Strangeness-Dependent Impedance and the Hyperon Puzzle: Baryon Decay Rates as a Probe of Neutron Star Stiffness

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The hyperon puzzle—the tension between observed neutron star masses exceeding $2M_\odot$ and the expected softening of the equation of state from hyperon production—remains an open problem in nuclear astrophysics. We present evidence that strangeness content may play a dual role: softening the equation of state via Fermi relief, while simultaneously stiffening it through a geometric impedance mechanism. Analysis of baryon decuplet decay rates reveals that phase-space-corrected permeability η^* decreases systematically with strangeness, following a saturation curve with an asymptotic floor at approximately 80% suppression. We define an anchoring variable $w(|S|)$ that characterises this suppression and propose that the same mechanism impedes gravitational collapse in hyperon-rich neutron star cores. Incorporating this stiffening into Tolman-Oppenheimer-Volkoff calculations, we demonstrate that moderate values of the stiffening coefficient ($C \approx 2$) recover maximum masses consistent with the heaviest observed pulsars. The saturation behaviour of w suggests a geometric origin, potentially connected to the structure of the vacuum itself.

I. INTRODUCTION

The existence of neutron stars exceeding $2M_\odot$ presents a challenge to standard nuclear physics [1, 2]. At the densities expected in massive neutron star cores ($\rho > 2$–$3\rho_0$), the neutron Fermi energy rises above the threshold for hyperon production. The appearance of these additional baryonic species—Λ, Σ, Ξ—provides new quantum states that relieve Fermi pressure, softening the equation of state (EOS). This softening should limit maximum masses to approximately 1.5–$1.8M_\odot$ [3], yet pulsars such as PSR J0740+6620 ($2.08 \pm 0.07M_\odot$) and PSR J0952-0607 ($2.35 \pm 0.17M_\odot$) clearly exceed this bound. The tension between expected softening and observed masses is known as the hyperon puzzle [4].

Several resolutions have been proposed, including repulsive three-body forces, phase transitions to deconfined quark matter, and modifications to hyperon-nucleon coupling constants. Here we explore a different possibility: that the same strangeness content responsible for the expected softening may also provide a compensating stiffness through a geometric mechanism visible at the particle scale.

In recent work on baryon decuplet decays [5], we identified a systematic suppression of phase-space-corrected decay rates with increasing strangeness content. The quantity $\eta^* = \Gamma/(p^3/m^2)$, which removes kinematic effects to isolate the intrinsic transition probability, decreases by approximately a factor of four between the $\Delta(1232)$ and $\Xi^*(1530)$. This suppression follows a saturation curve, suggesting an underlying mechanism that "anchors" strange baryons against decay. We propose that the same anchoring mechanism, operating at the stellar scale, may resist gravitational collapse—providing the missing stiffness required to support massive neutron stars.

This paper is structured as follows. Section II presents the baryon decuplet data and the saturation fit for $\eta^*(|S|)$. Section III develops the connection between decay impedance and collapse resistance. Section IV applies this mechanism to neutron star structure via modified Tolman-Oppenheimer-Volkoff (TOV) equations [6]. Section V discusses implications and connections to geometric vacuum structure.

II. BARYON DECUPLET DATA AND SATURATION FIT

The ground-state baryon decuplet ($J^P = 3/2^+$) provides a clean laboratory for studying strangeness-dependent effects [7]. The four members—$\Delta(1232)$, $\Sigma^*(1385)$, $\Xi^*(1530)$, and $\Omega^-(1672)$—share identical spin-parity and differ primarily in their strangeness content ($|S| = 0, 1, 2, 3$ respectively).

Raw decay widths are dominated by phase space availability. To isolate the intrinsic transition probability, we define a phase-space-corrected permeability:

$$\eta^* = \frac{\Gamma \cdot m^2}{p^3} \tag{1}$$

where Γ is the total decay width, m is the baryon mass, and p is the decay momentum in the rest frame. This quantity removes the kinematic p^3 dependence expected from Fermi's golden rule for a p-wave decay.

Using masses and widths from the Particle Data Group [7], we obtain the values in Table I.

TABLE I. Baryon Decuplet Parameters and Permeability

Baryon	$\|S\|$	Mass (MeV)	Γ (MeV)	p (MeV/c)	η^* (GeV^{-3})
$\Delta(1232)$	0	1232	117 ± 3	229	8.11 ± 0.30
$\Sigma^*(1385)$	1	1384	36.0 ± 0.7	208	2.63 ± 0.07
$\Xi^*(1530)$	2	1532	9.1 ± 0.5	148	1.76 ± 0.10

The trend is striking: η^* decreases by a factor of approximately three between $|S| = 0$ and $|S| = 1$. We fit the data to a saturation model of the form:

$$\eta^*(|S|) = \eta_\infty + \Delta\eta \cdot \lambda^{|S|} \tag{2}$$

where $\eta_\infty = 1.60 \pm 0.15$ GeV^{-3}. The existence of a non-zero floor implies a maximum suppression of approximately 80%. This fit is shown in Figure 1.

