

# The Remnant of GW170817: A Trapped Neutron Star with a Massive Incompressible Superfluid Core

Ahmad A. Hujeirat<sup>1</sup>, Ravi Samtaney<sup>2</sup>

<sup>1</sup>IWR, Universität Heidelberg, Heidelberg, Germany

<sup>2</sup>Applied Mathematics and Computational Science, CEMSE Division, KAUST, Thuwal, KSA

Email: AHujeirat@iwr.uni-heidelberg.de, ravi.samtaney@kaust.edu.sa

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## Abstract

Our bimetric spacetime model of glitching pulsars is applied to the remnant of GW170817. Accordingly, pulsars are born with embryonic incompressible superconducting gluon-quark superfluid cores (SuSu-matter) that are embedded in Minkowski spacetime, whereas the ambient compressible and dissipative media (CDM) are imbedded in curved spacetime. As pulsars cool down, the equilibrium between both spacetime is altered, thereby triggering the well-observed glitch phenomena. Based thereon and assuming all neutron stars (*NSs*) to be born with the same initial mass of  $M_{NS}(t=0) \approx 1.25M_{\odot}$ , we argue that the remnant of GW170817 should be a relatively faint *NS* with a massive central core made of SuSu-matter. The effective mass and radius of the remnant are predicted to be  $[2.8M_{\odot} < M_{rem} \leq 3.351M_{\odot}]$  and  $R_{rem} = 10.764$  km, whereas the mass of the enclosed SuSu-core is  $M_{core} = 1.7M_{\odot}$ . Here, about  $1/2 M_{core}$  is an energy enhancement triggered by the phase transition of the gluon-quark-plasma from the microscopic into macroscopic scale. The current compactness of the remnant is  $\alpha_c = 0.918$ , but predicted to increase as the CDM and cools down, rendering the remnant an invisible dark energy object, and therefore to an excellent black hole candidate.

## Keywords

Relativity: Numerical, General, Black Hole Physics, Magnetars, Neutron Stars, Pulsars, Superfluidity, Superconductivity, Gluons, Quarks, Plasmas, QCD

## 1. Introduction

The astronomical event GW170817 marks the beginning of a new era of multi-

messenger astronomy, in which detectors of gravitational waves and electromagnetic radiation operated almost simultaneously to follow up the merger event. Using LIGO detectors and advanced Virgo in combination with Fermi and INTEGRAL gamma-ray telescopes the event was localized to the galaxy 4993, in which two compact objects, most likely two neutron stars, were found inspiraling and to subsequently merge and form a massive compact object [see [1], and the references therein]. The component masses were inferred to lie between  $[1.0M_{\odot} \leq M_1, M_2 \leq 1.89M_{\odot}]$  in the high spin case and  $[1.16M_{\odot} \leq M_1, M_2 \leq 1.60M_{\odot}]$  in the low case. Approximately 10% of the total mass is predicted to have gone forming an accretion disk, ejecta, jets, X-ray flares and/or outflows [see [2], and the references therein]. While the exact nature of the remnant depends strongly on the final baryonic mass, it may still fall in one of the following three categories:

#### ■ A massive neutron star (HMNS)

Based on observational and theoretical considerations, the possibility that the merger of the two NSs yielded a short-living massive neutron star (HMNS) appears to be widely accepted [see [3] [4] [5], and the references therein]. On the long-term however, it is not clear if such a massive object would survive a gravitational collapse and end up as a stellar BH [see [6], and the references therein].

On the other hand, there are several observational signatures that obviously favor the formation a MNS. Namely, the occurrence of the gamma-ray burst GRB170817 approximately 1.7 seconds after the merger event [7] and the appearance of certain features 155 days later is a clear indication for reactivation of the central object. Moreover, the formation of a structured off-axis jet [3] [8], the detected emission powered by the radioactive decay of r-process nuclei synthesized in the ejecta [9] and that a surface magnetic field of order  $10^{12}$  G is required to match the EM-radiation hint that the remnant must be neutron-rich with a hard surface [see [4], and the references therein].

In particular, the observed steady brightening of GW170817 lasting less than 160 days after the merger, which is most likely powered by non-thermal synchrotron emission from plasmas propagating at relativistic speeds, may be well-considered for ejecta from a central compact object with hard surface. The Lorentz factors,  $\Gamma$ s, that correspond to plasma propagation in micro-quasar systems generally fall in the range of  $[3 \leq \Gamma \leq 10]$ , whereas  $\Gamma$ s of the observed ejecta in GW170817 hardly reach the lower range of this interval.

