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Article

A Theoretical Framework for Supernova Energy Amplification Through Exotic-Matter Formation

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Abstract

We explore a theoretical framework addressing the supernova shock revival problem through matter phase transitions during core collapse. Extending Lockyer’s geometric model, we investigate how extreme compression might induce reversible energy storage in modified nucleonic states. The proposed mechanism exhibits 2:1 energy release upon decompression, naturally yielding ~1% mass-to-energy conversion, matching observed explosion energies without fine-tuning. Analytical estimates suggest that the collapse energies could reach thresholds for such transitions, potentially explaining both shock revival and the supernova/black-hole dichotomy.

Keywords: core collapse; supernova explosion; shock revival; black-hole progenitors; neutron stars; gravitational binding energy; nuclear compression; exotic matter; energy amplification; mass-energy conversion; phase transition; high-density physics; stellar evolution; big bounce; theoretical particle models; beyond standard model physics

1. Introduction

Massive stars develop iron cores supported by electron degeneracy pressure. Once the Chandrasekhar mass limit is exceeded, the core becomes unstable and collapses on a dynamical timescale (~ 0.1 s). This collapse releases a vast reservoir of gravitational energy, partially transferred to the core as compressional heating and kinetic shock energy.

Traditional explanations for supernova shock revival include neutrino heating, convection, and standing accretion shock instabilities (SASI). However, in many numerical simulations the shock still stalls, and a robust explosion mechanism remains elusive.

In [1], we proposed a new mechanism: *the formation of exotic matter at the stellar center caused by extreme compression*. This matter absorbs substantial energy by increasing its number of internal nested energy levels. Once the core pressure drops, the unstable exotic matter disintegrates, isotropically releasing energy and contributing to shock revival.

To evaluate this mechanism quantitatively, we must compute the maximum compression energy delivered to the core by collapsing stellar layers. This article presents these calculations in detail.

2. Overview of Current Theoretical Model

2.1. Final Evolution of a Massive Star and Iron Core Formation

Stars with initial masses greater than $8 M_{\odot}$ undergo successive, increasingly brief fusion phases:

- Hydrogen $\rightarrow$ Helium (millions of years)
- Helium $\rightarrow$ Carbon (thousands of years)
- Carbon $\rightarrow$ Neon, Oxygen (a few years)
- Oxygen $\rightarrow$ Silicon (months)
- Silicon $\rightarrow$ **Iron** (a few days)

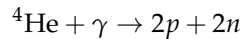
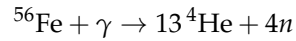
Iron-56, the nucleus with the highest binding energy per nucleon, marks the end of exothermic fusion. The core, composed of iron/nickel nuclei and degenerate electron gas, contracts slowly until it reaches $\sim 1.4 M_{\odot}$ (the Chandrasekhar limit), at which point it becomes gravitationally unstable.

2.2. The Collapse

Two main triggering mechanisms operate simultaneously:

2.2.1. a) Photodisintegration of Iron

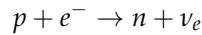
When central temperatures exceed $\sim 5 \times 10^9$ K (about 500 keV), gamma photons become energetic enough to dissociate iron nuclei:



These reactions absorb enormous energy (approximately 8 MeV per nucleon), reducing thermal pressure and accelerating collapse.

2.2.2. b) Electron Capture

As the core compresses, electrons in the degenerate gas reach increasingly high Fermi energies. Some become energetic enough for capture by protons:



Consequences include: reduced electron number (decreasing degeneracy pressure); neutrino escape (carrying away energy); and neutron-rich nuclei formation.

2.2.3. Runaway Collapse

- Initial collapse lasts milliseconds
- Core shrinks from ~ 5000 km to ~ 50 km
- Density reaches nuclear density ($\sim 10^{17}$ kg/m³)
- Matter becomes degenerate neutron fluid
- Collapse halts when neutron degeneracy pressure balances gravity

2.3. The Problematic Bounce and Shock Revival

When the inner core ($\sim 0.8M_\odot$) reaches nuclear density, it rebounds, generating a shock wave. This shock typically stalls at ~ 100 – 200 km due to energy losses from iron dissociation (~ 8 MeV/nucleon) and neutrino escape.

Standard revival mechanisms include neutrino heating (where neutrinos deposit energy in semi-transparent regions) and hydrodynamic instabilities (Rayleigh-Taylor, SASI, convection). Yet many simulations fail to produce robust explosions matching observations, indicating a missing energy source.

