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Unravelling the Mystery of Cosmic Baby: Triaxiality and Resolving the Companion Identification Problem of GW190814

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Abstract

Detection of Gravitational wave opens a new window to see the insights of Binary Systems. Using gravitational waves the secondary or companion object of binary system GW190814 has been detected which has estimated mass 2.5 – 2.67 $M_{\odot}$. A puzzle is created on its identification i.e., whether it was a heaviest neutron star or lowest mass black hole or any other compact object. **Taking into account the three important facts in the evolution of the (BH – NS) binary**:

- Consistency of no EM counterpart detection constrains neutron star surface magnetic field to $\lesssim 10^{15}$ G;
- The case of joint GW detection and EM upper limit rule out the theoretical possibilities that Neutron Stars in GW 200105, GW200115, and GW 190814 retain the surface dipolar magnetic fields $\gtrsim 10^{15}$ G until merger;
- Rule out the formation scenario where strongly magnetized neutron stars (i.e. magnetar) quickly merge with Black Hole.

I calculate the internal magnetic field and ellipticity of the companion compact object magnetar (i.e. neutron star) before marge with Black Hole in the event GW190814 are 1.861516 x 10^{18} G, 1.00696 x 10^{-3} and 3.4597071 x 10^{18} G, 2.218239 x 10^{-2}, respectively for optimistic and pessimistic cases. The estimated ellipticity values of the magnetar lies within the range 10^{-3} – 10^{-2} satisfying for becoming a triaxial star.

Based on these findings this author suggests that the companion compact object of GW190814 was a “triaxial star”.

Keywords: Gravitational Waves; Neutron Star; Magnetar; Triaxial Star

Abbreviations

HMXBs: High Mass X-Ray Binaries; LMXBs: Low Mass X-Ray Binaries; ULXPs: Ultra- Luminous X-Ray Pulsars; LOF: Local Outlier Factor; DDRMF: Density Dependent Relativistic Mean Field; BAT: Burst Alert Telescope; TOV: Tolman-Oppenheimer-Volkoff Equation; EOS: Equation Of State; LOF: Local Outlier Factor; AXPs: Anomalous X-Ray Pulsars; SGRs: Soft Gamma Repeaters; GW: Gravitational Wave; FRB: Fast Radio Bursts.

Introduction

Research on binary system received an acceleration when Hulse and Taylor [1] showed that orbital decay of a neutron star (NS) - neutron star binary system i.e., (NS-NS) releases gravitational radiation obeying the prediction of general relativity [2,3]. In the binary pulsar PSR J1913 + 16 two neutron stars are in spiraling each other and orbital decay of this system releases gravitational waves obeying the prediction of general relativity. This observation indicated an indirect proof of the existence of gravitational waves.

Compact binaries, such as white dwarfs (WD - WD), neutron stars (NS – NS), blackholes (BH – BH), NS – BH, WD – NS, consist of two closely orbiting stellar mass objects are two types - a) wide binaries which have lower orbital frequencies (i.e., detectable source for space – borne detector such as LISA) and b) close binaries which produce strong signal, thus, detectable at ground base detectors like LIGO, VIRGO.

In 2015, LIGO first directly detected the gravitational waves originated from the collision of black hole binary i.e., GW150914 event. Thus, using both gravitational waves and traditional light based electromagnetic spectrum astronomers are able to know more precisely about the compact object and it's properties.

Magnetars are considered as an exceptional compact object (i.e., isolated neutron stars) having surface magnetic field strength > 10^{14} G – 10^{15} G and dipolar magnetic energies exceeding it's rotational energies. Its internal magnetic field strength is 1 – 2 order more than its surface dipolar field i.e., ~ 10^{16} – 10^{17} G and even more i.e. 10^{18} G [4].

For a star modeled with full of incompressible matter and having a strong internal magnetic field Chandrasekhar and Fermi [5] showed that such a star will deform from its spherical symmetry axis i.e., magnetic field axis will become misaligned with the star's rotational axis. Due to this deformation induced along the magnetic field axis the gravitational waves (GWs) will be produced. Detection of gravitational waves emitted from the deformed stellar source i.e., magnetar provides us an opportunity for improving our present understanding regarding the influence of strong magnetic field in the matter under extreme conditions inside the star. The GWs generated by a rapidly rotating star are nearly constant-frequency.

Some configuration about its rotational axis (i.e., constant periodicity), is referred as "Continuous Gravitational Waves, which is different from the "Chirp" waveform generated by binary inspiral mergers.

Chandrasekhar S. [6] first proposed the concept of a "Triaxially Deformed" star in 1969. The classical solution of Maclaurin spheroids and Jacobian ellipsoids for self-gravitating and uniformly rotating, incompressible fluids in equilibrium provides two models of rapidly rotating stars. Bifurcation of these two models, i.e., the sequence of triaxial Jacobi ellipsoids diverges from that of the axisymmetric Maclaurin spheroids in the case of increasing in rotation of an equilibrium, appears when the ratio of kinetic energy (T) to gravitational energy (W) reaches T /|W| ~ 0.14 [7]. This means the configurations are no longer a precise ellipsoid in relativistic gravity or for compressible fluids, the triaxially deformed rotating compact star (or simply "Triaxial Star") are rather than 'ellipsoids'. The importance of this triaxial model in relativistic astrophysics is that it includes fluid compressibility for modeling the realistic neutron star as an axisymmetric and uniformly rotating configuration associated with the equation of state (EoS) of high density nuclear matter [8,9].

