The Extended Nuclear Matter Model with Smooth Transition Surface

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Introduction

The existence of electric fields close to their critical value

$$E_c = \frac{m_e^2 c^3}{e\hbar}$$

has been proved for massive cores of 10^7 up to 10^{57} [1, 2].

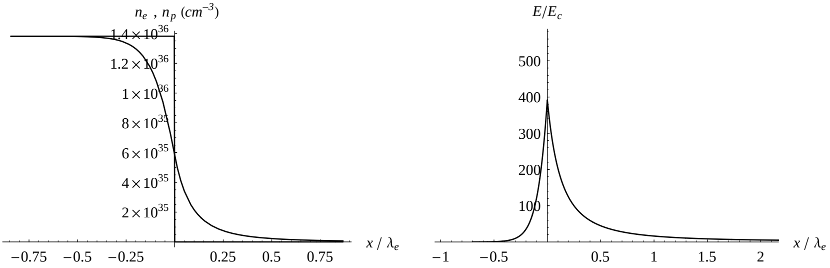


Figure: Number Densities and Electric Field in the Rotondo *et al.* case

Polytropic Index

$$\Gamma = \frac{d \ln P}{d \ln \rho}$$

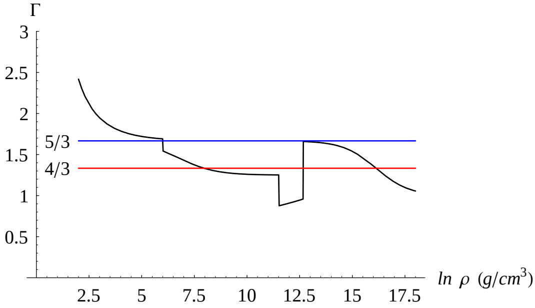


Figure: Polytropic Index for the Harrison–Hakano–Wheeler EOS

Poisson Equation + Equilibrium Condition

$$\nabla^2 V(r) = -4\pi e[n_p(r) - n_e(r)] \tag{1}$$

$$+$$

$$E_e^F = m_e c^2 \sqrt{1 + x_e^2} - m_e c^2 - eV = 0 \tag{2}$$

$$\Downarrow$$

Modified Relativistic TF Equation

$$\xi_e''(x) + \left(\frac{2}{x + R_c/a}\right)\xi_e'(x) - \frac{[\xi_e^2(x) - 1]^{3/2}}{\mu} + f_p(x) = 0 \tag{3}$$

$$\xi_e(0) = \sqrt{1 + [\mu\,\delta f_p(0)]^{2/3}}\,, \qquad \xi_e'(0) < 0\,, \qquad \xi_e(\infty) = 0\,.$$

$x=\frac{r-R_c}{a}$, $\frac{1}{a}=\sqrt{4\pi\alpha\lambda_e n_p^c}$, $\mu=3\pi^2\lambda_e^3 n_p^c$, $\xi_e=\sqrt{1+x_e^2}$, $\delta=\frac{n_e(0)}{n_p(0)}$, $fp(x)=\frac{n_p(x)}{n_p^c}$

Woods-Saxon Profile

$$f_p(x) = \frac{\gamma}{\gamma + e^{\beta x}} , \tag{4}$$

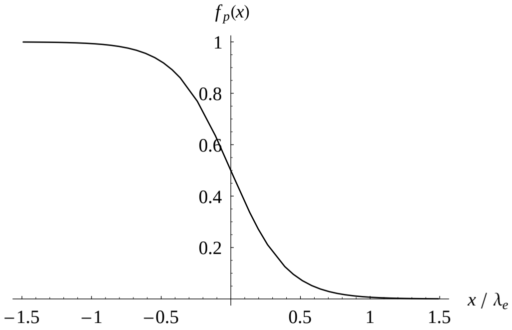


Figure: Proton profile for $\gamma = 1.5$, $\beta \approx 0.0585749$, $f_p(0) = 0.5$

Neutron Number Density

After integrating the TF equation, we can to calculate the neutron number density using the equilibrium condition of the direct and inverse β decay

β-equilibrium

$$n \longrightarrow e^- + p + \bar{\nu}$$

$$e^- + p \longrightarrow n + \nu$$

$$m_n c^2 \xi_n - m_n c^2 = m_p c^2 \xi_p - m_p c^2 + eV$$

The potential V is calculated using the equilibrium condition (2).

$$n_n(x) = \frac{[\xi_n^2(x) - 1]^{3/2}}{3\pi^2 \lambda_n^3}$$

Results of the Numerical Integration

We have integrated numerically the eq.(3) for several sets of parameters and initial conditions.