#### ■ A stellar black hole (SBH)

Whether the remnant was a short or is a long-living HMNS, its total mass is  $\mathcal{M}_{tot} \geq 2.6M_{\odot}$  to 90% confidence [see [11], and the references therein]. In the absence of extraordinary stiff EOSs with exotic repulsive nuclear forces of unknown origin, the object should ultimately collapse into a stellar black hole. Indeed, the revealed low X-ray flux from GW170817 indicates weak magnetic field that is typical to stellar BHs [12]. Other arguments favoring the formation of a BH have been discussed, though the results obtained may be biased, as these

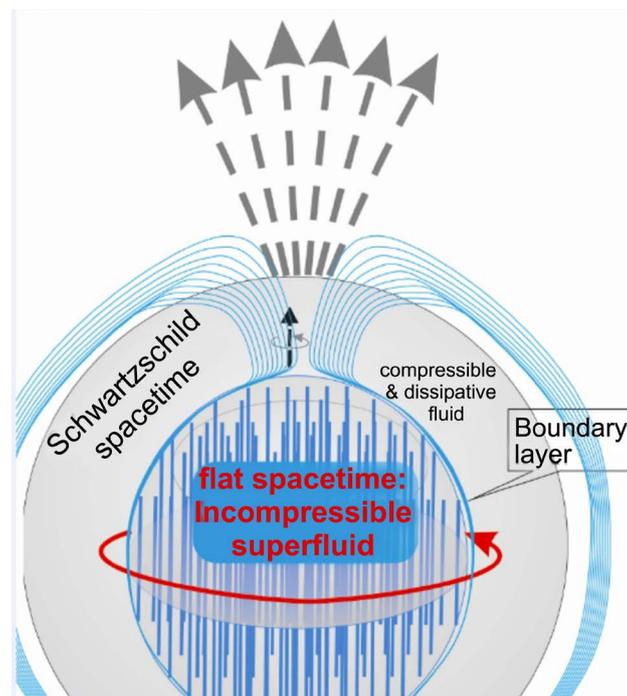
studies assume a priori the formation of a BH [see [6], and the references therein].

However, it should be noted here that determining the nature of the remnant would require solving the time-dependent general relativistic Navier-Stokes equations with radiative transfer and magnetic fields at the background of a dynamically varying spacetime, which is beyond the state-of-the-art simulations today. Also, the capability of receiving gravitational wave signals that carry information about the spin and compactness of the *NSs* shortly before and of the remnant immediately after the merger event are outside the sensitivity range of LIGO.

#### ■ Another type of a compact object

In the absence of direct and founded observational signatures that determine conclusively the nature of the remnant, the possibility that it might be neither a classical *NS* nor a stellar BH, but rather a new type of a compact object cannot be excluded. The fact that the mass of the remnant falls in the range of  $[2.5M_{\odot} \leq \mathcal{M} \leq 5M_{\odot}]$ , where neither stellar BHs nor normal neutron stars have ever been observed, makes this conjecture viable.

In the following, we discuss this conjecture in detail and argue that the remnant is most likely made of incompressible gluon-quark superfluid core embedded in a flat spacetime and surrounded by a shell of compressible and dissipative matter with a curved spacetime at the background as visualized in **Figure 1**.



**Figure 1.** A schematic description of the interior of the remnant of GW170817 as predicted by the bimetric spacetime scenario. While the incompressible superfluid in the core is enclosed in a Minkowski spacetime, the surrounding compressible and dissipative media is set to be imbedded in a curved spacetime. Both media are separated by geometrically thin boundary layer, where the pulsar's dynamo action is expected to operate.

## 2. The Remnant of GW170817 and Its Internal Structure

In the case of a quasi-static contraction of a massive  $NS$ : as the event horizon,  $R_H$ , and the star radius,  $R_*$ , approach each other, the stiffness of the EOS and therefore the compactness must increase. The sound speed should increase and reach roughly the speed of light at  $R_* = R_H(1 + \epsilon)$ , where  $\epsilon$  is a sufficiently small number. Indeed, it was repeatedly argued that the sound speed inside HMNSs must be larger than  $c/\sqrt{3}$  [see [13], and the references therein]. A possible limiting EOS may have the form:

$$P_L = n^2 \frac{\partial}{\partial n} (\epsilon/n) \xrightarrow{\epsilon \rightarrow a_0 n^2} \epsilon, \quad (1)$$

where  $a_0, n, P_L, \epsilon$  denote a constant coefficient, number density, local pressure and the density of internal energy, respectively. Here the rate of interaction of sub-nuclear particles, namely mesons and gluons, reaches the saturation limit, at which the chemical potential, *i.e.* energy per particle, attains its universal maximum value, which was predicted to be around  $n_{cr} \approx 3 \times n_0$ , where  $n_0$  is the nuclear number density [14]. In this case,

$$\epsilon = a_0 n^2 \xrightarrow{n \rightarrow n_{cr}} a_0 n_{cr}^2 = \epsilon_{cr} = \mathcal{O}(10^{36}) \text{ erg/cc} \quad (2)$$

In the present study, this EOS governs fluids that are the maximally compressible or purely incompressible. Under these conditions, the constituents are capable of resisting all kinds of external perturbations, including further contractions by gravity. However an EOS of the type  $\epsilon = P_L = \text{const.}$  is incompatible with traceless mass-energy tensors (METs) and therefore does not obey conformal invariance [13]. Similar to weakly compressible terrestrial fluids, the pressure in incompressible fluids loses its local thermodynamical character and turns into a mathematical term only<sup>1</sup>, which nevertheless must be chosen, so to ensure that  $dP_L/d\epsilon \leq 1$ .

