

Is a Black Hole a Neutron Star?

A Finite-Density Core Hypothesis

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Abstract

Black holes are strongly supported observationally by stellar and gas dynamics, gravitational-wave detections, and horizon-scale imaging. Their classical mathematical descriptions, however, contain singularities whose physical interpretation remains an open foundational issue. This paper examines a phenomenological alternative in which gravitational collapse terminates in a finite-density, rotating, neutron-star-like core rather than an infinite-density singularity. A limiting density $\rho_{\max} = 7.8 \times 10^{17} \text{ kg m}^{-3}$ is adopted as a working hypothesis, not as a consequence of General Relativity (GR) or of an established neutron-star equation of state. The resulting core radius is compared with the Schwarzschild and Kerr horizon radii. In the nonrotating approximation, the condition $R_n = 2GM/c^2$ gives a model-dependent horizon-crossing mass of approximately $4.86M_{\odot}$ and radius 14.35 km. Rotation is treated with Kerr geometry, and Cygnus X-1 and PSR J1903+0327 are used as illustrative cases. The conventional neutron-star stability limit, obtained from the Tolman–Oppenheimer–Volkoff (TOV) equations and an equation of state, is kept conceptually separate from the proposed horizon criterion. The paper also discusses the historical compact-object mass gap and the implications of GW230529.

1 Introduction and current status

In 1916 Karl Schwarzschild obtained the first exact spherically symmetric vacuum solution of Einstein’s field equations. In its modern interpretation, the maximally extended Schwarzschild geometry contains an event horizon at

$$R_h = \frac{2GM}{c^2}, \quad (1)$$

and a curvature singularity at $r = 0$. The event horizon is not a material surface; it is a causal boundary. Signals originating inside it cannot reach a distant external observer.

Einstein was skeptical that the idealized Schwarzschild singular behavior represented a realizable physical endpoint of stellar systems. Nevertheless, black holes are now strongly supported observationally. The Event Horizon Telescope produced the first horizon-scale image of M87* in 2019, while gravitational-wave observations have detected many mergers involving compact objects.

A historical precursor was John Michell’s 1783 “dark star” argument. Using Newtonian escape velocity, Michell considered stars sufficiently compact that even light, treated corpuscularly, could not escape. The resulting compactness scale has the same algebraic form as Eq. (1), although its physical interpretation is not that of a relativistic event horizon.

In 2023 Roy Kerr revisited the interpretation of black-hole singularities in *Do Black Holes Have Singularities?* [1]. Kerr argued that geodesic incompleteness established by singularity theorems should not automatically be identified with proof of a particular physical curvature singularity produced by realistic collapse. He also emphasized that the ring singularity of the ideal Kerr vacuum solution should not automatically be regarded as a physical material object.

Kerr’s discussion motivates reconsideration of the physical interior, but it does not derive the finite-density neutron-star-like core proposed here.

The hypothesis examined in this paper is therefore:

A black hole may contain a finite-density compact core hidden inside an event horizon, rather than matter compressed to an infinite-density singularity.

The purpose is to explore the quantitative consequences of this assumption and to distinguish them clearly from established results of GR and neutron-star physics.

2 Finite-density core hypothesis

The density inside a realistic neutron star is not uniform. Solutions of the TOV equations with realistic equations of state predict a density that generally increases toward the center. Nevertheless, for a simple first model we adopt the phenomenological limiting density

$$\rho_{\max} = 7.8 \times 10^{17} \text{ kg m}^{-3}. \quad (2)$$

This value is used as a characteristic nuclear-density scale. It is *not* an established universal upper density of matter and is not derived from GR or from a presently established neutron-star equation of state.

If a compact core of mass M is approximated as a sphere of uniform density $\rho_{\max}$, its physical radius is

$$R_n(M) = \left(\frac{3M}{4\pi\rho_{\max}} \right)^{1/3}. \quad (3)$$

Equation (3) is therefore a model relation rather than a realistic TOV density profile.

