The Tower of the Chandrasekhar Limits and Spin Periods of Pulsars

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Abstract: It is assumed in the mainstream cosmology that at the Chandrasekhar limit the white dwarfs explode due to the conditions in a Fermi gas. Here, within the Scale-Symmetric Everlasting Theory (S-SET), I showed that there appears the tower of the Chandrasekhar limits and that the stars/white-dwarfs with the threshold masses explode via a neutron-star state. Neutron stars behave as liquid crystal. There are the needed flat structures and the elongated rectangular prisms. There appears the upper limit for mass of neutron star, i.e. of the neutron black hole, equal to 24.81 solar masses. But due to perfect energy flow from core of a star toward its surface there as well appear at least three Chandrasekhar limits i.e. masses of stars which explode as Type Ia supernovae via sudden collapse of whole star to the neutron-star state which leads to violent full volumetric explosion so there is not created a neutron-star remnant – the threshold masses are 1.395, 11.20 and 0.891 solar masses. The first mass is the very well known Chandrasekhar limit whereas the second was the mass of, for example, the SN 1987A supernova. Energy is carried by the condensates of the Einstein-spacetime components which are the black holes in respect of the weak interactions or is carried by energetic neutrinos. The condensates with a mass 52.828 MeV are produced in centres of muons, with a mass 424.124 MeV are produced in centres of baryons, whereas energy of the neutrinos is the one fourth of the mass of neutral pion (33.743 MeV). Their number densities increase rapidly for the threshold masses of stars. Here, as well, are calculated the lower (0.000768 s) and upper (4,228 s) limits for spin periods of pulsars i.e. for stars with neutron core and iron crust. Presented here model is very simple and leads to observational facts.

1. Introduction

It is assumed in the mainstream cosmology that at the Chandrasekhar limit the white dwarfs explode due to the conditions in a Fermi gas. Here, within the Scale-Symmetric Everlasting Theory (S-SET) [1], I showed that there appears the tower of the Chandrasekhar limits and that the stars/white-dwarfs with the threshold masses explode via a neutron-star state.

Neutron stars behave as liquid crystal. There are the needed flat structures and the elongated rectangular prisms. The flat structures in such liquid crystal are the squares with neutrons in their vertices whereas the elongated rectangular prisms consist of parallel neutron squares (they are the analogs to the structures in the atomic nuclei – such model leads to the nuclear binding energies of atomic nuclei consistent with experimental data [2]). In neutron stars there is a lattice with mean side equal to $(A + 4B) / \mathrm{sqrt}(2)$, where $A + 4B = 2.7048$ fm is the radius of the last shell for the strong interactions which follows from the atom-like structure of baryons.

Here, as well, are calculated the lower and upper limits for spin periods of pulsars i.e. for stars with neutron core and iron crust.

2. The explosions of stars/white-dwarfs in which is not created a neutron-star remnant

The S-SET shows that the black holes in centres of galaxies consist of neutron black holes and neutron stars, i.e. structure of the black holes is grainy. There are not in existence black holes with infinite mass density.

Calculate the mass of neutron black hole i.e. the upper limit for mass of neutron stars. On the equator of such a black hole, the neutrons are moving with a speed close to the speed of light in 'vacuum' c but such an object is a sphere because inside it the Einstein spacetime, as a whole, rotates with the same angular speed as the neutron black hole. It follows from the fact that inside baryons are parts which mass density is much higher than the mass density of the Einstein spacetime [1] (density of the torus/charge in the core of baryons is about $4 \cdot 10^8$ times higher than the Einstein spacetime). It means that the neutron black hole is in the rest in relation to the Einstein spacetime so the neutrons are the non-relativistic fermions. The nucleons in such an object are placed in vertices of cubes and the lattice constant is equal to $a_L = (A + 4B) / 2^{1/2}$ ([1]: formula (183)). Binding energies of the neutrons are confined inside the neutron stars so we can neglect them in the calculations.

The radius of such a black hole is r_{NBH} and the mass m_{NBH} that satisfies the following formula:

$$r_{NBH} = G\, m_{NBH} / c^2. \tag{1}$$

If N_1 denotes the number of neutrons in such black hole then

$$4 \pi r_{NBH}^3 / 3 = N_1 a_L^3, \tag{2}$$

and

$$m_{NBH} = N_1 m_{neutron}. \tag{3}$$

Solving the set of formulae (1)-(3) we get
$N_1 = 2.946 \cdot 10^{58}$,
$m_{NBH} = 4.935 \cdot 10^{31}$ kg i.e. about 24.81 solar masses,
$r_{NBH} = 3.664 \cdot 10^4$ m i.e. 36.64 km.

In neutron black holes, the energy flow results from motions of the non-relativistic neutrons themselves.

