The Internal Structure of Neutron Stars from a New Perspective

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Abstract: This is a review article. Here we show that neutron stars, due to the atom-like structure of baryons and structure of spacetime, are mathematically very simple objects: they have an invariant density, a spherical shape although they spin very fast, they have no relativistic mass, and we can neglect the nuclear and gravitational binding energy.

1. Introduction

The atom-like structure of baryons described in the Scale-Symmetric Theory (SST) causes that the neutron stars (NSs) are mathematically very simple objects.

According to the SST, baryons have an atom-like structure [1]. There is the core composed of the torus which interacts both electromagnetically and strongly, and there is the central condensate which interacts due to the nuclear weak interactions. Dynamics of the virtual objects shows that outside the core are created the orbits/tunnels in the SST Einstein spacetime which is composed of the neutrino-antineutrino pairs. Radii of such tunnels are defined by following formula

$$R_d = A + dB\,, \tag{1}$$

where $A = 0.6974425$ fm ≈ 0.7 fm is the equatorial radius of the baryon core, $B = 0.5018395$ fm ≈ 0.5 fm, and $d = 0, 1, 2, 4$. The $d = 4$ for the last tunnel/orbit is calculated from the range of the strong interaction which is generated by the torus in the baryon core.

The surface density of the torus is ~300,000 times higher than in the SST Einstein spacetime so moving baryons create ordered flows in the SST Einstein spacetime. It causes that angular velocities of both neutron star and the part of the Einstein spacetime it overlaps are the same. We can see that neutron stars which are spinning for an external observer are at rest in relation to the part of the Einstein spacetime they overlap, so they do not gain relativistic mass and are always spherical in shape. There is no need to use the framework of General Relativity for rotating neutron stars i.e. the stationary axisymmetric space-time metric [2].

2. Calculations

We claim that besides a very thin iron crust and very thin layer of nuclear plasma on surface of each neutron star (which we neglect in our calculations), the neutron lattice is composed of cubes with neutrons in their vertices (see Fig.1). Such neutron lattice is the very stable object because of the strong interactions between pairs of neutrons located at the ends of diagonals of the side walls of the cubes. The length of the diagonals is equal to the effective range, $R_{eff,NS}$, of the neutron matter. From (1) we obtain

$$R_{eff,NS} = R_{d=4} = 2.70480 \text{ fm} . \quad (2)$$

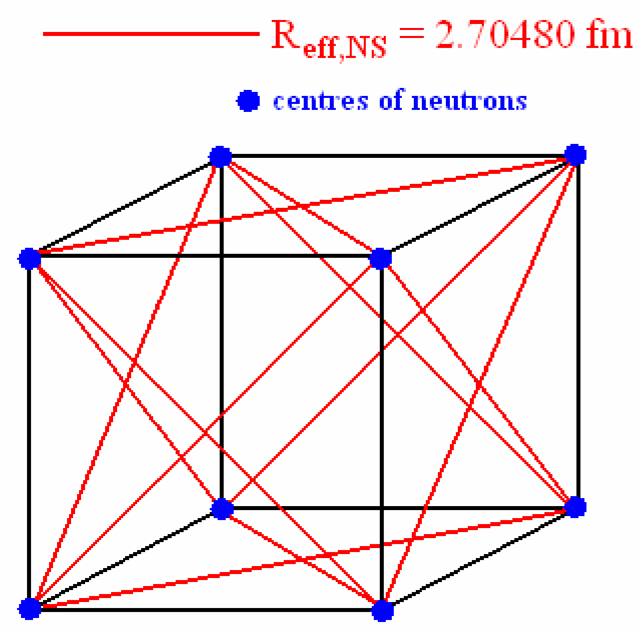

Fig.1
Effective range of the neutron matter.

This value is consistent with the mainstream value (~2.7 fm) [3] but due to the distribution of neutrons, we get a different density of neutron matter ρ_{NS}. Our value, contrary to the mainstream values, is invariant

$$\rho_{NS} = M_{Neutron} / (R_{eff,NS} / 2^{1/2})^3 = 2.39406 \cdot 10^{17} \text{ kg/m}^3 , \quad (3)$$

where $M_{Neutron}$ = 939.565 MeV is the mass of neutron calculated in SST [1].

Why is the effective range $R_{eff,NS}$ equal to the length of the diagonal and not of the side of the cubes and why is it equal to the radius of the last tunnel for the strong interactions of baryons? For diagonals smaller than ~2.7 fm (from (1) we have that there can be ~1.7 fm, ~1.2 fm, or ~0.7 fm) the tori in the cores of baryons, which due to the very strong short-distance quantum entanglement cannot be disturbed or destroyed [1] (the half-integral spin and electric charge of such tori are conserved), would partially overlap, which, because of the very high surface density of the tori, is forbidden. Moreover, the binding energy of neutrons is higher for shorter distances so cubes with the side equal to 2.7048 fm are not in the ground state.