In fact, fluids governed by the limiting EOS:  $P = \epsilon(> \epsilon_0)$  cannot accept stratification by gravity or, equivalently by the curvature of spacetime. Indeed, it was recently verified that once the matter at the very center of massive  $NS$ s become purely incompressible, then the embedding spacetime must flatten and become conformally flat [see [15], and the references therein]. The total energy of a stationary and zero-stratified supradense nuclear matter should consist of the rest energy only, as otherwise, thermal, magnetic and kinetic energies can be affected directly by gravity. Thus the energy state of purely incompressible supradense nuclear fluids should correspond to the universal lowest-possible energy state. Based thereon, our argument may be summarized as follows:

1) Under certain conditions, supradense nuclear fluids may become maximally compressible, *i.e.* purely incompressible, at which the energy density attains the universal maximum value  $\epsilon_{\text{max}}$ . Here the interaction rate between the constituents saturates as they communicate with each other at the speed of light. Energy divergence is prohibited as massless gluons are the mediators whilst the

<sup>1</sup>In terrestrial weakly incompressible fluid the pressure is treated as a Lagrangian multiplier.

quarks must motionless in space, but oscillatory in time. These conditions should apply to the gluon-quark-plasma inside individual baryons at zero-entropy.

2) The classical pressure in purely incompressible supradense nuclear fluids loses its local thermodynamical character. In fact, as the constituents communicate with each other at the speed of light, the interaction-power is sufficiently strong to smooth out all possible potential barriers between individual baryons, thereby enhancing their merger and forming an ocean of gluon-quark superfluid.

3) Purely incompressible supradense nuclear matter governed by the EOS,

$$P = \varepsilon_{\max} = \text{const.} \quad (3)$$

should have zero-entropy and embedded in a flat spacetime. This strong conjecture raises the possibility that entropy of matter and curvature of spacetime may have hidden connections.

### 3. Basic Assumptions and the Solution Strategy

Very recently, we applied the bimetric spacetime scenario of glitching pulsars to investigate the internal structures both of the Crab and Vela pulsars [16]. The model was capable of re-producing and explaining several mysterious features that observed to accompany both pulsars, namely the deriving mechanisms underlying the glitch phenomena and their rate of reoccurrence, the origin of under/overshootings observed to associate their glitch events as well as their cosmological fate. Based thereon, newly born pulsars are predicated to have the initial mass of  $1.25M_{\odot}$  and an embryonic SuSu-core of  $0.029M_{\odot}$  to evolve into a Crab-like pulsar after 1000 years and subsequently into a Vela-like pulsar 10,000 years later to finally fade away as an invisible dark energy object after roughly 10 Myr. The cores of both pulsars were predicted to have the masses:  $\mathcal{M}_{\text{core}}^{\text{Crab}} = 0.15M_{\odot}$  and  $\mathcal{M}_{\text{core}}^{\text{Vela}} = 0.55M_{\odot}$  [10].

In order to apply the model to the remnant of GW170817, the following assumptions must be made:

- The masses of the two merging NSs read:  $\mathcal{M}_{\text{tot}}^1 = \mathcal{M}_{\text{tot}}^2 = 1.4M_{\odot}$ , which fall in the mass-range revealed by observations [1]. Although our results are not too sensitive to these exact values, both masses are remarkably close to that of the Crab pulsar and therefore we may assume that both NSs should have the same cosmic evolution. Specifically, both NSs should have identical initial conditions, are perfectly isolated with no energy loss or gain from or to their surroundings. As in the case of the Crab and Vela pulsars, any mass-difference is due to age-difference: as the object ages, it becomes colder, the inertia of its SuSu-core increases, which is associated with a topological change of spacetime embedding its interior.

The total mass of the object consists of core's mass, half of which is baryonic matter while the other half is due to the enhanced gluon cloud enclosing the quarks on the macroscopic scale. The other contribution to  $\mathcal{M}_{\text{tot}}^1$  comes from the ambient normal fluid.

Based thereon each of two the *NSs* prior merger should have approximately the same age, same total masses as the Crab pulsar and therefore the same core's masses:  $\mathcal{M}_{core}^{Crab} = 0.15M_{\odot}$  [see [10], for further details].

