ICRANet Press Release
A New Paradigm of Black Hole Physics Leads to a New Quantum in Fundamental Physical Laws

A change of paradigm in black hole physics, leading to new perspectives in the role of the quantum in fundamental laws of physics, is finally reaching its most cogent confirmation by the introduction of the "inner engine" originating the GeV emission of GRB 130427A. This is explained in the new article [1], published today (22 November 2019) in The Astrophysical Journal, co-authored by R. Ruffini, R. Moradi, J. A. Rueda, L. Becerra, C. L. Bianco, C. Cherubini, Y. C. Chen, M. Karlica, N. Sahakyan, Y. Wang, and S. S. Xue.

Remo Ruffini, Director of ICRANet, recalls that this a final step of a 49 years effort. In our joint article of 1971 with John Archibald Wheeler, "Introducing the black hole" [2], we pointed out how the concept of "continuous gravitational contraction", conceived by Oppenheimer and Snyder [3] for the Schwarzschild geometry, had profound modifications by introducing the Kerr metric describing the gravitational field of a spinning mass [4]. We there introduced an effective potential technique to address the particle trajectories around the Kerr black hole (BH), see Problem 12.2 in [5], that led to: 1) the determination of the last stable orbits around the Kerr BH amply applied to the study of gravitational accretion in a vast number of processes, from active galactic nuclei (AGNs), to accretion disk around the BH, to the emission of gravitational waves, see ch. 33 and 34 in [6]; 2) the mass-energy formula of a Kerr BH [7], of a Kerr-Newman BH [8] later confirmed by [9] (see Figure 1) and 3) the progressive change of the Oppenheimer paradigm, based on a Schwarzschild "dead" BH, to the new paradigm envisaging the Kerr "alive" BH indicating the BH as the "largest storehouse of energy in the Universe" [10]. Precisely, the "inner engine" extracting the rotational Christodoulou-Hawking-Ruffini energy of the Kerr BH, has been identified today, after 49 years, in GRB 130427A [1] and has been already successfully extended to GRB 190114C [11]. These results have been made possible thanks to the outstanding data of the GBM and LAT detectors of the Fermi satellite, the BAT and XRT detectors of the Neil Gehrels Swift Observatory, and the optical and the higher energy detectors on the ground.

FIG. 1. Prof. Remo Ruffini and Prof. Roy Kerr with his wife at Prof. Stephen Hawking's home in Cambridge for dinner on 20 June 2017, celebrating the Christodoulou-Hawking-Ruffini mass-energy formula of the Kerr metric.

Laura Beccera, who has been collaborating with the group of Los Alamos National Laboratory (LANL) in the simulation of these GRBs, notices that this "inner engine" naturally forms in the binary-driven hypernova (BdHN) scenario of GRBs [12–14] (see Figure 2).

Rahim Moradi recalls: an extremely efficient electrodynamical process of BH energy extraction occurs in the "inner engine", composed of a rotating BH in a background of very low density ionized plasma and a magnetic field, aligned and parallel with the rotation axis. These features are in contrast with the usual assumptions of a vacuum solution, of asymptotic flatness, and more important, the "inner engine" must be, necessarily, non-stationary. The electrons accelerate to ultrahigh-energies at expenses of the BH extractable energy: the mass and spin of the BH decrease in time keeping constant the BH irreducible mass.

Jorge Rueda comments: Quantitatively, we obtained for both GRB systems the three "inner engine" parameters, the BH mass M, the spin α, and the magnetic field B_0, by requiring that the system satisfies three conditions: (1) the energetics of the GeV photon emission originates in the rotational energy of the BH; (2) the synchrotron radiation of the electrons in the magnetic field sets the timescale of the observed GeV luminosity; (3) the system is transparent to the emission of GeV photons. When applying this model to GRB 130427A, we find [1]: $\alpha = 0.5$, $M = 2.3$ solar masses, just above the critical mass for the gravitational collapse of a neutron star (NS), and $B_0 = 3 \times 10^{10}$ G, sufficient to explain the GeV emission via synchrotron radiation. For GRB 190114C [11]: $\alpha = 0.4$, $M = 4.4$ solar masses, and $B_0 = 4 \times 10^{10}$ G. Thus, for the first time, we have clear evidence that BHs in BdHNe I form by hypercritical accretion onto a NS. Figure 3 shows how the "inner engine" accelerates electrons away from the BH, emitting synchrotron radiation as a function of the pitch angle (angle between the electron motion and the magnetic field).

