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Neutron-Cored Black Holes: A Radius-Based Study

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Abstract:
Compact objects such as neutron stars and black holes probe gravitational physics at extreme densities and pressures. While neutron stars are supported by matter-based pressure, black holes are characterized by geometric trapping at the event horizon. In this work, we examine a simplified neutron-cored black hole model using a radius-based analysis of gravitational acceleration, escape velocity, and global confinement pressure for a fixed mass configuration. Standard gravitational relations are evaluated as explicit functions of radius, allowing direct comparison between matter-supported and geometry-dominated regimes without invoking exotic matter or modified gravity. The results show that confinement pressure exhibits a bounded profile with a well-defined maximum, rather than diverging monotonically, while the normalized escape velocity approaches the relativistic trapping condition near the Schwarzschild radius. A schematic geometric model is introduced solely to define radial regions used in the analysis. The study demonstrates that classical gravitational relations, applied consistently across neutron-scale and horizon-scale radii, provide a transparent and internally consistent framework for interpreting transitions between dense matter confinement and black-hole trapping.

Keywords: Neutron stars; Black holes; Schwarzschild radius; Escape velocity; Gravitational confinement pressure; Compact objects; Radial dependence

1. Introduction:

Compact astrophysical objects provide a unique testing ground for gravitational physics under extreme conditions. Among these, neutron stars and black holes represent the densest stable and unstable configurations known, respectively, and their properties are constrained by both observational data and well-established theoretical frameworks [1–3]. Neutron stars are supported against gravitational collapse by neutron degeneracy pressure and short-range nuclear interactions [10,11,12], while black holes are characterized by the formation of an event horizon beyond which matter and radiation are causally trapped [4].

Conventional treatments of black hole formation extrapolate gravitational collapse toward arbitrarily high densities, often invoking singular behavior at vanishing radius within classical general relativity [5]. In contrast, neutron matter already represents the densest empirically supported state of matter, with a finite and well-defined pressure scale inferred from neutron structure and neutron-star phenomenology [2,6]. This raises a natural question regarding the interplay between neutron-matter stiffness and gravitational confinement as a system transitions from matter-supported equilibrium to geometry-dominated trapping.

In recent years, increasing attention has been given to understanding compact-object interiors using radius-based and pressure-based descriptions, rather than focusing solely on asymptotic or singular limits [7–9]. Such approaches emphasize the role of global confinement pressure, escape velocity, and gravitational acceleration as functions of radius, allowing for transparent comparisons between different physical regimes without introducing exotic matter states or modifications to gravity.

Motivated by these considerations, the present work examines a simplified neutron-cored black hole model by systematically analyzing the radial dependence of gravitational acceleration, escape velocity, and confinement pressure for a fixed mass configuration. The goal is not to propose a new collapse mechanism, but to explore whether classical gravitational relations, when applied consistently across neutron-scale and horizon-scale radii, yield bounded and physically interpretable behavior.

To this end, we adopt standard expressions for gravitational acceleration, escape velocity, and global confinement pressure, and evaluate their behavior with respect to radius. The results are presented in normalized form to highlight characteristic transitions and extrema. A schematic geometric model is introduced solely to define radii and regions used in the analysis. No assumptions are made regarding detailed microphysics, equations of state, or quantum-gravitational effects.

This radius-based analysis provides a transparent framework for comparing neutron-scale stiffness with black-hole trapping behavior, and offers a consistent baseline for interpreting compact-object structure within established gravitational theory.

2.Main Framework

Neutron-Cored Black Hole: A Pressure-Limited Two-Zone Model:

2.1. Physical Motivation

Neutron stars represent the most compact and stable form of matter currently known in astrophysics. Their observed masses, radii, and stability indicate that neutron matter can sustain extraordinarily high internal pressures without undergoing further collapse. These objects therefore provide a natural empirical benchmark for the limits of matter compression under gravity.

Previous analyses of neutron confinement and strong interaction pressure demonstrate that neutron matter exhibits a finite and well-defined pressure ceiling, beyond which additional compression is not physically supported. This pressure-limited behavior plays a central role in determining neutron star stability and maximum mass.

The present work is motivated by the observation that the characteristic pressure and density scales inferred from neutron star phenomenology are consistent with a pressure-bounded confinement model of neutron matter. This raises a fundamental question: what occurs when gravitational mass exceeds neutron star stability limits while the pressure response of matter remains finite?