Another crucial information about the conditions for triaxial star formation is the deformation in the shape of the compact stars, i.e., the "ellipticity". For example, a star may collapse into a blackhole under the conditions that the supernova fall back accretion can spin up a freshly formed neutron star with a strong magnetic field of 5 x 10^{14} G as rapidly as T / |W| ~ 0.14 for 50 – 200 s before the collapse [5].

This suggests that a triaxially deformed compact stars, as discussed above, could form transiently from enormous stellar core collapse. Once such triaxial star is produced, the massive value of gravitational waves emitted allow us to extract attributes from high density nuclear matter.

A neutron star or magnetar (special type of neutron star with internal strong magnetic field) can be deformed into a triaxial compact star by its intrinsic ultra-strong core magnetic field [6-8]. Recently, Parui RK [10] proposes that "Cosmic Baby", i.e., Swift J1818.0 – 1607 be a traiaxial star. It is a newly born neutron star (i.e. magnetar) having internal core magnetic field ~ 8.9 x 10^{17} G. In this study I investigate the nature of the debated companion object of GW190814 taking into account the ellipticity's stability and the effect of internal strong magnetic field in the light of the characteristics of cosmic baby as triaxial star.

The paper is organized as follows: In Sec. 2 triaxiality of a star and possible neutron star's maximum mass under LOF condition is discussed. A brief view of the effect of strong internal magnetic field on the maximum mass is described in Sec. 3. Tilt angle associated in magnetar's triaxial deformation deals in Sec.4. Deformation of a magnetar due to its internal strong magnetic field is discussed in Sec. 5. Sec. 6 deals with the details of discovery of GW190814. In Sec. 7 we discuss systematically the properties of magnetic star, deconfined strange quark matter, ellipticity, interior magnetic field. Sec.8 deals with the Cosmic Baby and its Triaxial nature. Details of present investigation are included in Sec. 9 and conclusion in Sec.10.

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Triaxiality and Significance of Neutron Star Maximum Mass

Possession of greatest compactness of astrophysical objects makes them the most effective sources of gravitational waves. As neutron star and black holes are the most compact objects in the universe they are also the brightest sources of gravitational waves [11]. Compact binaries [12] consisting of a pair of neutron star (i.e., NS – NS) or black holes (i.e., BH – BH) or a neutron star and a black hole (NS – BH or BH – NS) are very powerful emitters of gravitational radiation. In broad sense, rotating neutron stars [13], especially triaxial neutron stars [14] are the best one for space based and ground based detectors. Gravitational wave emission from rotating neutron stars can be divided into two classes: (a) emission due to the normal modes of oscillation of the fluid core, and (b) emission due to some non-fluid agent (such as crust, or an internal strong magnetic field) deforming the star [14]. Most of the research into gravitational wave emission associated with the, rotating neutron star are done while the second type of emission is neglected. In the second type, i.e., triaxial neutron star, neutron stars are not considered being a simple fluid, but instead being able to support some sort of stain [15-17]. The significance is that

- Such type star could then be a triaxial (i.e., support some sort of “mountain”), and radiate gravitationally at twice its rotation rate.
- There is no gravitational wave instability for such, and also there will be no viscous process within it.
- This allows a perfect conversion of kinetic energy (T) to gravitational energy (W).

Therefore, triaxially deformation due to strong internal magnetic field is very delicate, sensitive as it is bound on neutron star structure [18,19].

It is noteworthy that the solution of hydrostatic equilibrium Tolman-Oppenheimer-Volkoff equation (TOV) indicates the critical value M_{max} of neutron star depends on the equation of state (EOS) of matter inside the star [20,21]. Rhoades CE, et al. [22] estimated neutron star’s critical or absolute mass $M_{max} = 3.2\ M_\odot$ without considering the realistic equation of state and neglecting effects of rotation and exotic behavior [23]. Using Local Outlier Factor (LOF) algorithm in the statistical analysis of the observed mass distribution of neutron star (Table 1) [24],

Sl. No.	Maximum Mass ($M_\odot$)	sd	Outlier	LOF scores
1	2.74	0.21	yes	2.234
2	2.56	0.52	no	1.996
3	2.3	0.70	no	1.832
4	2.4	0.12	no	1.676
5	2.27	0.16	no	1.395
6	2.14	0.10	no	1.128

Table 1: Neutron star’s maximum masses, standard deviation (sd) with six LOF scores (Parameters taken from Rocha LS, et al. [25]).