Ruffini adds: The "inner engine" operates in a sequence of discrete "quantized" steps, authentic electric discharges, emitting a "blackholic quantum" of energy [15]: $\mathcal{E} = \hbar\Omega_{\rm eff}$. Along the rotation axis, electrons gain the total potential energy: $\Delta\Phi = \hbar\omega_{\rm eff}$. Here, $\Omega_{\rm eff}$ and $\omega_{\rm eff}$ are effective frequencies that depend only on fundamental constants, the electron mass, charge, and the Planck mass; on the neutron mass, and on the three "inner engine" parameters. We obtain for the "blackholic quantum", $\mathcal{E} \sim 10^{37}$ erg, a maximum energy of electrons, $\Delta\Phi \sim 10^{18}$ eV, and the emission timescale of the synchrotron radiation, 10^{-14} s, leading to a GeV photon luminosity of 10^{51} erg/s. Every quantized event takes away only 10^{-16} of the rotational energy of the BH, implying that the process can be long-lasting, providing ionized plasma to feed the BH be present.

C. L. Bianco and She-Sheng Xue also recall: All of the above imply a full shift of paradigm from the traditional, gravitational accretion of high-density matter onto a BH. It seems to be too expensive for Nature to accelerate high-density matter in bulk, against the gravitational pull of the BH, to bring it to a distance of 10^{16}–10^{17} cm, where it becomes transparent to high-energy photons. Our "inner engine", instead, uses a more efficient process of electrodynamical accretion, acting on very low density ionized plasma of 10^{-14} g cm^{-3} [16], producing the observable high-energy emission directly close to the horizon of the BH, where the rotational energy of the Kerr BH is extracted.

Narek Sahakyan, Mile Karlica, Yen Chen Chen, and Yu Wang comment: We are eager to apply this model, successfully used for GRB 130427A [1] and GRB 190114C [11], to extract the energy of BHs of much larger masses in AGNs (e.g. the central BH of M87 of nearly 10^{10} solar masses), for which the "inner engine" repetition timescale is of the order of hours [15].

Christian Cherubini and Simonetta Filippi comment: One of the most intriguing aspects of this result is that the emission of the blackholic quantum of 10^{37} erg, with a timescale of 10^{-14} s, occurs in the entire Universe in view of the ubiquitous and homogeneous cosmological presence of GRBs. It is interesting that a scenario proposing a possible role of GRB in the evolution of life in our Universe was introduced in [17] and may now be further quantitatively extended following the observation of GRB 130427A.