Rather than assuming unlimited compressibility or invoking singular behavior, this study explores the consequences of extending neutron star physics into the black hole regime under the constraint of finite neutron pressure. The resulting model naturally leads to a compact object consisting of a neutron-density core surrounded by a gravitationally trapped shell.

In this sense, a neutron-cored black hole emerges as a direct continuation of neutron star physics, governed by the same pressure constraints that stabilize neutron matter, with gravity acting primarily through geometric confinement rather than additional material compression.

Traditional black hole treatments often extrapolate gravitational collapse by assuming continued compressibility of matter beyond nuclear density. In contrast, neutron matter, supported by both theoretical confinement analyses and neutron-star observations, exhibits a finite pressure response with a well-defined upper limit. The present work examines the implications of applying this pressure constraint to the black hole regime, in which gravitational collapse is expected to transition from material compression to geometric confinement once the neutron pressure ceiling is reached.

2. 2 Core Hypothesis

A black hole may be modeled as a pressure-limited object consisting of a neutron-density core surrounded by a gravitationally trapped shell.

Key assumptions:

- Neutron matter provides the **maximum sustainable inward pressure** available to known physics.
- Gravity cannot compress matter beyond this pressure ceiling.
- Additional mass accumulation modifies the system's geometry rather than increasing central density.

This leads naturally to a **neutron-cored black hole** configuration.

2.3 Two-Zone Structural Description

2.4 Zone I: Neutron Core (Pressure-Dominated Region)

The inner region consists of matter at approximately neutron density. In this zone:

- Internal pressure is governed by neutron confinement physics.
- The pressure reaches a maximum value characteristic of neutron matter.
- Further compression is physically unavailable once this limit is attained.

The neutron core therefore defines a **minimum radius** for stable matter confinement under extreme gravity.

2.5 Zone II: Gravitational Shell (Geometry-Dominated Region)

Surrounding the neutron core is an extended region dominated by gravitational effects:

- Mass added to the system accumulates primarily in this outer shell.
- The escape velocity increases with radius and reaches the speed of light at the Schwarzschild boundary.
- Gravitational trapping arises from spacetime geometry rather than additional material compression.

Importantly, matter in this region does **not** increase the pressure of the neutron core.

3. Governing Relations

The system is described using standard gravitational relations:

- Escape velocity as a function of radius
- Gravitational acceleration
- Pressure inferred from confinement force per unit area

No modification to general relativity is assumed externally. The novelty lies in applying a **finite pressure response** internally, consistent with known neutron physics.

3.1. Escape Velocity Behavior

The escape velocity increases monotonically as radius decreases and reaches the speed of light at the Schwarzschild radius. Beyond this point:

- Escape velocity does not diverge.
- The event horizon forms as a geometric boundary.
- Gravity ceases to act as an additional compressive mechanism.

This saturation behavior indicates that gravitational collapse transitions from a **compressive regime** to a **purely geometric trapping regime**.

3.2. Pressure Profile and Collapse Limitation

The pressure profile exhibits a clear and physically significant structure:

- Pressure rises toward the neutron core radius.
- A maximum pressure is attained at neutron density.
- Beyond this radius, pressure decreases rapidly despite increasing enclosed mass.

This demonstrates that gravitational collapse does **not** produce unlimited pressure. Instead, collapse stalls once the neutron pressure ceiling is reached, preventing singular compression.

3.3. Interpretation: Why a Singularity Does Not Form[13]:

The absence of a singularity follows directly from physical constraints:

1. Matter exhibits a finite pressure response.
2. Neutron matter already saturates this response.
3. Gravity cannot supply infinite inward pressure.
4. Additional mass therefore increases spatial extent, not density.

Thus, a black hole is best interpreted as a **pressure-bounded object enclosed by an event horizon**, rather than an object of infinite density.

3.4. Definition of a Neutron-Cored Black Hole

A neutron-cored black hole is defined as a compact gravitational system in which:

- The central core consists of neutron-density matter at maximum sustainable pressure.
- The surrounding region is a gravitational shell governed by spacetime geometry.
- The event horizon encloses the system without requiring singular behavior.
- Growth occurs via shell expansion rather than further core compression.

3.5. Role of Parametric Analysis

The quantitative behavior of mass, escape velocity, gravitational acceleration, and pressure as functions of radius is evaluated through a parametric analysis. These results are used to generate the figures presented in this work.

The full numerical evaluation and tabulated data are provided separately for reference.

3.6. Summary of the Main Result

Black holes do not crush matter beyond neutron limits; they confine it behind geometry.