3. Exotic-Matter Model

Lockyer's model (Appendix 10) reproduces proton/electron and neutron/electron mass ratios to 7 and 6 significant digits using only physical constants. This model features 18 nested energy layers with a constant $\sqrt{2}$ progression between successive energy levels.

We extend this model by proposing that during collapse, neutrons absorb energy by increasing their number of internal layers, forming "exotic" neutrons stable only under strong confinement.

3.1. Energy Threshold from Lockyer's Model

In Lockyer's model, the last layer (18th) corresponds to 538.54 times the electron mass. With the electron mass being 0.511 MeV, this gives:

$$\text{Shell}_{18} = 538.54 \times 0.511 \text{ MeV} = 275.2 \text{ MeV}.$$

Assuming only even numbers of shells are allowed, adding two new shells yields:

$$\text{Shells}_{19-20} = E_{18}(\sqrt{2} + 2) = 275.2 \times 3.414 \approx 939.59 \text{ MeV} \quad (1)$$

3.2. Key Energy Relationship

A fundamental insight emerges: forming a 20-shell exotic neutron requires:

$$\Delta E = \text{Shells}_{19-20} = 939.6 \text{ MeV} = m_n c^2$$

which equals the rest energy of a standard neutron. This leads to the transformation:

$$n + m_n c^2 \rightarrow n_{20}^*$$

where n_{20}^* denotes the 20-shell exoneutron with total energy $2m_n c^2 = 1879.2 \text{ MeV}$.

3.3. Formation Mechanism Sequence

The exotic-matter formation proceeds through the following sequence:

1. **Shock wave propagation:** The rebounding shock wave travels inward toward the core center. Initially, it lacks sufficient energy density to transmute ordinary matter into exotic states.
2. **Energy concentration at the center:** As the shock converges geometrically at the core center, its energy density increases dramatically. At the center, the concentrated energy reaches the 939.6 MeV per neutron threshold required to add two internal energy shells.
3. **Exotic-matter formation:** Neutrons in the central region transform into exoneutrons₂₀, absorbing shock energy.
4. **Pressure reduction:** Once part of the shock energy has been absorbed to create exotic matter, the associated pressure drops below the stability threshold.
5. **Exotic matter disintegration:** The unstable exotic matter completely disintegrates, releasing both the absorbed compression energy and the rest mass energy of the original neutrons.

The complete cycle bifurcates based on residual pressure:

- **If residual pressure remains sufficient:** The exotic core persists, forming a black hole (high-mass progenitors).
- **If pressure becomes insufficient:** Exotic matter destabilizes and decays, powering a supernova explosion (typical core-collapse).

4. Energy Available During Collapse

4.1. Gravitational Energy of Collapsing Layers

Consider a shell of mass dm at radius r with enclosed mass $M(r)$. Its gravitational potential energy is:

$$dU = -\frac{GM(r)}{r} dm. \quad (2)$$

During rapid collapse, this converts to kinetic energy deposited upon impact. Falling from initial radius R to core radius R_c delivers approximately:

$$\Delta U \approx GM(r) dm \left(\frac{1}{R_c} - \frac{1}{R} \right). \quad (3)$$

For the outer envelope, $R \gg R_c$, so $1/R \ll 1/R_c$, simplifying to:

$$\Delta U \approx \frac{GM(r) dm}{R_c}. \quad (4)$$

Integrating over all layers gives the total central energy delivered.

4.2. Energy Per Nucleon in Supernova Collapse

For a typical progenitor [9]:

- Collapsing mass: $M \sim 1.5M_{\odot}$ (iron core plus infalling layers)
- Core radius at shock convergence: $R_c \sim 30$ km (standard bounce radius)

The gravitational energy delivered is:

$$U_{\text{tot}} \sim \frac{GM^2}{2R_c}. \quad (5)$$

With $M = 3.0 \times 10^{30}$ kg and $R_c = 3.0 \times 10^4$ m:

$$U_{\text{tot}} \sim \frac{6.67 \times 10^{-11} (3.0 \times 10^{30})^2}{2(3.0 \times 10^4)} \sim 1.0 \times 10^{46} \text{ J}.$$

The number of nucleons is: $N \sim M/m_p \approx 1.8 \times 10^{57}$. Average energy per nucleon:

$$E_{\text{nuc}} \approx 5.55 \times 10^{-12} \text{ J} \approx 34.6 \text{ MeV}.$$

4.3. Enhanced Energy Budget

4.3.1. Core Contraction

If exotic-neutron formation reduces the core radius by factor $\sqrt{2}$ (from $R_1 = 30$ km to $R_2 \simeq 21.2$ km), additional gravitational energy is released:

$$\Delta U = \frac{GM^2}{2} \left(\frac{1}{R_2} - \frac{1}{R_1} \right) \approx 4.10 \times 10^{45} \text{ J},$$

corresponding to $\Delta E_{\text{nuc}} \approx 14.35$ MeV per nucleon.