- The incompressible superfluid cores of both objects should have survived the violent merger and preserved their inertia. While this assumption appears to be too strong, it may be supported by the following arguments:
  - Similar to gluon-quark plasma inside individual baryons, the incompressible gluon-quark superfluid inside the cores of pulsars cannot live in free space, but hidden behind a confining quantum barrier. The effective energy of the potential barrier is sufficiently strong to protect the core against deformations by tidal forces. Indeed, the sound crossing time of each core is predicated to be one million times shorter than the dynamical time scale during the inspiraling phase of both *NSs* prior merger.
  - In QCD, the bag energy confining gluon-quark plasmas inside individual baryons is of order 300 MeV. When  $N$  baryons are set to merge together under zero-temperature and pure incompressibility conditions, then the size,  $V$ , and mass of the resulting super-baryon must increase with  $N$ , *i.e.*  $dV/dN = const$ . Recalling that roughly 99% of the effective energy of an individual baryon is due to the gluon field, then the energy of the gluon cloud confining the quarks inside the super-baryon must moderately increase with  $N$ , *i.e.* an energy enhancement of the type:  $d\mathcal{E}^{gluon}/dN = \alpha_0 N^{\beta}$  is forbidden as  $N$  is typically of order  $\mathcal{O}(10^{57})$ , so that any value of  $\beta > 0$  would lead energy divergence. A reasonable prediction would be that the merging process of  $N$ -neutrons at zero-temperature is energetically upper-bounded by the constant:  $d\mathcal{E}^{gluon}/dN = 2\varepsilon_0$ , where  $\varepsilon_0$  is the rest energy of a neutron.

One may conjecture that the extra energy originates from the gluon field necessary for stably confining the quark-ocean inside the super-baryons and shield it from the outside universe [17]. Indeed, the effective energy stored in the creation of the short-living pentaquark that was detected in the LHC experiment was found to be about 4.5 GeV, which is consistent with our scenario [18], though the physical conditions are completely different: while the plasma at the LHC is characterized by very high temperature and extremely low density, the matter in the central cores of pulsars should be supradense nuclear with temperature much lower than the corresponding Fermi one.

- The incompressible supranuclear dense matter inside the cores of *NSs* must have the lowest possible energy state and behaves as a single quantum entity. Such a fluid is expected to be well-equipped to resist all types of external perturbations, including tidal deformation. In this case, the only source left for energy emission would be the ambient compressible and dissipative nuclear fluid in the shell.

#### 4. The Numerical Approach

Based on the above-mentioned arguments, the mass and size of the remnant's core may be obtained here by extrapolating the sizes of the cores of the well-studied

Crab and of the Vela pulsars as well as recalling that the remnant should turn invisible, once the object has metamorphosed entirely into a SuSu-object. Thus a NS with the initial mass of  $M_0 = M(t=0) = 2.5M_\odot$  will double its mass at the end of its visible lifetime, *i.e.*  $M(t=\infty) = 5M_\odot$ .

In **Figure 2** we show the distribution of effective masses of the cores versus the total masses of the objects. Here we use the tabulated values shown in **Figure 2** to construct the quadratic mass-function in units of  $M_\odot$ :

$$\mathcal{M}_{core} = 0.108507 \mathcal{M}_{tot}^2 + 0.652778 \mathcal{M}_{tot} - 0.976562, \quad (4)$$

which applies for  $\mathcal{M}_{tot} \geq 1.25M_\odot$ .

Let  $t = t_0$  denote the time, at which the two NSs merged together. Based on observations the total mass of both objects is:  $M_{tot}(t = t_0 - \epsilon_{t_0}) = 2.8M_\odot$ , which consists of  $2.5M_\odot$  baryonic matter and  $0.3M_\odot$  of dark energy, where  $t = t_0 - \epsilon_{t_0}$  corresponds to the time shortly before the merger event and  $\epsilon_{t_0}$  denotes a short instant.

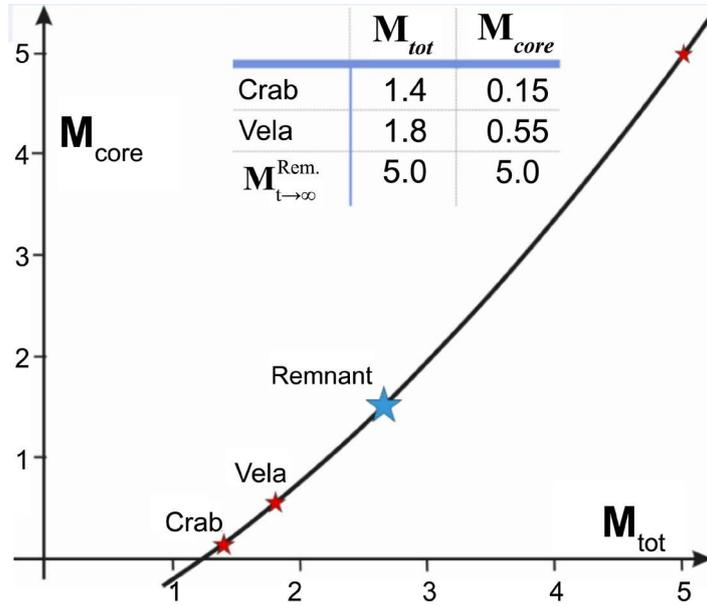
Based on the mass-function  $\mathcal{M}_{core}$ , the core's mass of the remnant appears to have undergone a dramatic increase during the merger from  $0.3M_\odot$  to  $1.7M_\odot$ , which implies an additional input of dark energy that amounts to  $0.55M_\odot$ , yielding a massive NS of  $3.351M_\odot$ , and consisting of  $2.5M_\odot$  in the form of baryonic matter and  $0.85M_\odot$  of dark energy.