Examples

δ	$\xi_e'(0)$	$n_p^c(cm^{-3})$
0.9662053	$-0.868051226336790$2	1.38×10^{36}
0.97829293547	-0.899201	2.76×10^{36}

Physical Parameters

$N_e = N_p$	A	E_{peak}/E_c	$R_c(km)$
10^{54}	1.61×10^{56}	95	5.56
2×10^{54}	2.35×10^{56}	125	5.56

Number Densities

$$n_e(x) = \frac{[\xi_e^2(x) - 1]^{3/2}}{3\pi^2\lambda_e^3}, \quad n_p(x) = n_p^c f_p(x)$$

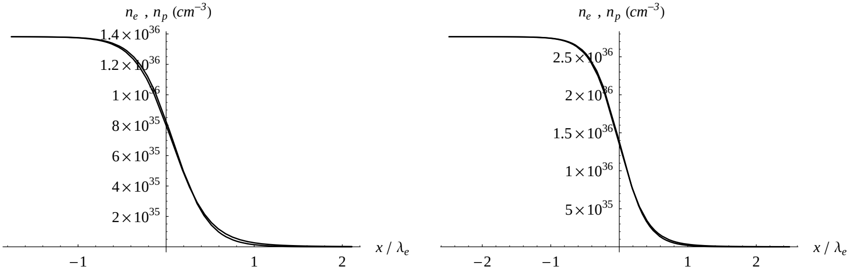


Figure: Electron and Proton Number Density

Charge Separation

$$\Delta = \frac{n_p(x) - n_e(x)}{n_p^c}$$

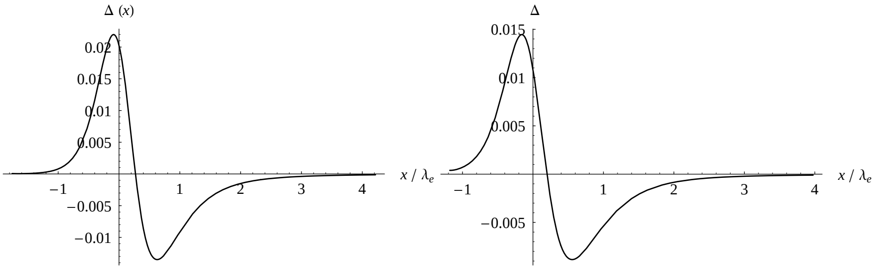


Figure: Charge separation function

Electric Field

$$\frac{E}{E_c} = -\frac{\lambda_e}{a}\xi_e'(x)$$

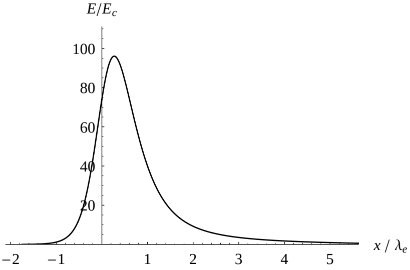


Figure: Electric field in units of the critical field E_c

Effect of the Sharpness

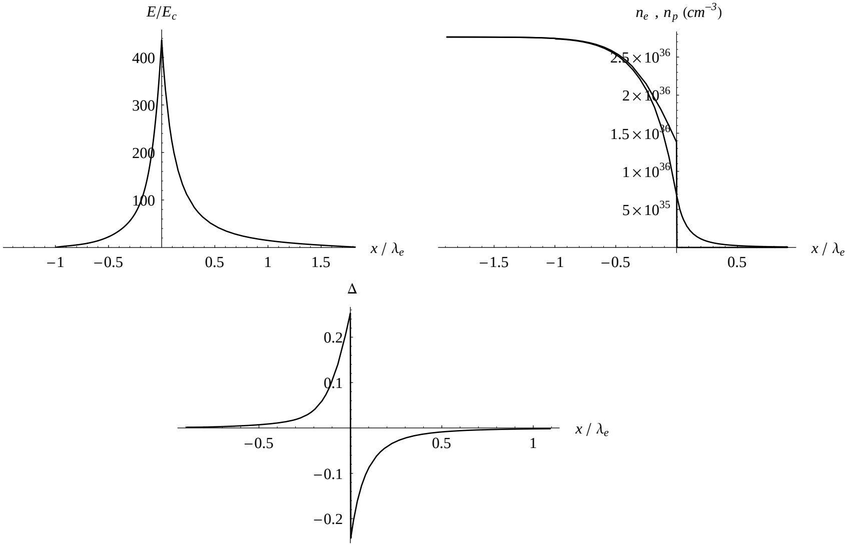
Example

δ	$\xi_e'(0)$	$n_p^c(cm^{-3})$
0.496633412	-3.616	2.76×10^{36}

Physical Parameters

$N_e = N_p$	A	E_{peak}/E_c	$R_c(km)$
2×10^{54}	2.34×10^{56}	420	5.56

Effect of the Sharpness



Concluding Remarks

- We confirm the existence of overcritical electric fields about the transition surface between the core and the crust of neutron stars when it is smooth.
- The intensity of the electric field depends on the proton density mainly by two factors:
  (i) the value of n_p about the surface
  (ii) how it changes about the surface (sharpness)
- The extension of the electric field (its width) depends mainly on the extension of the proton density about the surface.
- A sharper density about the core surface intensifies the electric field.

Work in Progress ...

- We are studying the way to calculate the proton distribution function in a self–consistent way:
  (i) appropriate treating of phase transition core–crust
  (ii) inclusion of gravitational potential
  (iii) solve the problem within the framework of General Relativity

- A. B. Migdal, D. N. Voskresenskii and V. S. Popov, *JETP letters*, **24** 186 (1976)
- R. Ruffini, M. Rotondo and S. S. Xue, *Int. Journal of Mod. Phys D*, **16** 1 (2007)