4.3.2. Dynamical Infall of Outer Layers

The kinetic energy of infalling outer layers multiplies the static-core energy by a factor ~ 2.5 (range 2–3). Including this enhancement:

$$E_{\text{nuc}}^{\text{dyn}} \simeq 34.6 \text{ MeV} \times 2.5 \simeq 86.5 \text{ MeV}.$$

4.3.3. Total Combined Energy

Combining dynamical infall and core contraction effects:

$$E_{\text{nuc}}^{\text{total}} \simeq 86.5 \text{ MeV} + 14.35 \text{ MeV} \simeq 100.9 \text{ MeV}.$$

4.4. Energy Concentration Mechanism

The average energy per nucleon (100.9 MeV) remains below the 939.6 MeV threshold. However, geometric concentration at the core center provides the necessary energy density. When a spherical shock converges, its energy focuses into a progressively smaller volume. If energy concentrates in a fraction f of the core volume:

$$E_{\text{concentrated}} = \frac{E_{\text{nuc}}^{\text{total}}}{f}$$

For $f = 0.01$ (1% volume concentration, realistic for spherical convergence):

$$E_{\text{concentrated}} \approx \frac{100.9 \text{ MeV}}{0.01} \approx 10.1 \text{ GeV}$$

This comfortably exceeds the 939.6 MeV threshold required for exoneutron₂₀ formation. Even with conservative focusing ($f = 0.1$), concentrated energies reach 1.0 GeV, sufficient to trigger the exotic transformation.

5. Energy Amplification Mechanism

5.1. Amplification Factor

The transformation process exhibits an **energy amplification factor of 2**:

Standard neutron : 18 shells, $E = 939.6 \text{ MeV}$ (6)

Exoneutron₂₀ : 20 shells, $E = 939.6 + 939.6 = 1879.2 \text{ MeV}$ (7)

The complete cycle:

$$n + 939.6 \text{ MeV} \rightarrow n_{20}^* \rightarrow 1879.2 \text{ MeV}$$

Energy balance:

- **Energy invested:** 939.6 MeV to form one exoneutron₂₀
- **Energy recovered:** 1879.2 MeV upon disintegration
- **Net gain:** 939.6 MeV (100% return plus original investment)

5.2. Positive Feedback Mechanism

This creates a powerful positive feedback loop:

$$E \rightarrow \text{exoneutrons} \rightarrow 2E \rightarrow \text{more exoneutrons} \rightarrow 4E \rightarrow \dots$$

5.3. Comparison with Classical Supernova Theory

In classical supernova models, gravitational energy dissipates through irreversible processes:

- **Photodisintegration:** Absorbs $\sim 8 \text{ MeV/nucleon}$ irreversibly
- **Neutrino emission:** Carries away $\sim 99\%$ of collapse energy
- **Inefficient heating:** Only $\sim 1\%$ of neutrino energy is reabsorbed

This progressive energy loss causes the shock to stall at 100–200 km from the center.

In our exotic-matter model:

- **Energy storage:** Compression energy stores reversibly in internal neutron structure
- **Energy amplification:** Disintegration yields twice the invested energy
- **Positive feedback:** Released energy enables further exotic-matter formation
- **Shock revival:** Amplified energy overcomes losses and revives the stalled shock

6. Application to Supernova Explosions

6.1. Self-Limiting Chain Reaction

The explosive nature of the process self-limits its extent. As energy releases:

$$\text{Energy release} \rightarrow \text{Pressure increase} \rightarrow \text{Matter ejection} \rightarrow \text{Pressure drop} \rightarrow \text{Process stops}$$

Only a fraction X of the core neutrons undergo exotic transformation before the explosion disperses the material.

6.2. Predicted Explosion Energy

If $X = 1\%$ of neutrons transform and disintegrate:

$$E_{\text{explosion}} = 0.01 \times N \times 1879.2 \text{ MeV} \approx 1.1 \times 10^{44} \text{ J}$$

which matches observed supernova energies.