This pressure-limited interpretation offers a physically grounded alternative to singular collapse while remaining compatible with established gravitational theory at observable scales.

4. MAIN FRAME:

4.1 Main Framework and Definitions

This work examines gravitational confinement and pressure limits in compact objects, with particular focus on the transition from neutron-supported matter to geometry-dominated trapping. The analysis is carried out using standard classical and relativistic relations, applied consistently across neutron-scale and black-hole–scale configurations.

4.2 Fundamental Constants and Symbols:

The following symbols are used throughout:

- c — speed of light in vacuum=3×10^{8} m/ s
- G — gravitational constant = 6.67×10^{-11} m^{3} kg^{-1} s^{-2}

- ρ— mass density (kg m^{-3})~ Neutron Density ≈ $4x10^{17}$ kg m^{-3}
- R — radius (m)
- M — mass (kg)
- Ms — solar mass
  Ms — 2×10^{30} kg
- n — number of solar masses

4.3 Mass–Density Relation [10]:

For a spherically symmetric configuration of uniform density ρ, the mass contained within radius R is

$M = 4/3 \text{ x } \pi \text{ x } R^3 \text{x } \rho$ kg (1)

Where, ρ is the density in kg/m^3

4.4 Black Hole and Neutron Core Mass

In the present analysis, the mass of the black hole is taken to be equal to the mass of its neutron core:

Mbh = Mnc = n x Ms (2)

Where, n is the number of solar masses.

4.5 Schwarzschild (Event Horizon) Radius[12]:

For a non-rotating, uncharged configuration, the event horizon coincides with the Schwarzschild radius:

Rsh =2 G x M/c^2 m (3)

This radius defines the transition to geometry-dominated confinement.

4.6 Neutron Core Radius[11]:

Assuming the neutron core consists of matter at a characteristic confined neutron density ρ_n , its radius is obtained from the mass–density relation:

$$\text{Rnc}=Rnc = \left(\frac{3xMnc}{4x\pi x\rho_n}\right)^{1/3} \quad (4)$$

4.7 Gravitational Acceleration

The local gravitational acceleration at radius R is given by

$$g_r = \frac{GxM}{R^2} \quad (5)$$

4.8 Escape Velocity

The escape velocity from radius R is

$$V_{esc} = \left(\frac{2xGxM}{R}\right)^{1/2} \quad (6)$$

This quantity is used to identify the onset of relativistic trapping as Vesc→c

4.9 Gravitational Confinement Pressure

A characteristic gravitational confinement pressure Ps(R) is defined as

$$P_s(R) = \frac{3xGxM^2}{8x\pi xR^4} \quad (7)$$

This pressure represents a **global confinement stress** required to support mass M within radius R. It is not a local thermodynamic pressure or an equation-of-state quantity, but a scaling measure suitable for comparing material pressure limits with gravitational demand.

5. Parameter Selection for Numerical Analysis

For illustration, we consider a compact object of mass

n=15 (8)

corresponding to Black Hole and Neutron Core mass respectively

$Mbh = Mnc = 15 \text{ x } Ms = 3\times10^{31}$ kg (9)

The confined neutron density is taken as

$\rho_n = 4\times10^{17}$ kg m^{-3} (10)

From these values:

- **Schwarzschild radius (Rsh):**

Substitution in Equation (6) yields

$$Rsh = \frac{2xGx(3x10^{31})}{c^2} = 4.45\times10^4 \text{ m}$$

- **Neutron core radius (Rnc)**

Substitution in Equation (4) yields

$$Rnc = \left(\frac{3x(3x10^{31})}{4x\pi x(4x10^{17})}\right)^{1/3} = 2.26\ x\ 10^4\text{m}$$

5.1 Interpretation

The proximity of Rnc and Rsh for this mass scale highlights the narrow regime separating matter-supported confinement from geometry-dominated trapping. This framework enables a direct comparison between neutron confinement pressure and gravitational confinement demand without invoking exotic matter states or unbounded compressibility.

6. Ref. to Appendix A: Relations between Mass, Gravity, Escape Velocity, and Confinement Pressure:

In this appendix, we summarize the interrelation between mass, gravitational acceleration, escape velocity, and gravitational confinement pressure as functions of radius for the compact configuration considered in the main text. All quantities are evaluated consistently using the definitions introduced in Section 2, with mass held fixed and radius treated as the independent variable.