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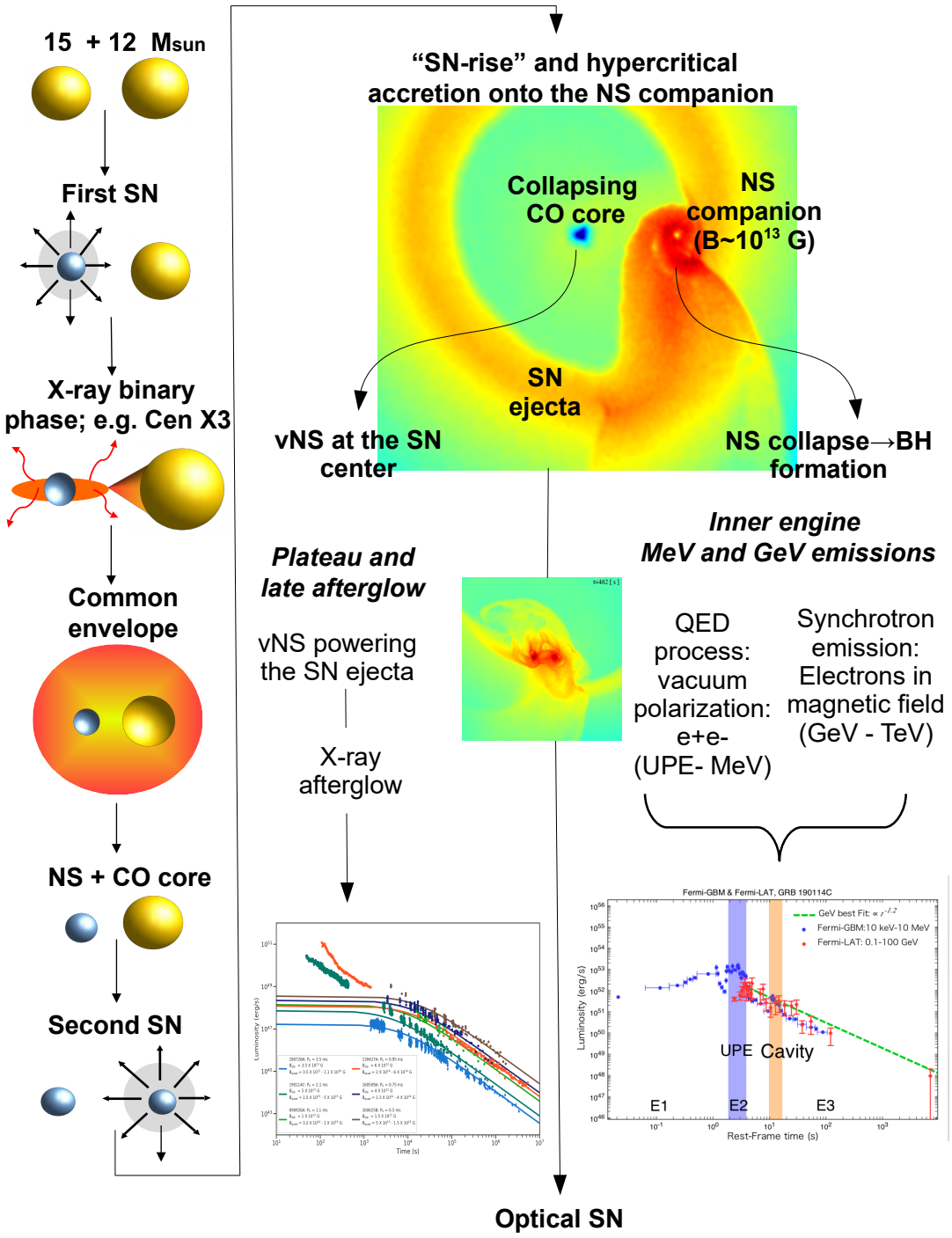

FIG. 2. The evolutionary path (left-hand side, from up to down) leading to the progenitor of a BdHN I, the carbon-oxygen star (CO_{core})-NS binary [18, 19]. The BdHN I starts with the second supernova (SN) explosion ("SN-rise"), leaving a newborn NS (νNS), and producing a hypercritical accretion process onto the NS companion [13]. As the NS reaches the critical mass, a BH is formed [14, 20], and a cavity is formed around it [16]. The newborn BH, the embedding magnetic field inherited from the collapsed NS, and the surrounding low-density ionized plasma, conform the "inner engine" of the GRB, which explains the high-energy GeV emission via synchrotron radiation.