It is obvious that in a star/white-dwarf, for energy flows are responsible objects which mass should depend on mass of the star. Within S-SET we showed that coupling constants are directly proportional to energies of carriers of energy [1]. It leads to conclusion that the carriers of energy in stars/white-dwarfs have energies directly proportional to their masses.

Stability of a star follows from the equivalence of the produced nuclear energy and the emitted energy. When produced nuclear energy too quickly leaks from a star then we should observe a collapse of the star whereas when the produced nuclear energy starts to interact with baryons, i.e. when the energy is confined inside a star, then the star must violently explode. We seek the threshold masses of stars/white-dwarfs for which there appears at first sudden collapse and next violent explosion. This means that we should look for carriers of energy interacting weakly with baryonic matter. Weakly interacting carriers of nuclear energy cause that temperature of a star suddenly drops and the star suddenly collapses. It causes that there appears very hot and dense nuclear plasma. Such plasma becomes non-transparent even for the weakly interacting carriers. The number density of the weakly interacting carriers suddenly increases so the star violently explodes.

Which carriers interact weakly with baryonic matter and are enough stable to carry the released nuclear energy? The S-SET shows that they are the condensates of the luminal Einstein-spacetime components and two of them are the black holes with respect of the weak interactions. One type of such condensates is produced in centre of muon – it consists of a condensate and two energetic neutrinos. The total mass of such condensate is the half of the mass of a muon i.e. $M_{weak,muon} = 105.656 / 2 = 52.828\ \mathrm{MeV}$ ([1]: the explanation below formula (55)). The mass of the second condensate is $Y = 424.124\ \mathrm{MeV}$ ([1]: the explanation below formula (49)) – such condensates are produced in centre of baryons and it as well is the black hole in respect of the weak interactions.

Calculate the threshold masses of stars in which the two different weak condensates carry the released nuclear energy. Such stars/white-dwarfs explode without a neutron-star remnant.

The muon condensate leads to the mass of the Type Ia supernovae (it is the approximate limit which appears in the Chandrasekhar theory)

$$M_{Ia\text{-}supernova,1} = m_{NBH} M_{weak,muon} / m_{neutron} \approx 1.395 \text{ solar masses.} \tag{4}$$

The second limit appears in the S-SET only and it was the mass, for example, of the SN 1987A supernova

$$M_{Ia\text{-}supernova,2} = m_{NBH} Y / m_{neutron} \approx 11.20 \text{ solar masses.} \tag{5}$$

We should not observe a neutron-star remnant in the place of the supernova SN 1987A explosion. This result is consistent with the last observations [4]. There is the Press Release, published on 22 January 2015, concerning data from the High Energy Stereoscopic System (H.E.S.S.). Among other things, we can read as follows: “Surprisingly, however, the young supernova remnant SN 1987A did not show up, in contrast to theoretical predictions. But we’ll continue the search for it”.

The smallest threshold mass in the tower of the Chandrasekhar limits follows from the simplest structure of the neutral pions which are responsible for the strong interactions in the stars/white-dwarfs. A neutral pion can consist of two gluons [1]. Due to the weak interactions, the two gluons can decay to four neutrinos [1]. Energy of each such energetic neutrinos is about $E_{neutrino} = m_{pion,o} / 4 = 33.743\ \mathrm{MeV}$. Such neutrinos can very effectively carry energy from the core of a white dwarf to its surface so it leads to the Type Ia explosion.

Calculate the third threshold mass of a star/white-dwarf

$$M_{Ia\text{-}supernova,3} = m_{NBH} E_{neutrino} / m_{neutron} \approx 0.891 \text{ solar masses.} \tag{6}$$

It is consistent with the theory of white dwarfs presented here [5].

The Type Ia supernovae with the threshold mass equal to 0.891 solar masses should be fainter than the original Type Ia supernovae with a mass of 1.395 solar masses. The supernovae with the lowest mass appear in more distant Universe than the original ones so they give an illusion that our Universe accelerates its expansion. But S-SET shows that there is as well the second reason which leads to such illusion, i.e. the duality of relativity [6].

3. Pulsars

Generally, pulsars evolved from the neutron black holes due to the inflows of the dark energy but there can appear as well neutron stars produced in the explosions of white dwarfs. The very early Universe was the cosmic loop composed of binary systems of protogalaxies [1]. Axis of rotation and magnetic axis in each protogalaxy overlapped and they were tangent to the cosmic loop. The same concerns the neutron black holes the protogalaxies consisted of [1]. When the very early Universe started to expand, to stabilize the protogalaxies, their axes of rotation tried to overlap with direction of their velocity – the same concerns the neutron black holes. It leads to conclusion that there appeared neutron black holes in which magnetic axis did not overlap with axis of rotation. In the extreme case, the magnetic axes were and are perpendicular to the axes of rotation so we should observe two pulses per period. Here, we will calculate the spin periods for such pulsars.

