Stellar Black Holes Do Not Exist

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Abstract Considering the importance of rotation during the collapse of a type II supernova of a very massive star, the metric that must be considered for the possibility of black hole formation is, of course, the Kerr metric. On the other hand, there are many different types of matter that are possible for neutron matter under high densities, such as a Fermi gas of neutrons, a superfluid of neutrons, etc. And the latest LHC data (from the TOTEM Collaboration) on the nucleon hard core indicate that when two nucleons get at distances smaller than 0.5 fm, there is a gigantic repulsion between them which has been observed at energies of up to 13 TeV. When we take all this information together into account, we find out for the first time that stellar black holes do not exist at all. It is also shown that stars made up of a quark-gluon plasma are not generated by means of the core-collapse mechanism of a massive star.

Keywords Black holes, Tolman-Oppenheimer-Volkoff limit, quark-gluon plasma stars, supernovae

1. Introduction

For many astrophysicists, a very massive star with a mass above 90 solar masses, at the end of its evolutionary stage, becomes a black hole, because during the collapse of the star, the formed iron-nickel core acquires a mass that exceeds the Tolman-Oppenheimer-Volkoff limit (TOV limit) [1]. However, the physical mechanism for the formation of a black hole is not found in any book on General Relativity or in any scientific article**. Therefore, black hole formation is just an assumption.** It is important to note the caveat that Oppenheimer and Volkoff included in their 1939 article [1] "If… the effect of repulsive forces, that is, of increasing pressure for a given density above the value given by Fermi's equation of state, this could tend to avoid collapse." And it is important to highlight that in 1939 the knowledge on the nuclear force was very preliminary and, at that time, we did not know that neutrons were composed of quarks. Weinberg warns in [2] "However, it is not known whether a massive star will actually develop a trapped surface or simply explode into fragments with mass small enough to form stable white dwarf neutron stars.", which is a very original suggestion.

Of course, the nuclear force plays a big role in the formation or not of a neutron star from the iron-nickel core. In the literature we find many nucleon-nucleon potentials. Miller [3] lists more than 40 different potentials, and state that there are more. And Naghdi [4] compares many nucleon-nucleon potentials. For the purpose of this article it is more than enough to consider the Reid's effective potential from 1968 [5], displayed in Figure 1. In this case it is for a neutron-proton pair with aligned spins. It shows that the force between two nucleons is very repulsive for short distances (<0.8 fm) and has a minimum around – 100 MeV. Let us recall that the repulsive part of the nuclear force was proposed in 1951 by Jastrow [6]. In 1968 we did not know yet how large the repulsive part of the force was. We knew that the repulsion had to do with the internal structure of the nucleons which had been found in the late 1950s by Hofstadter [7, 8] at SLAC. He discovered that both the proton and the neutron have a hard core with a radius of about 0.25 fm. However, since then there is no consensus on the true nature of the repulsive part which is commonly known as the nucleon hard core. It became more known from the experimental point of view after 2006 through the data of Islam eta al. at energies of 546 GeV, 630 GeV and 1.8 TeV [9] at the Linear Hadron Collider (LHC). Later on it was observed by the LHC's TOTEM Collaboration at 7 TeV [10, 11], 8 TeV [12] and 13 TeV [13].

Let us have a graphical idea of what a 13 TeV repulsion means. Taking a look at Figure 1 we see that from zero upwards there is a repulsive part of about 120 MeV. Well, 13 TeV is almost 110,000 times 120 MeV!!!!!! It is like an infinite wall!! Therefore, the repulsion is unsurpassed!

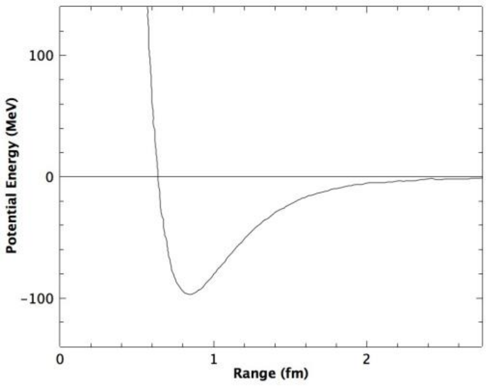

Figure. 1. Reid potential for two nucleons (proton-neutron pair with aligned spins) as a function of the distance between them. The potential has a minimum at about 0.8 fm. With this potential we can clearly see that the system of two nucleons can become bound and have a negative binding energy. Source: [5]

On the other hand, from the 1930s on and up to the present day, there have been important theoretical developments on fermionic and bosonic systems and on the bosonization of fermionic systems, including neutrons. From the 1960s on there was the development of the Standard Model of Particle Physics that allowed the theoretical possibility of a quark-gluon plasma which is a matter constituted by deconfined quarks and gluons. And, indeed, on April 8, 2005, Brookhaven National Laboratory announced the creation of a new state of hot and superdense matter in the form of a perfect liquid, that is, a liquid with no viscosity, at a temperature of about $4x10^{12}$ K [14]. It was achieved by means of the giant atom smasher the Relativistic Heavy Ion Collider (RHIC).

Regarding the possibility of black hole formation, rotation plays an important role in the collapse of a very massive star into a more compact object. This is an absolute truth inferred from the existence of pulsars, which are neutron stars with extremely high angular velocities. The slowest neutron stars have periods in the range of 30 s. Therefore, the appropriate metric to consider for the possible formation of a black hole is the Kerr metric [15] rather than the Schwarzchild metric which does not take rotation into account. In the Kerr metric, the singularity is a ring in the central part of the star's equatorial plane. That is, in the Kerr metric there is no singularity in the so-called Schwarzchild radius, which is removed by rotation. Therefore, we can strongly state that it is completely delusional to use the Schwarzchild's singularity, that is, the so-called Schwarzchild's radius in the description of black holes.

