Effects of Neutron-Antineutron transitions in Neutron Stars

Itzhak Goldman

Physics Department, Afeka College
and
Astrophysics Department, Tel Aviv University

22nd Lomonosov Conference, Moscow, August 2025

Goldman, Mohapatra, Nussinov, and Shrock,
Phys. Rev. Letters,134, 052701 (2025)

Introduction

There has been interest in searching for neutron - antineutron oscillations for several reasons, e.g. such oscillations could be relevant for the baryon asymmetry of the universe.

We use upper limits on the transition obtained from terrestrial experiments, to estimate the effects of neutron - antineutron transitions on:

- 1. Cooling of Neutron stars.
- 2. Spin- down of pulsars.
- 3. Rate of change of the orbital period of binary pulsars. .

It turns out that the effects are negligibly small.

item 1. was considered in Buccella et al.(1987). The constraint presented here is stronger by 6 orders of magnitude, due to the advances in the terrestrial experiments.

Lower limit on the transition timescale from terrestrial experiments.

$\tau_m = \frac{1}{\Gamma}$ where Γ is the rate of the $n \to \bar{n}$ transition,

- From SuperKamiokanda : $\tau_m > 3.6 \times 10^{32}$yr
- From SNO: $\tau_m > 1.48 \times 10^{31}$yr

Energy lost in the Neutron star per transition.

The antineutron created in the transition annihilates with another neutron producing pions and depositing an energy of $2m_n$. The pions are π^0 and π^+ that lead also to π^0 by $\pi^+ n \to \pi^0 p$.The π^0 decay to photons via $\pi^0 \to \gamma\gamma$.

Neutron stars.

- Mass: $\sim (1.4 - 2)M_\odot . M_\odot = 2 \times 10^{33} gr$.
- Radius: $\sim (10 - 12)$ km .
- Total number of neutrons: $N_n \sim 10^{57}$.

Rate of Neutron Star mass decrease.

The total number of neutrons changes according to

$$\frac{dN_n(t)}{dt} = -\frac{N_n(t)}{\tau_m} \tag{1}$$

thus,

$$N_n(t) = N(0)e^{-t/\tau_m} \tag{2}$$

Since $\tau_m >>$ the age of the universe (1.38×10^{10} yr) it follows that

$$\frac{dN_n(t)}{dt} = -\frac{N_n(0)}{\tau_m}. \tag{3}$$

The total mass changes according to

$$\frac{dM}{dt} = -2m_n\frac{dN_n(t)}{dt} = -\frac{2M(0)}{\tau_m} = -\frac{2M}{\tau_m}. \tag{4}$$

Effect on Neutron Star Cooling.

The photon luminosity of a neutron star due to the transition is

$$L_{n\to\bar{n}} = |\dot{M}|c^2 = \frac{2M}{\tau_m}c^2 = 4.4\times 10^{14} erg/s(\frac{M}{1.4M_\odot})(\frac{3.6\times 10^{32}yr}{\tau_m}) \quad (5)$$

Old neutron stars have photon luminosities of $10^{32} - 10^{33}$ erg/s $>> L_{n\to\bar{n}}$.

Effect on pulsar spin -down.

The rotation period of pulsars increases with time (spin-down) due to magnetic braking that reduces the angular momentum, of the rotating neutron star.
observational values of the spin- down are typically in the range

$$\frac{\dot{p}}{p} = (10^{-6} - 10^{-9})yr^{-1} \quad (6)$$

Effect on pulsar spin -down; continued.

This is also the rate of decrease of the star angular momentum, since the moment of inertia does not change by the magnetic braking.

$$\left(\frac{\dot{L}}{L}\right)_{observed} = -(10^{-6} - 10^{-9})yr^{-1} \tag{7}$$

The neutron -antineutron transition changes the moment of inertia and therefore the angular momentum:

$$\frac{\dot{L}}{L} = \frac{\dot{I}}{I} = \frac{\dot{M}}{M} = -5.6 \times 10^{-33} yr^{-1} \left(\frac{3.6 \times 10^{32} yr}{\tau_m}\right). \tag{8}$$

Therefore the effect of the transition is negligible.

Effects of the transition on rate of change of orbital periods of binary pulsars.

Jeans (1924) obtained that if the masses of a binary system change due to emission of radiation (isotropic in the local frame of each star) the binary orbital period, p_b. changes according to

$$\frac{\dot{p}_b}{p_b} = -2\frac{\dot{M}_t}{M_t} \; , \quad M_t = M_1 + M_2. \tag{9}$$

Applying it to the binary pulsar PSR1913+16 where the two components are neutron stars and $M_t = 2.83 M_\odot$ leads to

$$\frac{\dot{p}_b}{p_b} = \frac{4}{\tau_m} = 1.1 \times 10^{-32} yr^{-1} (\frac{3.6 \times 10^{32} yr}{\tau_m}). \tag{10}$$

The residual value (observed minus that due to gravitational radiation) is

$$\frac{\dot{p}_{b\,res}}{p_b} = (5, 2 \pm 4.5) \times 10^{-12} yr^{-1}. \tag{11}$$

conclusions

- The effects of neutron - antineutron transitions in neutron star are extremely small and thus would not be observable.
- It is important to further advance the terrestrial experiments.

Thank You!