Strong-interaction physics provides qualitative motivation for resistance to compression. Nucleon–nucleon interactions develop a strong short-range repulsive component, and measurements of the proton’s internal pressure distribution reveal very large QCD stresses [5]. These observations motivate consideration of short-range resistance to compression, but they do not by themselves establish Eq. (2) or prove that gravitational collapse to a black hole cannot occur.

Hypothetical alternatives such as quark stars and preon stars have also been discussed in the literature [3]. Their possible existence illustrates that the state of matter above ordinary neutron-star densities is not settled observationally.

3 Nonrotating horizon-crossing condition

For a nonrotating spherical object, compare Eq. (3) with the Schwarzschild horizon radius, Eq. (1). The boundary at which the assumed physical core radius equals the horizon radius is

$$\left(\frac{3M}{4\pi\rho_{\max}} \right)^{1/3} = \frac{2GM}{c^2}. \quad (4)$$

Solving for M gives

$$M_{\text{HC}} = \left(\frac{3c^6}{32\pi\rho_{\max}G^3} \right)^{1/2}. \quad (5)$$

For Eq. (2),

$$\boxed{M_{\text{HC}} \simeq 4.86 M_{\odot}}, \quad \boxed{R_n = R_h \simeq 14.35 \text{ km}}. \quad (6)$$

We call M_{HC} the *model horizon-crossing mass*. It should not be interpreted as a universal minimum black-hole mass predicted by GR.

Within this simplified nonrotating model,

$$M < M_{\text{HC}} : \quad R_n > R_h, \quad (7)$$

$$M > M_{\text{HC}} : \quad R_n < R_h. \quad (8)$$

Thus the proposed finite-density core becomes hidden behind a Schwarzschild horizon above the model crossing mass.

4 Rotating compact objects and Kerr geometry

Real astrophysical compact objects generally carry angular momentum. The Schwarzschild solution is the exact $J = 0$ limit; the exterior spacetime of an isolated rotating black hole is described by the Kerr solution. Define the dimensionless spin parameter

$$a_* \equiv \frac{cJ}{GM^2}, \quad 0 \leq a_* \leq 1, \quad (9)$$

and the gravitational radius

$$r_g = \frac{GM}{c^2}. \quad (10)$$

The Kerr length parameter is

$$a = \frac{J}{Mc} = a_* r_g. \quad (11)$$

The outer event horizon is

$$R_{h+} = r_g \left(1 + \sqrt{1 - a_*^2} \right). \quad (12)$$

The Kerr curvature singularity is defined by

$$\Sigma = r^2 + a^2 \cos^2 \theta = 0, \quad (13)$$

which occurs at $r = 0$, $\theta = \pi/2$ in Boyer–Lindquist coordinates. In Kerr–Schild/Cartesian representations it has a ring scale a . To avoid confusing this with an ordinary spherical radius, we denote the characteristic Kerr ring scale by

$$R_{\text{ring}} \equiv a = a_* r_g. \quad (14)$$

The comparison $R_n < R_{\text{ring}}$ used below is an *additional model-dependent scale hypothesis*; it is not a condition for black-hole formation derived from Kerr geometry.

For the extremal limit $a_* = 1$,

$$R_{\text{ring}} = r_g, \quad R_{h+} = r_g, \quad (15)$$

so $R_{\text{ring}} = R_{h+}$. Equivalently, both are one-half of the Schwarzschild radius $2r_g$ associated with the same mass.