The gravitational acceleration at radius R is given by $g(R)=GM/R^2$, while the corresponding escape velocity follows from Vesc (R)=2GM/R . The characteristic gravitational confinement pressure is defined as $Ps(R)=3GM^2/(8\pi R^4)$, representing the global inward stress required to confine mass M within radius R. These quantities are not independent: the pressure scales with the square of the gravitational force per unit area, while the escape velocity reflects the same mass–radius coupling expressed in kinematic form.

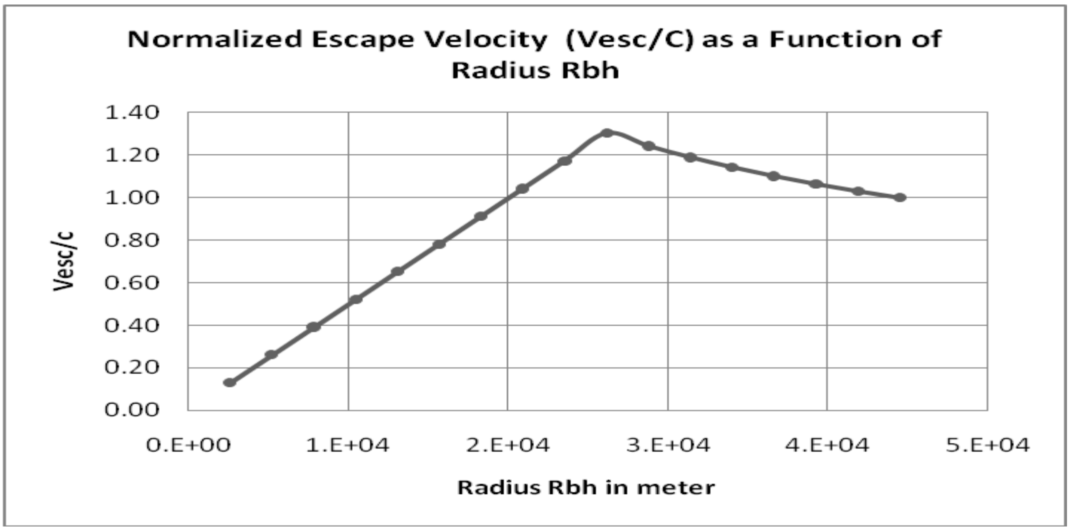

Figure-1

Figure 1 presents the normalized escape velocity Vesc/c as a function of radius, illustrating the approach to the relativistic trapping condition as the Schwarzschild radius is approached.

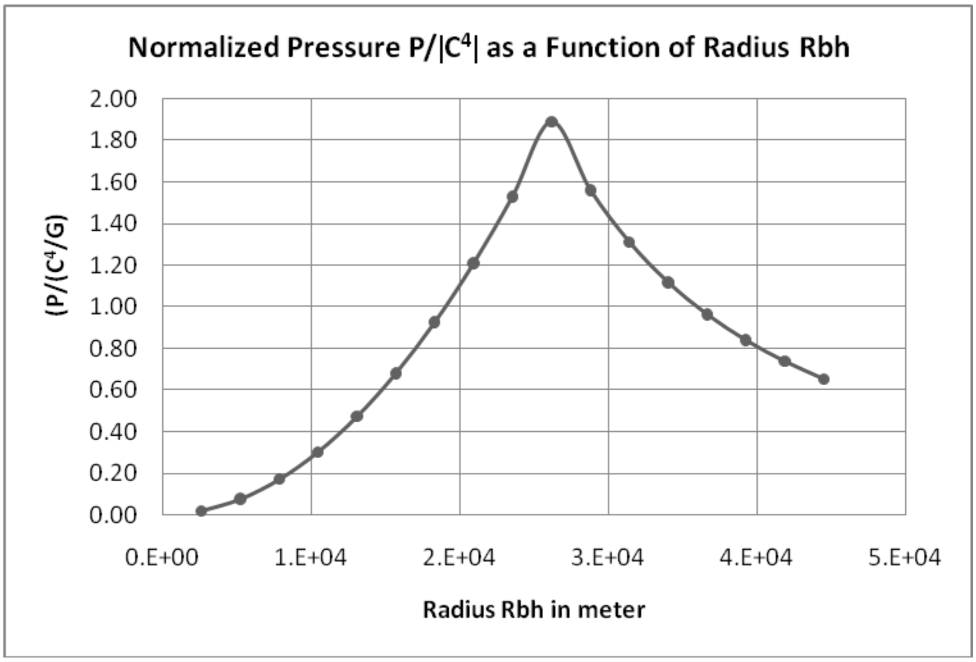

Figure-2

Figure 2 shows the corresponding normalized confinement pressure, highlighting the radius at which the required pressure reaches a maximum and subsequently decreases as geometric confinement becomes dominant where $|c^4| \approx 8 \times 10^{33}$ kg m^{-2}. Together, these figures demonstrate how increasing gravitational strength does not lead to unbounded pressure growth but instead signals a transition from matter-supported confinement to geometry-dominated trapping.