The mechanism underlying the injection of dark energy into the system here may be explained as follows:

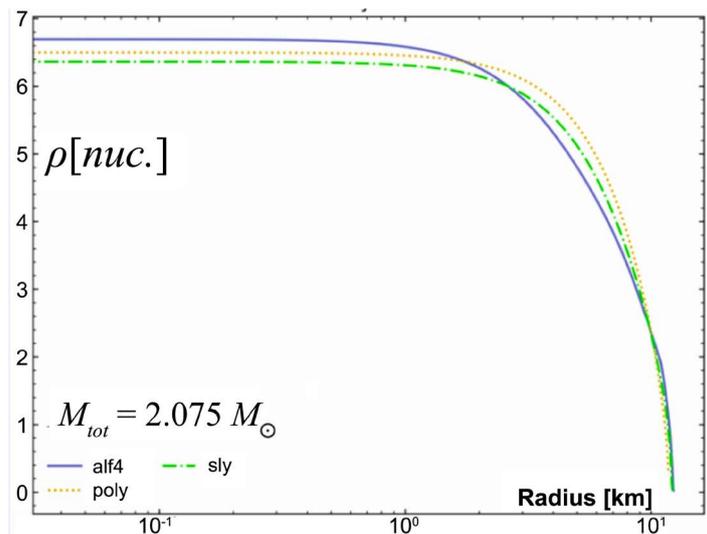
When the matter at the center of a massive NS is compressed by the surrounding curved spacetime, the separation between two arbitrary baryons,  $\ell_b$ , may decrease down and become comparable to the mean free path  $\ell_g$ , between quarks in individual baryons and at zero-temperature. In this case a free energy  $\Delta\epsilon^+$  of order  $ch/2\ell_g$  would be generated and may easily surpass the 0.939 GeV limit, beyond which baryon's merger becomes a viable process.  $\Delta\epsilon^+$  is expected to be stored locally, and specifically to enhance the surface tension needed for confining the enclosed ocean of quarks. At certain time, this energy would be liberated, once the core has decayed into a pure baryonic matter.

Based thereon, the Tolman-Oppenheimer-Volkov equation (TOV) was solved, using the core mass and its energy-density as input parameters. In the present case, the inertia of the core is expected to significantly enhance the curvature of spacetime and therefore the distribution of matter in the shell surrounding the core. The matter here is set to obey the polytropic EOS:  $P = \mathcal{K}\rho^\gamma$ . In order to obtain the optimal values of  $\mathcal{K}$  and  $\gamma$ , the TOV equation was solved for the maximum possible mass that can be obtained using the EOSs "alf4" and "sly" [19] [20]. As shown in **Figure 3**, the resulting mass turns to be:  $\mathcal{M}_{NS}^{\max} = 2.075M_\odot$ , which is approximately equal to that of PSR J0348+0435.

Interestingly enough, using "alf4" and "sly" EOSs, the central density obtained here roughly equal to the universal maximum value:  $\rho_{\max} = 6 \times \rho_0$ , at which the fluid turns purely incompressible superfluid.



**Figure 2.** The total mass of the core (baryonic and dark energy) versus total mass of the entire object (*i.e.* the mass of the core and overlying baryonic shell) are displayed, using a polynomial interpolation of the values tabulated in the figure. Part of these values have been adopted from [10].



**Figure 3.** The internal structure of a marginally stable massive NS using the three different EOSs: alf4 [19], sly [20] and poly (*i.e.* the polytropic EOS in which the coefficient  $\mathcal{K}$  and  $\gamma$  were optimized to fit the other two profiles). Except poly, non of the EOSs, including other 12 models, where capable of stably modelling the interiors of NSs more massive than  $2.075M_{\odot}$ .

The fitting procedure of the polytropic EOS with “alf4” and “sly” (see **Figure 3**), yielded the following values:

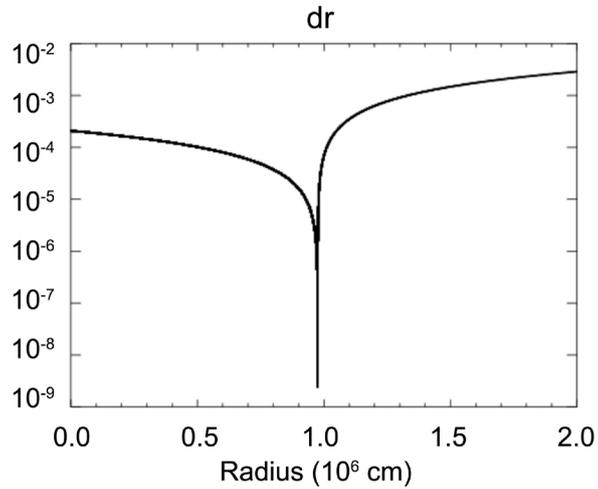
$$\begin{aligned} \mathcal{K} &= 1.98183 \times 10^{-6} \\ \gamma &= 2.72135 \end{aligned} \tag{5}$$