6.3. Agreement with Established Energy Budgets

A significant success of this model is its quantitative prediction matching observed supernova energies. To reach the 939.6 MeV threshold for exoneutron₂₀ formation, the exotic-matter chain reaction **requires** that approximately 1% of stellar matter undergoes complete disintegration. Remarkably, this 1% conversion fraction matches precisely the $\sim 1\%$ mass-to-energy conversion derived from supernova energy budgets [7,9]. This alignment provides indirect confirmation that the exotic-matter mechanism captures the essential physics of core-collapse explosions.

6.4. Contrast with Failed Explosions

In black-hole-forming collapses, external pressure remains sufficiently high to confine exoneutrons. No disintegration occurs, and the exotic core persists. This explains:

- Why black hole formation releases much less explosive energy
- Why some collapses produce explosions while others do not
- The threshold behavior between supernova and black hole formation

The pressure threshold for confining exoneutron₂₀ constitutes the precise dividing line between these two outcomes.

7. Black-Hole-Forming Collapse

For a 25–40 $M_{\odot}$ progenitor:

- Collapsing mass: $M \sim 2.5\text{--}3.0 M_{\odot}$
- Minimum radius before horizon formation: $R_c \sim 10\text{--}15$ km

Total delivered energy:

$$U_{\text{tot}} \sim (5\text{--}8) \times 10^{46} \text{ J.}$$

Number of nucleons:

$$N \sim (3\text{--}4) \times 10^{57}.$$

Energy per nucleon:

$$E_{\text{nuc}} \sim 800 \text{ MeV to } 1.2 \text{ GeV.}$$

Transforming all neutrons into exoneutrons requires only 939.59 MeV per neutron—exactly within the estimated energy range. The black hole forms through complete conversion of neutrons into 20-layer exoneutrons (n_{20}^*).

7.1. Internal Structure of Black Holes

As the black hole grows, central pressure increases, potentially creating increasingly dense concentric shells. Additional energy shells beyond 20 become accessible:

From Lockyer's model extensions:

$$\text{Shells}_{19-22} = E_{18}(\sqrt{2} + 2 + 2\sqrt{2} + 4) = 275.2 \times 10.2426 \approx 2818.8 \text{ MeV} \quad (8)$$

$$\text{Shells}_{19-24} = E_{18}(\sqrt{2} + 2 + 2\sqrt{2} + 4 + 4\sqrt{2} + 8) = 275.2 \times 23.8995 \approx 6577.1 \text{ MeV} \quad (9)$$

This leads to a progression of exotic states:

$$n_{20}^* : 939.6 + 939.6 = 1879.2 \text{ MeV (1.88 GeV)}$$

$$n_{22}^* : 939.6 + 2818.8 = 3758.4 \text{ MeV (3.76 GeV)}$$

$$n_{24}^* : 939.6 + 6577.1 = 7516.7 \text{ MeV (7.52 GeV)}$$

In this model, black holes contain no mathematical singularities—only exotic matter of progressively increasing density from the surface toward the center.

8. Discussion

Our calculations demonstrate consistency between the exotic-matter model and observations of both supernovae and black hole formation. Stellar collapse naturally reaches energies sufficient for exotic-matter formation, supporting its role in halting collapse, triggering rebound, and supplying explosion energy.

The key advancement presented here is the **energy amplification mechanism** (Section 5). Unlike classical models where energy dissipates progressively, the exotic-matter model stores compression energy and amplifies it through disintegration. This resolves the fundamental energy budget problem in core-collapse supernovae.

The comparison with classical theory (Section 5.3) highlights why previous mechanisms struggle: they dissipate energy irreversibly, while the exotic-matter mechanism conserves and amplifies it.

The framework also resolves the "shock-revival" problem and replaces the mathematical singularity in black holes with physically meaningful, finite-density exotic cores.

9. Conclusions

We have demonstrated that collapsing massive stellar envelopes naturally drive cores to energies sufficient for exotic-matter formation. The bifurcation between black hole formation and supernova explosion emerges directly from the stability properties of this exotic phase.

A major achievement of this model is its quantitative prediction matching observed supernova energies. The self-regulating chain reaction of exotic-matter formation and disintegration naturally converts approximately 1% of core neutrons to energy—precisely the fraction required by observational constraints [7]. This 1% conversion yields explosion energies of $1 - 2 \times 10^{44}$ J, explaining why supernovae exhibit such consistent energy outputs despite varying progenitor masses.

Central to the mechanism is the **energy amplification factor of 2**: when exotic neutrons disintegrate, they release twice the energy required to form them. This creates a positive feedback loop capable of reviving stalled shocks and powering supernova explosions.