The upper limit for mass, $M_{NS,upper}$, and radius, $R_{NS,upper}$, of neutron stars we obtain from the boundary condition that spin speed on equator of NS should be equal to the speed of light in “vacuum” c = 299,792,458 m/s.

The below system of two equations leads to $R_{NS,upper}$ and $M_{NS,upper}$

$$R_{NS,upper} = G\, M_{NS,upper} / c^2 = 36.64 \text{ km} , \quad (4)$$

where G = 6.6740007 $m^3 / (kg\ s^2)$ is the gravitational constant calculated in SST [1],

$$M_{NS,upper} = \rho_{NS}\, 4\, \pi\, R_{NS,upper}^{3} / 3 = 24.81 \textbf{ solar masses}\,, \tag{5}$$

Such a biggest neutron star we call “the neutron black hole (NBH)” because it has the spin speed equal to c on its equator.

The binding energy of neutrons in neutron stars that follows from the nuclear strong interactions, due to the very short time of interactions ($\sim 10^{-23}$ s), is frozen inside the neutron star so there is no need to take it into account in calculations of NS mass.

But why can we also neglect the gravitational potential binding energy?

For example, let’s calculate the gravitational potential binding energy of a neutron, ΔE_g, located at the surface of the neutron black hole

$$\Delta E_g = -G\, M_{NS,upper}\, M_{Neutron} / R_{NS,upper} = -M_{Neutron}\, c^2 = -939.565 \text{ MeV}\,. \tag{6}$$

This value suggests that such neutron behaves as a virtual neutron because the sum of its mass and binding energy is equal to zero. So, do we really have to consider the change in mass due to gravitational interaction? Well, no, and this is due to phenomena occurring in the SST Einstein spacetime.

When a star collapses into a neutron star or neutron stars collide, potential gravitational energy must be emitted, and this is due to the divergent flows in the SST Einstein’s spacetime, which the external observer observes as ripples in the spacetime. But due to the tremendous dynamic pressure in Einstein’s spacetime ($\sim 5 \cdot 10^{44}$ Pa [1]), a reverse flow occurs that restores the initial state of local spacetime. Thus, it is the dynamic pressure in Einstein’s spacetime that means that we do not have to take into account the gravitational potential binding energy in the calculations of the mass of a neutron star.

We can say that the neutrons on the NBH surface are accompanied by virtual gravitational quanta of the potential binding energy with energy equal to the mass of the neutron, and such gravitational quanta are exchanged between the neutrons on the star’s surface. It is the gravitational quantum-star resonance! Such quanta are part of the zero-energy field.

The energy of virtual gravitational quanta on surfaces of NSs is not a linear function of the star’s mass but the mass of the star, $M_{NS,i}$, and the energy of the virtual gravitational quanta with the highest number density, $\Delta E_{g,i}$, should depend in the same way on the temperature of the star, so these two quantities are directly proportional to each other

$$\Delta E_{g,i} \sim M_{NS,i}\,. \tag{7}$$

From the boundary condition we have

$$M_{Neutron} \sim M_{NS,upper}\,. \tag{8}$$

From (7) and (8) we obtain the equation for the gravitational quantum-star resonance

$$M_{NS,i} / M_{NS,upper} = \Delta E_{g,i} / M_{Neutron}\,. \tag{9}$$

From (9), for $\Delta E_{g,i}$ equal to the characteristic masses for the atom-like structure of neutron, we obtain masses of NSs that behave in a strange way.

Using the formula (9), we calculated the lower limit for mass of NSs and described the gamma-ray bursts (GRBs).

We also showed that the interaction of our NSs with dark-matter (DM) loops leads to the conclusion that the TOV limit is an illusion.

The gravitational binding energy/mass of two neutrons, ΔM_{nn}, in distance $R_{eff,NS}$ we can calculate from formula

$$\Delta E_g^{*} = -G\, M_{Neutron}^{2} / R_{eff,NS} = -\Delta M_{nn}\, c^2 , \qquad (10)$$

so we have

$$\Delta M_{nn} \approx 7.70 \cdot 10^{-67}\ \mathrm{kg}\ . \qquad (11)$$

This value is close to the mass of the lightest non-rotating-spin neutrino-antineutrino pairs ($\sim 6.67 \cdot 10^{-67}$ kg) so between neutrons in NSs are exchanged the Einstein-spacetime components.

Colliding NSs with a total mass less or equal to 24.81 solar masses can merge into single neutron star, while NBHs cannot.

We should also remind that in SST neutrinos acquire their gravitational masses because they are immersed in the SST tachyon Higgs field and because gravitational fields are gradients created in the SST Higgs field by masses, so the "gravitational waves" detected by LIGO-Virgo are only indirectly related to gravitational fields.

3. Summary

In this paper, based on the atom-like structure of baryons described in SST, we have expanded the physical side of the NS theory to show that the theory is complete.

Due to the formation of tunnels/orbits in spacetime as a result of the virtual strong interactions, even the most massive neutron star (i.e. NBH) cannot collapse into black hole with a central singularity.

SST shows that General Relativity is neglecting some important phenomena and so leads to the wrong conclusions.

References

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