Radius of a neutron black hole can increase due to two phenomena i.e. due to the initial inflows of the dark energy, [1] or due to the beta decays of the neutrons. Both phenomena lead to creation of iron crust on neutron star. The iron crusts are very stable whereas the beta decays of neutrons, which take place below the crusts, are the not speedy processes so the increases in volume of the iron crusts should be sudden and should appear in time distances very long in comparison with the spin periods.

Due to the beta decays, atmospheres of pulsars mostly should contain protons, alpha particles and electrons but the atmospheres should be very thin. The friction between an atmospheres and surface of a pulsar causes that surface temperatures of pulsars should be relatively very high.

At first calculate how spin period T depends on density of neutron black hole

$$T = 2 \pi r_{NBH} / (G m_{NBH} / r_{NBH})^{1/2}, \tag{7}$$

where $m_{NBH} = 4\pi r_{NBH}^3 \rho_{NBH} / 3$, where ρ_{NBH} is the mass density of the neutron black hole

$$\rho_{NBH} = m_{neutron} / [(A + 4B) / 2^{1/2}]^3 = 2.394 \cdot 10^{17} \text{ kg/m}^3. \tag{8}$$

Finally, we obtain

$$T = [3 \pi / (G \rho_{NBH})]^{1/2} = 0.000768 \text{ s}. \tag{9}$$

It is the lower limit for the spin period of a pulsar and this value is about 1.8 times lower than the today known lowest spin period – it is for PSR J1748-2446ad and it is 0.00140 s [7].

Due to the inflows of the dark energy, mass of pulsars can be smaller than the neutron black hole but from formula (9) results that spin period of a pulsar depends only on mean mass density of a neutron-iron pulsar.

At the end of evolution, each neutron-iron pulsar transforms into iron pulsar. Calculate the upper limit for spin period for iron pulsar. We assume that density of iron is $\rho_{Pulsar,Fe} = 7900$ kg/m^3. From formula (9) we obtain

$$T_{Pulsar,upper-limit} = [3 \pi / (G \rho_{Pulsar,Fe})]^{1/2} = 4{,}228 \text{ s}. \tag{10}$$

On the assumption that an iron pulsar has mass of the neutron black hole, from following formula

$$\rho_{NBH} = \rho_{Pulsar} (r_{Pulsar} / r_{NBH})^3, \tag{11}$$

we obtain that radius of such pulsar is $r_{Pulsar,Fe} = 1.1423 \cdot 10^9$ m – it is about 1.64 times greater than the radius of the Sun. It is easy to calculate that the rotational velocity for the iron pulsar is 1700 km/s i.e. anywhere from ten to twenty hundreds of km/s.

The obtained upper limit is about 3 times higher than the today known highest spin period – it is for RX J0146.9+6121 and it is about 25 min [8].

4. Summary

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But due to perfect energy flow from core of a star toward its surface there as well appear at least three Chandrasekhar limits i.e. masses of stars which explode as Type Ia supernovae via sudden collapse of whole star to the neutron-star state which leads to violent full volumetric explosion so there is not created a neutron-star remnant – the threshold masses are 1.395, 11.20 and 0.891 solar masses. The first mass is the very well known Chandrasekhar limit whereas the second was the mass of, for example, the SN 1987A supernova. Energy is carried by the condensates of the Einstein-spacetime components which are the black holes in respect of the weak interactions or is carried by energetic neutrinos. The condensates with a mass 52.828 MeV are produced in centres of muons, with a mass 424.124 MeV are produced in centres of baryons, whereas energy of the neutrinos is the one fourth of the mass of neutral pion (33.743 MeV). Their number densities increase rapidly for the threshold masses of stars.

The Type Ia supernovae with the threshold mass equal to 0.891 solar masses should be fainter than the original Type Ia supernovae with a mass of 1.395 solar masses. The supernovae with the lowest mass appear in more distant Universe than the original ones so they give an illusion that our Universe accelerates its expansion. But S-SET shows that there is as well the second reason which leads to such illusion, i.e. the duality of relativity.

Here, as well, are calculated the lower and upper limits for spin periods of pulsars i.e. for stars with neutron core and iron crust. The lower limit is 0.000768 s whereas the upper one is 4,228 s (it is for the transient Be star Binary Systems). The lower limit is about 1.8 times lower than the today known lowest spin period (for PSR J1748-2446ad is 0.00140 s) whereas the upper one is about 3 times higher than the today known highest spin period (for RX J0146.9+6121 is ~ 25 min).

Presented here model is very simple and leads to observational facts.

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