When pressure remains high, a non-singular exotic core persists, forming a black hole. When pressure drops, exotic layers collapse and release their amplified stored energy, producing the supernova and its characteristic neutrino burst.

This framework not only solves the supernova energy problem but also strengthens the theoretical consistency of the exotic-matter paradigm. In particular, it reinforces the physical foundations of the cyclic-universe "Big Bounce" scenario previously proposed in [1], where exotic matter plays an analogous role during cosmic contraction.

10. Brief Description of Lockyer's Model

Lockyer's model conceptualizes the positron as a cube with edges based on the reduced Compton wavelength ($\lambda'_e = \hbar / (m_e c) \approx 3.8615932 \times 10^{-13}$ m). The proton models as a positron (level 0) containing 18 nested energy layers (levels 1–18). The positron cube edge length shortens by a factor deduced from the electron's magnetic moment, using only physical constants. For the complete description of Lockyer's original model, refer to [6].

Projected onto a plane perpendicular to the rotation axis giving the magnetic moment, the cube appears as a square. Each inner layer's 'square' inscribes with a 45° rotation relative to its containing square, reducing dimensions by factor $\sqrt{2}$:

$$L_{\text{inner}} = \frac{L_{\text{outer}}}{\sqrt{2}}. \quad (10)$$

Rest mass originates from photon momentum ($p = h/\lambda$) confined in rotating layers, with energy contributions:

$$m = \frac{e^2}{m_e 4\pi c^2 \lambda'_e d \epsilon_0}, \quad d = \frac{1 - \sqrt{2}/2}{2} - \frac{a_u}{\sqrt{2}}, \quad a_u = 2 \left(\sqrt{1 + \frac{\alpha}{2\pi}} - 1 \right). \quad (11)$$

Mass contributions per level i (1 to 19):

$$m_1[i] = \frac{(\sqrt{2})^{i-1}}{1 - \sqrt{2}a_u}, \quad m_2[i] = m \cdot \frac{(\sqrt{2})^{i-1}}{1 - \sqrt{2}a_u}. \tag{12}$$

The neutron adds an electron (mass m_e , charge $-e$) sharing level 0 with the positron (mass m_e , charge $+e$), doubling the energy of level 1.

10.1. Calculations

Proton mass ratio:

$$m_p/m_e = \sum_{i=1}^{19} (m_1[i] + m_2[i]). \tag{13}$$

Neutron mass ratio includes doubling of first two levels:

$$m_n/m_e = \sum_{i=1}^{19} (m_1[i] + m_2[i]) + \sum_{i=1}^2 (m_1[i] + m_2[i]). \tag{14}$$

10.2. Results and Discussion

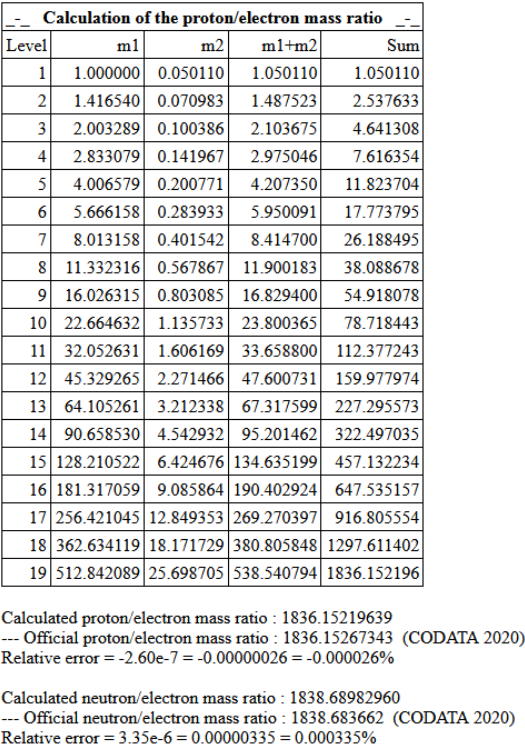


Figure 1. JavaScript code result, showing mass contributions per level.

Our JavaScript implementation yields:

- Proton: $m_p/m_e = 1836.1521964$, error -2.6×10^{-7} relative to CODATA 1836.15267343 (seven significant digits)
- Neutron: $m_n/m_e = 1838.6898296$, error 3.35×10^{-6} relative to CODATA 1838.68366173 (six significant digits)

Note: Each level's contribution $(m_1[i] + m_2[i])$ equals the previous contribution multiplied by $\sqrt{2}$.

Our JavaScript implementation of Lockyer's model is detailed in [5]. The original BASIC code appears in the appendix of Lockyer's monograph [6].

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