Assuming  $\rho_{max}$  to exist in our universe, then the physical conditions governing

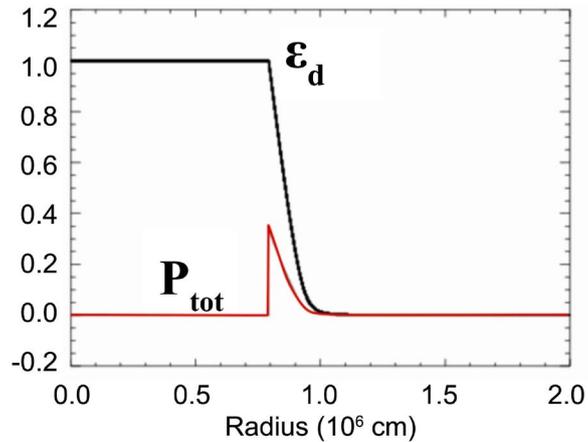
both the cores of MNS and of the remnant of GW170817, must be identical.

In order to accurately capture the strong gradients in the vicinity of the remnant’s surface, the explicit adaptive mesh refinement (EAMR) method has been employed [16]. Here approximately  $10^5$  grid points have been used reaching an aspect ratio of  $dr_{\max}/dr_{\min} \approx 10^5$  (see **Figure 4**). In **Figure 5** the profiles of the normalized total energy density and the total pressure throughout the entire object versus radius are shown. These are defined as follows:

$$\varepsilon_d = \varepsilon_{bar} + \varepsilon_\phi, \quad P_{tot} = P_{bar} + P_\phi, \quad (6)$$



**Figure 4.** The non-linear distribution of the grid spacing versus radii. Here the density of grid points was optimized in order to capture the fine structures of the remnant in the vicinity of its surface.



**Figure 5.** The profiles of the energy density  $\varepsilon_d$  and the total pressure,  $P_{tot}$ , versus radius in units of  $2\varepsilon_{cr}$ . Inside the core, where the spacetime is flat, the energy density attains the constant value  $\varepsilon_d = 2\varepsilon_{cr}$  (see Equation (2), Equation (6) and Equation (7)). Outside the core, where the matter is compressible and dissipative, the radial-distribution of  $\varepsilon_d$  is determined by solving the TOV equation at the background of a Schwarzschild spacetime using the “poly” EOS. The total pressure inside the core is the superposition of the normal local pressure and the negative pressure due to vacuum. While  $P_{tot}$  vanishes inside the core, it becomes equal to the local pressure outside it.

where

$$\begin{aligned} \varepsilon_\phi &= \frac{1}{2}\dot{\phi}^2 + V(\phi) + \frac{1}{2}(\nabla\phi)^2 \\ P_\phi &= \frac{1}{2}\dot{\phi}^2 - V(\phi) - \frac{1}{6}(\nabla\phi)^2 \end{aligned} \tag{7}$$

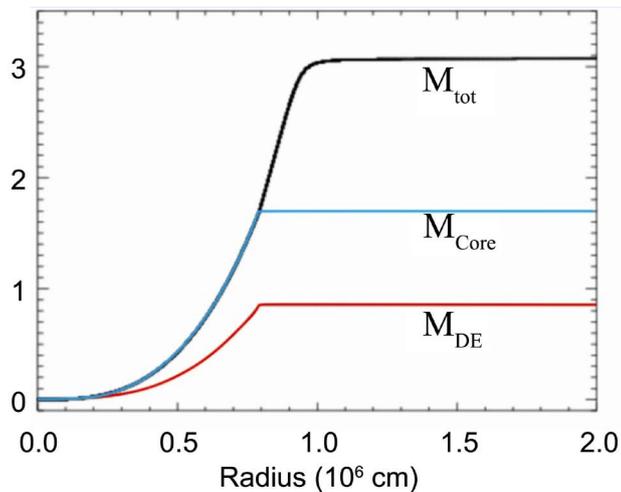
Here  $\phi, V(\phi)$  generally denote the scalar field and its interaction potential with the baryonic matter. In the present case,  $\phi$  is a spatially averaged gluon field and  $V(\phi)$  is the potential energy of the gluon-cloud embedding the quarks inside the super-baryon. The subscript “bar” denotes the contribution due to baryonic matter whereas  $\phi$  due to vacuum. The scalar field,  $\phi$ , is assumed to be significantly enhanced when undergoing a phase transition from the micro into the macroscale. Such enhancement is necessary in order to maintain the super-baryon stable, while hiding it from the outside world [see [21], and the references therein]. Inside the core, the incompressible superfluid is stationary and therefore  $\phi$  is spatially and temporary constant, *i.e.*

$$\dot{\phi} = \nabla\phi = 0. \tag{8}$$

In this case  $V(\phi) = \varepsilon_{bar}$ , which is equal to the effective resistive pressure,  $P_L$ , required to maintain the quarks apart at a minimum distance  $\ell_{min}$  which is of order 0.6 fm.