5 Case study: Cygnus X-1

As an illustrative stellar black-hole system, take

$$M = 21.2 M_{\odot}, \quad (16)$$

with the frequently quoted high-spin value $a_* \simeq 0.98$ used here as a representative input. Equation (3) gives

$$R_n \simeq 23.45 \text{ km}, \quad (17)$$

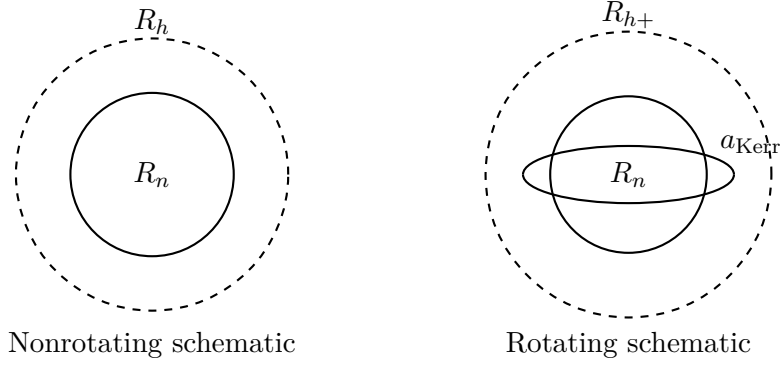


Figure 1: Schematic comparison only. The Kerr ring scale a is not a spherical shell and should not be interpreted as a Boyer–Lindquist radius enclosing the core.

while

$$r_g \simeq 31.31 \text{ km.} \quad (18)$$

At $a_* = 0.98$,

$$R_{\text{ring}} \simeq 30.68 \text{ km,} \quad R_{h+} \simeq 37.54 \text{ km.} \quad (19)$$

Thus, within the assumptions of the present model,

$$\boxed{R_n < R_{\text{ring}} < R_{h+}} \quad (20)$$

for this adopted spin.

For fixed $M = 21.2M_\odot$, R_n is constant in the uniform-density approximation while R_{ring} and R_{h+} vary with spin. Table 1 summarizes the result.

Table 1: Cygnus X-1 model radii for $M = 21.2M_\odot$.

a_*	R_n (km)	$R_{\text{ring}} = a$ (km)	R_{h+} (km)
0.00	23.45	0.00	62.61
0.10	23.45	3.13	62.45
0.20	23.45	6.26	61.98
0.30	23.45	9.39	61.17
0.40	23.45	12.52	60.00
0.50	23.45	15.65	58.42
0.60	23.45	18.78	56.35
0.70	23.45	21.91	53.66
0.80	23.45	25.04	50.09
0.90	23.45	28.17	44.95
0.95	23.45	29.74	41.08
0.98	23.45	30.68	37.54
0.99	23.45	30.99	35.72
1.00	23.45	31.31	31.31

The first result is

$$R_n < R_{h+} \quad (21)$$

throughout the formal Kerr range $0 \leq a_* \leq 1$. Thus, according to the horizon criterion of this paper, the assumed finite-density core is hidden behind the event horizon for every spin in the table.

The additional model scale condition $R_n < R_{\text{ring}}$ is reached when

$$a_{*,\text{crit}} = \frac{R_n}{r_g} = \frac{23.45}{31.31} \simeq 0.749. \quad (22)$$

Therefore, under this additional hypothesis, $R_n < R_{\text{ring}} < R_{h+}$ for $a_* > 0.749$ (with equality of R_{ring} and R_{h+} at the extremal limit).

6 Case study: PSR J1903+0327

PSR J1903+0327 provides an illustrative rotating neutron-star case. Taking

$$M = 1.67M_{\odot} \quad (23)$$

and, for illustration only, assuming $a_* = 0.5$, Eq. (3) gives

$$R_n \simeq 9.96 \text{ km}. \quad (24)$$

For this mass,

$$r_g \simeq 2.47 \text{ km}, \quad (25)$$

so

$$R_{\text{ring}} \simeq 1.23 \text{ km}, \quad R_{h+} \simeq 4.60 \text{ km}. \quad (26)$$

Hence

$$\boxed{R_n > R_{h+} > R_{\text{ring}}}. \quad (27)$$

The stellar surface therefore lies outside the formal Kerr horizon radius calculated from the same mass and assumed spin. These Kerr radii are reference scales only: because the material surface lies outside them, they do not describe an actual black-hole horizon or physical ring singularity for the neutron star.

