxy to extragalactic sources all the way to the highest cosmological redshift at Z= 10 and higher prior to the decoupling era. The BHs, typically of 2-10 Solar Masses, originate from the collapse of "baryonic matter". The great novelty is the current discovery of BHs much larger masses, at 4.6 10^6 all the way to 10^{10} solar masses originating from *Dark Matter* and manifesting themselves from cosmological Z=10 in supermassive BHs, all the way to Z=2 under the form of Quasars.

Precisely this topic has been indicated as a high priority in the Penrose-Ruffini exchange. Progress has been made daily in ICRANet by Arguelles, Rueda , Ruffini (January 11, 2024); Ruffini - Vereshchagin March 2025, and Ruffini, Della Valle - Wang Yu (March 2025). They examine BH composed of both Dark Matter and Baryonic matter and determine their evolution. Of great relevance for this new paradigm are the observations of the Red-Dots by the James Webb Space Telescope of NASA: **"Red-Dots messenger of C*DM*B, a Cosmic *Dark-Matter* Background"** coeval to the better known **"C*M*B Cosmic *Microwave* Background"**.

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

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

About the Research Team

This study was conducted by researchers from ICRANet, ICRA, INAF, University of Ferrara, University of Science and Technology of China, the Universidad Nacional Autónoma de México, Al-Farabi Kazakh National University. Their work advances our theoretical understanding of black hole energetics, merging general relativity with high-energy astrophysics.

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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