Consequently, inside the core we have  $\varepsilon_d = 2\varepsilon_{bar}$ , but a vanishing total pressure  $P_{tot}$ . Outside the core, however,  $\varepsilon_d$  runs as dictated by the TOV-equation at the background of a Schwarzschild spacetime and using the polytropic EOS with the parameters specified in Equation (5).

Following Equation (4), the total mass of the core is  $1.7M_\odot$ , half of which is made of baryonic matter and the other half is due to the macroscopic enhancement of the gluon field (see Figure 6). Using the polytropic EOS with the parameters

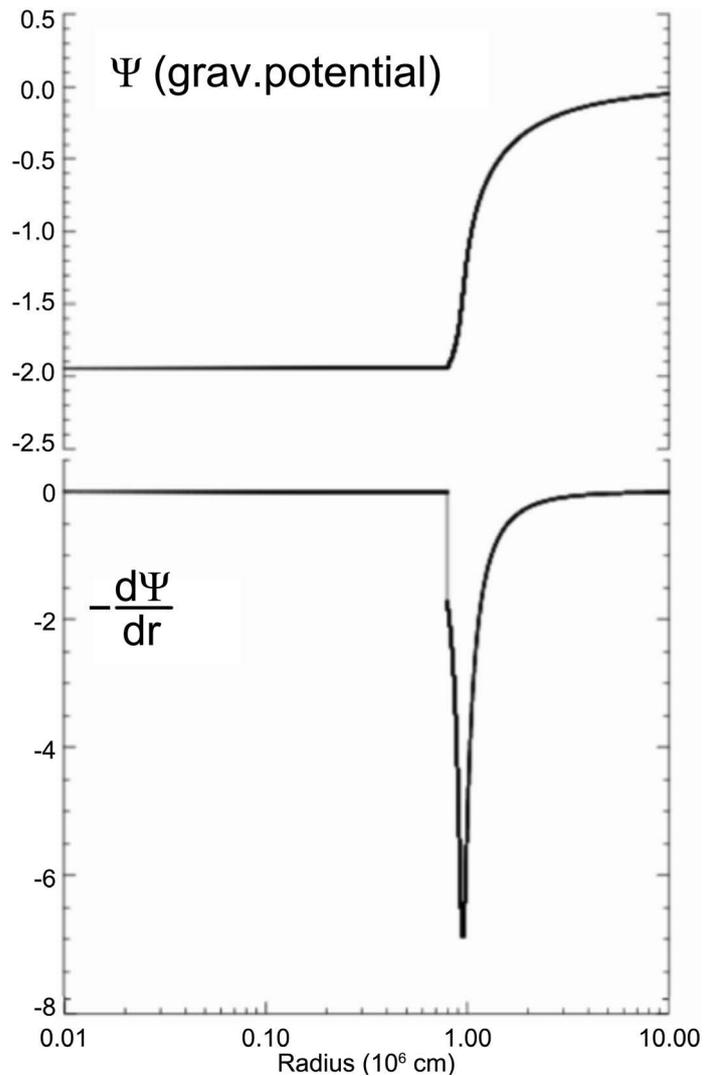


**Figure 6.** The radial-distributions of the total effective mass of the remnant  $M_{tot}$ , the total mass of the core,  $M_{core}$ , and the contribution of dark energy,  $M_{DE}$ , to the effective mass of the core. The final masses here read:  $M_{tot} = 3.351M_\odot$ ,  $M_{core} = 1.7M_\odot$  and  $M_{DE} = 0.85M_\odot$ .

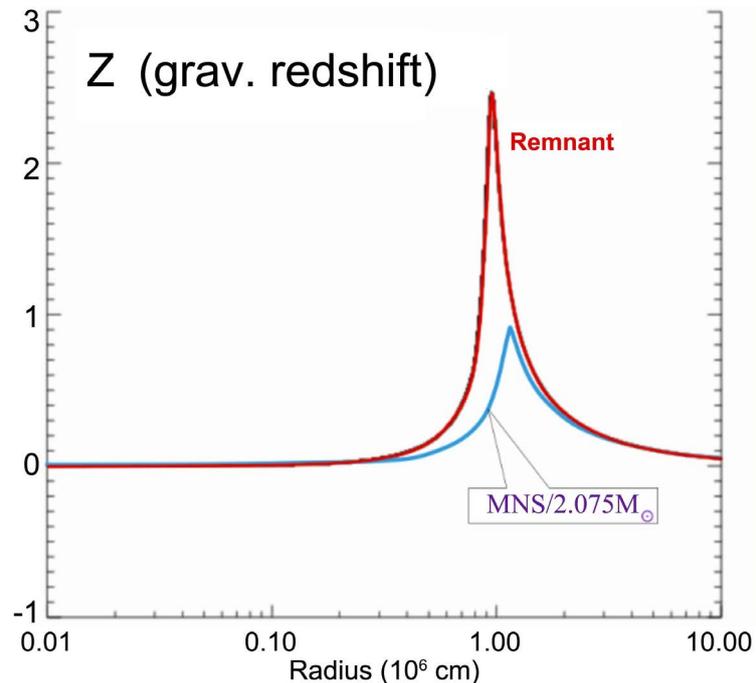
given in Equation (5), the TOV equation was integrated to determine the radius and therefore the compactness of the remnant. Our high-resolution numerical calculations yielded the radius of  $R_m = 10.764$  km for a remnant mass of  $3.351M_\odot$  to give rise to a compactness parameter:  $\alpha_c = 0.918$  as shown in **Figures 6-8**.