The assumed $a_* = 0.5$ should not be confused with a directly measured Kerr spin parameter. For a neutron star,

$$a_* = \frac{cI\Omega}{GM^2}, \quad (28)$$

so its value depends on the moment of inertia I and therefore on the stellar structure and equation of state.

7 TOV stability and the compact-object mass interval

The horizon criterion alone does not determine the maximum mass of a stable neutron star. Relativistic stellar equilibrium is governed by the TOV equations,

$$\frac{dm}{dr} = 4\pi r^2 \frac{\varepsilon}{c^2}, \quad (29)$$

$$\frac{dP}{dr} = -\frac{G(\varepsilon + P)(m + 4\pi r^3 P/c^2)}{c^2 r^2 (1 - 2Gm/(rc^2))}, \quad (30)$$

together with an equation of state $P(\varepsilon)$. For each EOS, the maximum stable nonrotating configuration occurs at the turning point of the mass–central-density sequence. Current multimessenger analyses favor a representative nonrotating maximum mass of roughly

$$M_{\text{TOV}} \sim 2.2 - 2.3M_{\odot}, \quad (31)$$

with a characteristic maximum-mass radius near 12 km, although these are not universal constants [7].

The present model therefore contains two conceptually distinct scales:

1. the EOS/TOV stability scale, $M_{\text{TOV}} \sim 2.2 - 2.3M_{\odot}$;
2. the nonrotating model horizon-crossing scale, $M_{\text{HC}} \simeq 4.86M_{\odot}$.

The interval

$$\boxed{M_{\text{TOV}} \lesssim M \lesssim M_{\text{HC}}} \quad (32)$$

should be described as a *model-predicted transition interval*, not as an observationally empty mass gap.

Historically, X-ray-binary samples suggested a scarcity of compact objects between the heaviest neutron stars and black holes of roughly $5M_{\odot}$ and above, motivating the term “lower mass gap.” More recent gravitational-wave observations have identified compact objects within the traditional interval.

8 GW230529 and binary-spacetime qualification

The 2023 gravitational-wave event GW230529 changed the observational picture of the compact-object mass gap. The heavier component was inferred to have a mass of approximately $2.5\text{--}4.5M_{\odot}$, while the lighter component was approximately $1.2\text{--}2.0M_{\odot}$. Current analyses favor a low-mass black hole for the heavier component and a neutron star for the lighter component, although the nature of the heavier object was not established unambiguously from the gravitational-wave signal alone.

The inferred primary mass lies within the traditionally discussed lower mass-gap region and also overlaps the model transition interval defined above. However, a distinction is required between a compact object whose near-object exterior can be approximated as stationary Kerr and a compact object observed in the strongly dynamical late-inspiral and merger regime. Cygnus X-1 is itself a binary, but its near-black-hole geometry can be treated approximately as a stationary Kerr exterior for many purposes. GW230529, by contrast, was detected through a compact-binary inspiral in which orbital dynamics and tidal fields contribute to the spacetime.

Therefore, applying isolated Kerr relations directly to the individual components of GW230529 is an approximation. A decisive test of the present finite-density-core hypothesis in such a system would require a relativistic two-body treatment, including tidal effects and the conditions for apparent/common-horizon formation. GW230529 should consequently be regarded as an important potential test of the model rather than simply excluded from consideration.

9 Discussion

The proposal developed here should be separated into three layers:

1. **Established relativistic structure:** the Schwarzschild and Kerr horizon relations, and the EOS-dependent TOV stability problem.
2. **Phenomenological finite-density assumption:** $\rho_{\text{max}} = 7.8 \times 10^{17} \text{ kg m}^{-3}$, leading through Eq. (3) to a finite core radius.
3. **Additional Kerr-scale hypothesis:** the comparison $R_n < R_{\text{ring}} = a$, used as a characteristic-scale condition. This comparison is not required by standard Kerr geometry and requires further physical justification.