The appendix figures are provided to establish internal consistency between gravitational acceleration, escape velocity, and confinement pressure within the adopted framework, and to support the interpretation discussed in the main text.

7. Conclusions

In this work, we examined a simplified neutron-cored black hole model by analyzing the radial dependence of gravitational acceleration, escape velocity, and confinement pressure for a fixed mass configuration. The objective was not to introduce new interaction mechanisms, but to explore whether known gravitational relations remain internally consistent when evaluated across radii spanning a dense neutron core and the surrounding event-horizon geometry.

Using standard definitions for gravitational acceleration, escape velocity, and global confinement pressure, we showed that these quantities are tightly coupled through their shared dependence on mass and radius. When expressed as functions of radius, the resulting profiles exhibit well-defined extrema and transitions, indicating that gravitational compression does not lead to monotonically increasing pressure. Instead, the analysis reveals a characteristic radius at which the required confinement pressure reaches a maximum before decreasing as geometric trapping becomes dominant.

The normalized escape-velocity profile further highlights this transition, showing the approach to the relativistic trapping condition near the Schwarzschild radius. Together, the pressure and velocity trends support a picture in which matter-supported confinement and geometry-dominated trapping represent distinct regimes, separated by a smooth radial transition rather than a singular divergence.

A schematic neutron-cored configuration was introduced solely to clarify the geometric regions and radial coordinates used in the analysis. No assumptions were made regarding the detailed microphysics inside the neutron core or beyond the event horizon. The results therefore remain agnostic with respect to the equation of state, quantum effects, or specific collapse mechanisms.

Overall, the study demonstrates that classical gravitational relations, when consistently applied, naturally lead to bounded pressure behavior and clear radial transitions in compact objects. These findings provide a transparent framework for interpreting neutron-scale stiffness and black-hole trapping within a single, radius-based description, without invoking exotic matter states or modifying established gravitational theory.

This approach provides a simple baseline for comparing matter-supported and geometry-dominated regimes in compact astrophysical objects.

References:

1. Shapiro, S. L., & Teukolsky, S. A., *Black Holes, White Dwarfs, and Neutron Stars*, Wiley (1983).
2. Lattimer, J. M., & Prakash, M., *Science* **304**, 536 (2004).
3. Haensel, P., Potekhin, A. Y., & Yakovlev, D. G., *Neutron Stars 1*, Springer (2007).
4. Misner, C. W., Thorne, K. S., & Wheeler, J. A., *Gravitation*, Freeman (1973).
5. Hawking, S. W., & Ellis, G. F. R., *The Large Scale Structure of Space-Time*, Cambridge (1973).
6. Baym, G., Pethick, C., & Sutherland, P., *Astrophys. J.* **170**, 299 (1971).
7. Oppenheimer, J. R., & Volkoff, G. M., *Phys. Rev.* **55**, 374 (1939).
8. Tolman, R. C., *Phys. Rev.* **55**, 364 (1939).
9. Lattimer, J. M., *Annu. Rev. Nucl. Part. Sci.* **62**, 485 (2012).
10. V. T. Ingole, Anant S. Wadatkar “A Classical Derivation of the Neutron Strong Force from Internally Confined Charge Structure.” Advanced International Journal for Research (AIJFR), Volume 7, Issue 1 (January-February 2026)
11. V. T. Ingole, Anant S. Wadatkar “A Yukawa-Like Neutron Short-Range Force Profile via Classical Methods.” International Journal for Multidisciplinary Research (IJFMR), Volume 8, Issue 1, (January-February 2026)
12. V. T. Ingole, Anant S. Wadatkar “A Pressure-Based Criterion for the Stability of Self-Gravitating Matter with a Vacuum Tension Interpretation (VTI).” International Journal for Multidisciplinary Research (IJFMR), Volume 8, Issue 1, (January-February 2026)
13. V. T. Ingole, Treatise “Black Hole Made Easy”, Research Gate.