Obviously, the predicated value of the remnant's radius here is consistent with the recent investigations [see [22], and the references therein].

In **Figure 7** we show the Schwarzschild metric exponent,  $\Psi$ , which is, in the limit of weak gravitational field, reduces to the gravitational potential. Inside the core, where the embedding spacetime is flat,  $\Psi$  attains a negative constant value, but increases abruptly throughout the ambient medium and goes to zero at infinity. Across the surface,  $\Psi$  undergoes a dramatic spatial variation. This can be seen from  $d\Psi/dr$ , which vanishes inside the core, but then decreases and increases dramatically in the vicinity of the remnant's surface. Thus free particles in this region would experience rapid acceleration and deceleration, thereby



**Figure 7.** The radial distribution of the gravitational potential,  $\Psi$ , and its negative radial derivative throughout the remnant and the surrounding space.



**Figure 8.** The radial distribution of the gravitational redshift,  $Z$ , throughout the remnant and the surrounding space (red-colored) to be compared to that of a massive  $NS$  (MNS/blue-colored) with  $MNS = 2.075M_{\odot}$ .  $Z$  at the surface of the remnant is roughly four times larger than  $Z$  at the surface of the MNS.

giving rise to radiation emission that are strongly redshifted and may appear four times fainter than those emitted from the surface of massive and highly compact  $NS$ s (see **Figure 8**).

## 5. Summary

In this paper we have presented a model for the remnant of GW170817, which is based on the bimetric spacetime scenario of glitching pulsars. Accordingly, the core is made of incompressible superconducting, gluon-quark superfluid (Su-Su-matter) embedded in a flat spacetime, whereas the ambient compressible and dissipative medium is set to be imbedded in a Schwarzschild spacetime.

The present study relies on our previous investigation of the cosmic evolution of the Crab and Vela pulsars as well as on the topological change of spacetime inside pulsars as the driving mechanism for the glitch phenomena in pulsars.

Based thereon we have found that the remnant must have a total mass of  $\mathcal{M}_{tot}^{rem} = 3.351M_{\odot}$ , a radius  $R_{rem} = 10764$  km and it should enclose a massive SuSu-core of  $\mathcal{M}_{core}^{rem} = 1.7M_{\odot}$ . The matter inside the shell surrounding the core is compressible and dissipative and its stratification is dictated by the curvature of the embedding Schwarzschild spacetime. The massive object is deeply trapped in spacetime and the radiation emitted from its surface would be redshifted, reaching  $Z \approx 3$ , *i.e.* approximately 5 to 7 times more fainter than  $Z$ 's at the surfaces of normal  $NS$ s.

Thus the remnant is actually a  $NS$ , which has a massive SuSu-core overlaid by

a neutron-rich matter. On the cosmological time scale, when all secondary energies in the shell have exhausted<sup>2</sup>, its compactness would saturate around one, thereby turning the object invisible and making it an excellent black hole candidate.

The dark energy in the SuSu-core of the remnant is predicated to be  $0.85M_{\odot}$ . This energy enhancement originates from the phase transition of the gluon field from microscopic scale inside separated baryons into the macroscopic scale, where the core behaves as a single quantum entity, but still hidden from the outside universe.

However, while the model is based on several reasonable assumptions, work must be still done to verify their validities, specifically:

- The existence of a universal maximum density and the state of pure incompressibility;
- The origin of gravitation and its hidden connection to entropy;
- The viability of the bimetric spacetime scenario inside pulsars;
- The mechanisms underlying the glitch phenomena in pulsars and young neutron stars.

Finally, similar to newly born pulsars, a significant part of the rotational energy prior to the merger should have been stored both in the core and in the overlying shell of the remnant. The resulting configuration is expected to considerably deviate from spherical symmetry and therefore serves a rich source for the emission of gravitational radiation with  $\nu > 10^3$  Hz. However, this range of frequencies is far beyond the current sensitivity range of LIGO.

Moreover, when correlating the total entropy production to the revealed radiation power from GW170817, we find that the entropy is much below the expected value from an object of  $2.78M_{\odot}$ , irrespective of whether the remnant is a massive NS or a stellar BH [4]. Indeed, a massive entropy-free superfluid core may nicely explain the origin of the entropy deficiency here.

Assuming the next generation of high resolution observations would render our scenario reasonable, then current scenarios related to the fate of the first generation of NSs, the relatively small number of NSs and BHs in the Galaxy, the origin of dark matter and dark energy in the universe must be revisited.

## Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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<sup>2</sup>Energies other than the rest one.

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