The principal falsifiable nonrotating prediction is the horizon-crossing scale $M_{\text{HC}} \simeq 4.86M_{\odot}$ under the assumed density law. A conclusively identified slowly rotating black hole well below this value would require modification of the assumed density, the uniform-density radius relation, or the proposed horizon criterion. Conversely, agreement of a population boundary with M_{HC}

would not by itself prove the model, because stellar evolution and selection effects can also shape the observed compact-object mass distribution.

A complete theory of a finite-density black-hole interior would require more than matching a spherical core radius to an exterior horizon. It would require a stress–energy tensor and equation of state, a regular rotating interior solution, junction conditions to an exterior spacetime, stability analysis, and predictions that distinguish the model observationally from standard black-hole solutions.

10 Conclusions

This paper explores the hypothesis that a black hole may contain a finite-density, neutron-star-like core rather than an infinite-density material singularity. With the phenomenological assumption $\rho_{\max} = 7.8 \times 10^{17} \text{ kg m}^{-3}$, a uniform-density approximation gives a nonrotating horizon-crossing mass $M_{\text{HC}} \simeq 4.86 M_{\odot}$. This is a model prediction, not a universal lower black-hole mass in GR.

For rotating objects, the Kerr outer horizon is

$$R_{h+} = \frac{GM}{c^2} \left(1 + \sqrt{1 - a_*^2} \right).$$

For Cygnus X-1 with $M = 21.2 M_{\odot}$, the assumed core radius is approximately 23.45 km and remains inside the Kerr outer horizon over the full formal spin range. At the representative value $a_* = 0.98$, the model gives $R_n \simeq 23.45 \text{ km}$, $R_{\text{ring}} \simeq 30.68 \text{ km}$, and $R_{h+} \simeq 37.54 \text{ km}$. For PSR J1903+0327 with $M = 1.67 M_{\odot}$ and illustrative $a_* = 0.5$, the corresponding model radius lies outside the formal Kerr horizon scale, consistent with a visible neutron star in the proposed classification.

The conventional maximum neutron-star mass must be obtained independently from the EOS and relativistic stellar equilibrium. A representative nonrotating value is $M_{\text{TOV}} \sim 2.2\text{--}2.3 M_{\odot}$. The interval between this stability scale and the model horizon-crossing scale is therefore a theoretical transition interval of the present hypothesis, not an observationally empty region. GW230529 demonstrates why this distinction is necessary and provides a potential future test requiring a two-body relativistic treatment.

References

- [1] R. P. Kerr, “Do Black Holes Have Singularities?”, arXiv:2312.00841 (2023). <https://arxiv.org/abs/2312.00841>
- [2] “Neutron star,” background density ranges and overview. https://en.wikipedia.org/wiki/Neutron_star
- [3] J. Hansson and F. Sandin, “Preon stars: a new class of cosmic compact objects,” Phys. Lett. B 616 (2005) 1–7, arXiv:astro-ph/0410417. <https://arxiv.org/abs/astro-ph/0410417>
- [4] Background discussion of short-range nucleon interactions: https://en.wikipedia.org/wiki/Nuclear_force
- [5] Jefferson Lab, “Quarks Feel the Pressure in the Proton.” <https://www.jlab.org/news/releases/quarks-feel-pressure-proton>
- [6] LIGO/Caltech, compact-object mass graphic (historical population illustration). <https://www.ligo.caltech.edu/image/ligo20181203a>
- [7] Z. Kasza and G. Wolf, neutron-star equation-of-state constraints and maximum-mass inference, arXiv:2605.00437 (2026). <https://arxiv.org/abs/2605.00437>

- [8] LIGO–Virgo–KAGRA Collaboration, GW230529 discovery and interpretation. <https://ligo.org/detections/gw230529/>