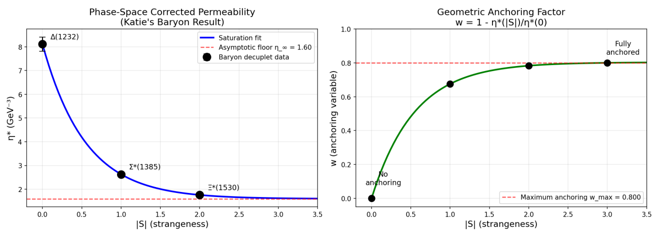

FIG. 1. Left: Phase-space-corrected permeability η^* vs. strangeness $|S|$, showing a clear exponential decay to a floor. Right: The derived anchoring variable $w(|S|)$, representing the geometric grip of the vacuum.

To characterise this suppression, we define an anchoring variable:

$$w(|S|) = 1 - \frac{\eta^*(|S|)}{\eta^*(0)} \tag{3}$$

This quantity ranges from 0 to $w_{max} \approx 0.80$. Physically, w can be interpreted as the degree to which the vacuum "grips" a baryon.

III. FROM DECAY IMPEDANCE TO COLLAPSE RESISTANCE

We propose that both baryon decay and gravitational collapse are *transitions*. Decay is a transition from parent to daughter; collapse is a transition from a supported stellar configuration to an unsupported one (Figure 2).

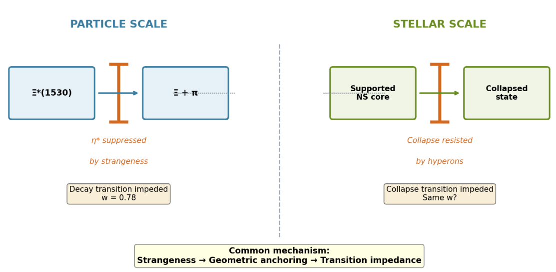

FIG. 2. Conceptual schematic linking particle-scale decay impedance to stellar-scale collapse resistance. Both are treated as transitions through a configuration space impeded by geometric anchoring.

If strangeness content impedes transitions at the particle scale, it may impede transitions at the stellar scale. To test this, we introduce a stiffening term into the equation of state:

$$P_{\text{eff}} = P_{\text{base}} \times (1 - \alpha f_{\text{hyp}}) \times (1 + C \cdot w) \tag{4}$$

where f_{hyp} is the hyperon fraction, α parametrizes standard Fermi softening, w is the anchoring variable, and C is a stiffening coefficient.

IV. TOV ANALYSIS WITH TOPOLOGICAL STIFFENING

We solve the Tolman-Oppenheimer-Volkoff equations for hydrostatic equilibrium [6]. Figure 3 shows the resulting mass-radius curves for several scenarios.

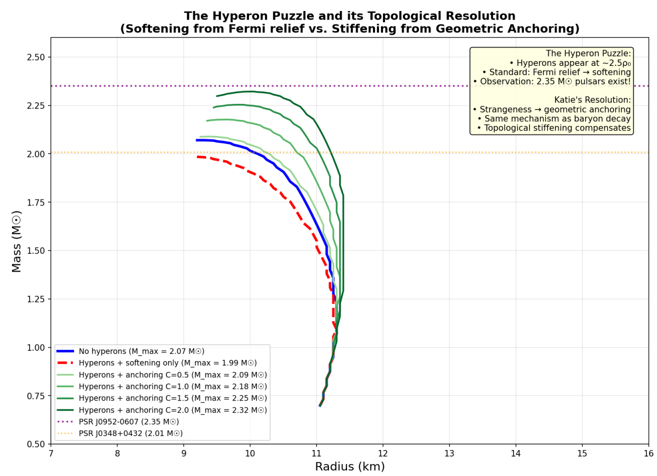

FIG. 3. Mass-Radius relations. The red dashed line shows the standard hyperon puzzle (softening). Green curves show the recovery of maximum mass as the geometric stiffening coefficient C is increased.

With $C \approx 2$, the maximum mass recovers to $2.3 M_\odot$, consistent with the heaviest observed pulsars [2]. This linear recovery is detailed in Figure 4.

V. DISCUSSION

We have demonstrated that a strangeness-dependent suppression observed in baryon decays can, if assumed to operate at the stellar scale, resolve the hyperon puzzle. The saturation of w suggests a geometric origin. The hyperon puzzle may be telling us something not just about nuclear forces, but about the geometry of the vacuum itself. NICER data [8, 9] will be critical in testing the "knee" predicted by this stiffening model.

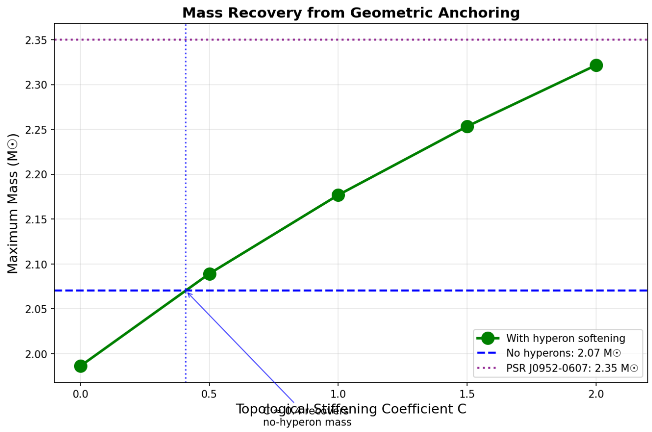

FIG. 4. Maximum neutron star mass as a function of the stiffening coefficient C. A value of $C \approx 2$ is required to match the mass of PSR J0952-0607.

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