2. How Nature Always Prevents the Formation of Stellar Black Holes

In 1939, Oppenheimer and Volkoff [1] established the limit of $0.7M_S$ (M_S means solar mass), which became known as the Tolman-Oppenheimer-Volkoff limit (TOV limit), for the stability of a neutron star against the gravitational collapse. Currently the TOV limit is between 2.2 and 2.9 M_S [16]. However, this article is from 1996 and the authors considered the system of neutrons as a Fermi gas and disregarded the large repulsion of the nuclear force. They overlooked that when fermions in a Fermi gas are forced very close against each other, they simply pair up to avoid the restriction of the Pauli principle, and thus the system becomes a Bose-Einstein condensate and thus, obviously, the temperature and pressure drop. Therefore, an iron-nickel core, compressed beyond the TOV limit, becomes just a neutron star made up of a neutron superfluid and not a black hole. In fact, we have known for more than 40 years (please, see [17] for a review) that the innermost layers of neutron stars are made up of neutron superfluids. Pairing is achieved at the expense of the repulsive potential energy which is always guaranteed as shown in the data above from the LHC. The other possibility for the iron-nickel core is to explode or fragment into smaller pieces as proposed above by Weinberg. Therefore, there is never the formation of any ring singularity. In a recent paper, Roy Kerr [18] sheds doubt on the real existence of the ring singularity, and I show now that it does not exist at all.

3. An Approximate Relation Between Radius and Mass for Superfluid Neutron Stars

Superfluid neutron matter has densities between $5x10^{16}$ kg/m^3 and 10^{18} kg/m^3 [19]. For this density range we obtain the lower and upper limits for the neutron star radii $4.7N^{1/3}$ km and $21.2N^{1/3}$ km, where N is the number of solar masses. And indeed, in 2022 a neutron star was found with a mass of about $0.77M_S$ and a radius of about 10.4 km [20], and therefore it has an average density of about $3.3x10^{17}$

kg/m^3 and is constituted of a superfluid of neutrons. Therefore, we get the correct order of magnitude. And this confirms what the authors state in the article: the equation of state of this star is different from what was expected.

It is obvious that there must be a limit for N and we can obtain a rough estimate for it in the following way. The minimum of the Reid potential is about -100 MeV. Therefore, neutrons and protons from the upper layers of the star must have a maximum kinetic energy of about 100 MeV in order to get bound to the nucleons on the surface of the iron-nickel core. Therefore, using Newtonian dynamics we have that the initial potential energy of a proton (or neutron) at r = R (radius of the progenitor star) is

$$E_{p0} = - (GMm_p)/R \qquad (1)$$

where M is the progenitor star mass and m_p is the proton mass. The final potential energy of the proton (or neutron), when it hits the iron-nickel core is

$$E_p = - (GM_cm_p)/R_c \qquad (2)$$

where M_c is the iron-nickel core mass. As $R_c << R$ (R_c is just a couple of kilometers), we have from the conservation of energy for the proton

$$K = GM_cm_p/R_c \qquad (3)$$

where K is the kinetic energy of the proton (or neutron) when it reaches the core. Making K = 100 MeV, R_c = 21.2$N^{1/3}$ km, $M_c = NM_S$ and the density = 5x10^{16} kg/m^3 we obtain N of the order of 2. Therefore, this is the upper mass limit for a superfluid neutron star. If we consider particles heavier than the proton, that is, nuclei from the inner and upper layers of the star, according to what is well known from Nuclear Physics, the binding between them and the nucleons on the surface of the iron-nickel core would be much less than -100 MeV (that is, less negative) and thus, there would be too much kinetic energy remaining and, therefore, these particles would just bounce back due to the strong repulsion between nucleons.

4. Are There Stars Made Up of a Quark-Gluon Plasma?

The answer is no. Let us see why. It was shown above that two solar masses is an upper limit for the mass of a superfluid neutron star. If we take this limit as a lower value for the mass of a star made up of a quark-gluon plasma (QGP) and take the density as 4x10^{18} kg/m^3 [21] for a QGP we obtain a radius of about 6.2 km for the remaining star originated from the core. When we insert these data into Equation (3) we obtain K = 225 MeV which is more than twice the maximum kinetic energy that is possible for binding. Therefore, a star made up of a quark-gluon plasma is never formed by means of the core-collapse mechanism. This is in line with the very important and deep study carried on about the nuclear force [22] which arrived at the conclusion that at higher densities, such as in the centers of neutron stars, the particles that best describe the system are nucleons rather than quarks.

5. Very Massive Stars Form Supernovae or Just Explode When They Collapse

The greater the mass of the progenitor star, the greater are the kinetic energies from the star's upper and inner layers that will reach the iron-nickel core and therefore, their kinetic energies K plus the minimum of Reid potential (–100 MeV) will yield a very large remaining kinetic energy, and, thus, this means that the matter would just bounce back or would be transferred to the nucleons of the core and could cause the explosion of the star. That is, they do not form black holes. The larger the mass of the progenitor star, the larger is the transfer of kinetic energy from the upper and inner layers of the star to the iron-nickel core, and thus the larger is the probability that the star will just explode. Let us always take into account that the repulsion is always guaranteed from the data of the TOTEM Collaboration. And this is certainly what happened in the case of the supernova AT2021lwx [23].

6. Conclusion

Let us recall the famous quote of Arthur Eddington against the existence of black holes **"I think that there should be a law of Nature to prevent the star from behaving in this absurd way."** [24] And as I show above, the mechanism is just the almost infinite repulsion between two nucleons at extremely close distances. Therefore, we can say it loud: stellar black holes do not exist at all!

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