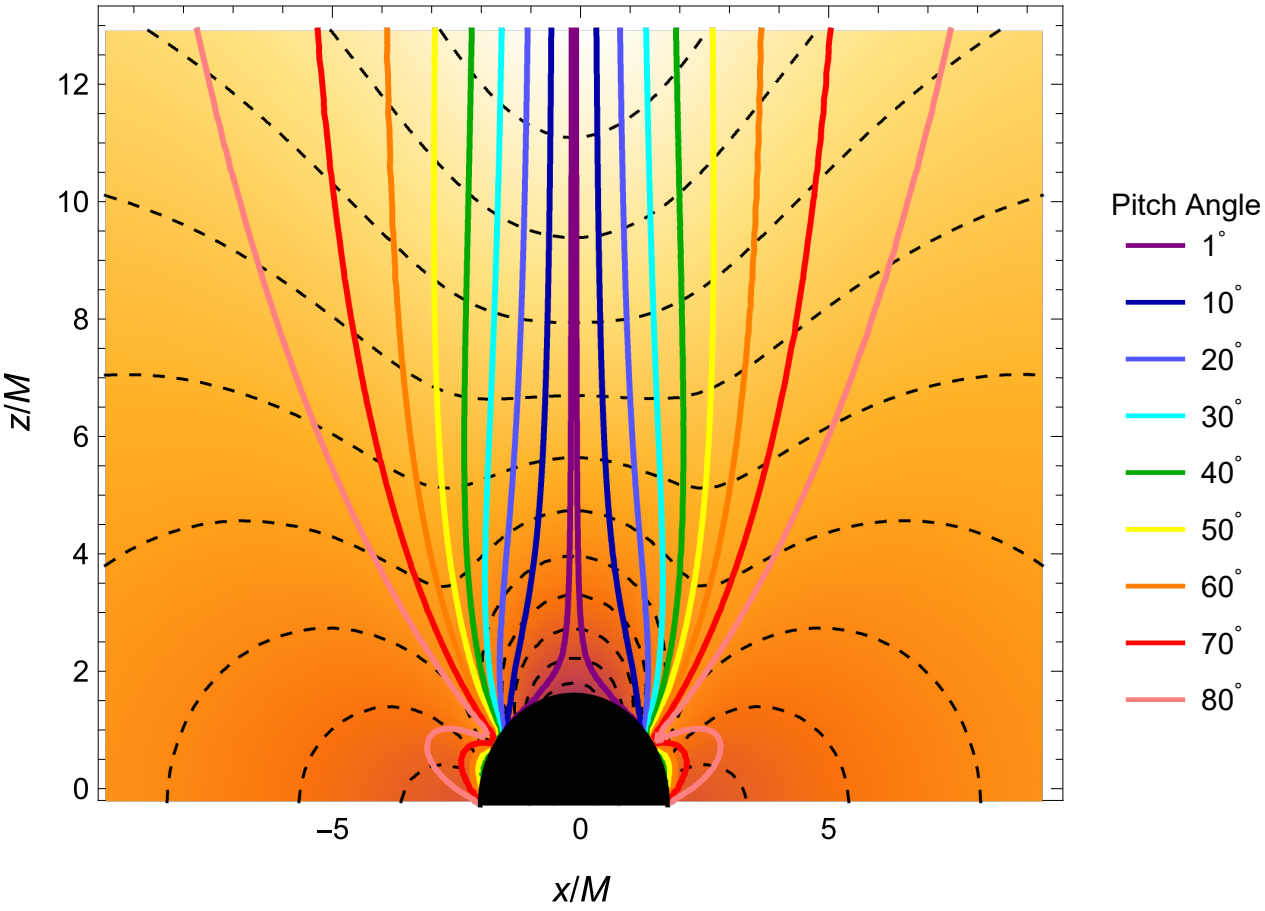

FIG. 3. Figure taken from [11] with the kind permission of the authors. Contours of constant pitch angle (colored curves from purple to pink) of electrons moving in the uniform magnetic field around the rotating BH (filled black disk). The black dashed curves represent contours of constant electric energy density, and the colored background shows how it decreases with distance. Compare and contrast these theoretical expectations with the recent observational data of M87 (see Figure 4 in [21]), which harbored a supermassive BH of nearly 10^{10} solar masses.

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