Rocha LS, et al. [25] found the unconfirmed maximum mass = 2.74 $M_\odot$ as an outlier, and consistent mass M_{max} = 2.59 $M_\odot$ for the masses 2.56 $M_\odot$ and 2.30 $M_\odot$ are the border where m = 2.30 $M_\odot$ is below the maximum mass limit with the highest standard deviation. They also found the possibility of more massive neutron star than the present value 2.30 $M_\odot$ i.e., the possibility of neutron star maximum mass is 2.6 $M_\odot$ that has been estimated from the asymmetric merger of GW190814 event. Therefore, the light mass 2.5 – 2.6 $M_\odot$ in the GW 190814 merger is very important because observed mass of neutron star from gravitational wave signal GW170817 event (binary neutron star merger) provided a constraint suggesting a low mass value of neutron star is below 2.3 $M_\odot$. Neutron star – blackhole mass distribution hints a mass gap region between highest neutron star mass and lowest black hole is (2 – 5) $M_\odot$ [26,27]. If confirmed that neutron star would have a maximum mass $M_{max} > \sim 2.5\ M_\odot$ then the mass gap reduces to (2.5 – 5) $M_\odot$ [28,29]. However, question still remains - whether the neutron star maximum mass remains at 2.6 $M_\odot$ or may be even more. If so, then how massive could a neutron star be complying the theoretical and observational values.

α	$B(\rho_o)$	γ = 1		γ = 2		γ = 3		γ = 4	
		M_{max} $M_{\odot}$	$R_{1.4}$ $M_{\odot}$ (km)	M_{max} $M_{\odot}$	$R_{1.4}$ $M_{\odot}$ (km)	M_{max} $M_{\odot}$	$R_{1.4}$ $M_{\odot}$ (km)	M_{max} $M_{\odot}$	$R_{1.4}$ $M_{\odot}$ (km)
0.01	2.59×10^{16}	2.177	13.63	2.188	13.63	2.268	13.63	2.485	13.64
0.02	5.05×10^{16}	2.182	13.66	2.22	13.65	2.394	13.67	2.664	13.7
0.03	7.79×10^{16}	2.19	13.71	2.262	13.69	2.5	13.72	2.782	13.78
0.04	9.90×10^{16}	2.2	13.78	2.31	13.74	2.589	13.79	2.869	13.86
0.05	1.23×10^{17}	2.212	13.87	2.359	13.89	2.665	13.86	2.939	13.95
0.06	1.47×10^{17}	2.227	13.98	2.409	13.88	2.731	13.94	2.997	14.05

Table 2: Strength of Magnetic field B (ρ_o) at saturation density (ρ_o) = 0.153 fm^{-3}, Maximum mass (M_{max}) in $M_{\odot}$ and Radius (km) at M = 1.4 $M_{\odot}$ for a considered Equation of State (EoS) with the surface magnetic field $B_s = 10^{12}$ G and Magnetic field at the center $B_0 = 2.5 \times 10^{18}$ G (Parameters taken from Watanabe C, et al. [30]).

Effect of Core Strong Magnetic Field on Neutron Star Maximum Mass

Neutron star's fundamental properties i.e. mass, radius and observable manifestation such as rotation dynamics, thermal and rotation evolutions are strongly affected by extreme dense matter and ultrastrong magnetic fields in the interior of neutron stars (i.e., magnetars). The magnetic field strength for neutron stars is $10^{12} - 10^{15}$ G on the surface. Studies of anomalous x-ray pulsars (AXPs) and soft gamma repeaters (SGRs) hint surface magnetic field of magnetar can be more than 10^{15} G and its internal magnetic field i.e., at the core, would be few times of 10^{18} G [31,32]. In order to check the effect of such strong magnetic field on the magnetar mass we consider the density dependent form of the magnetic field as [33,34].

$$B(\rho) = B_{surface} + B_o\left(1-\exp\left\{-\alpha\left(\rho/\rho_o\right)^{\gamma}\right\}\right) \qquad (1)$$

where $B_{surface}$ = the magnetic field on the surface of the magnetar (i.e. neutron star), B_o = central magnetic field is expected for magnetars, α,γ are two free parameters that define the magnetic field changes based on the density of neutron star (i.e., magnetar). These two parameters are indicator of fast or slow magnetic field decrease from the center to the surface of the magnetar. I consider the recent results obtained by Watanabe C, et al. [30], Bordbar GH, et al. [35], Mallick R, et al. [36]. Considering the core magnetic field of neutron star (i.e. magnetar) $B_{core} = 1.75 \times 10^{18}$ G, 4.38×10^{18} G and using the density dependent magnetic field parameterization eqn. (2) Mallick R, et al. [36] found that with the increase in magnetic field the mass of neutron star (i.e. magnetar) increases but at $B_{core} = 2.6 \times 10^{18}$ G no maximum mass is observed. This means that the magnetar (i.e. neutron star) has no maximum mass for a strong enough magnetic field. Significant finding of their study is for higher magnetic field the mass of the magnetar increases of the order of few percent i.e., 3 – 4 % only.

In another study Bordbar GH, et al. [35] found an important result that the maximum mass and radius of a magnetar (i.e. neutron star) are increases with the increasing magnetic field for considered density dependent magnetic field. The highest value of estimated neutron star's mass is 2.11 $M_{\odot}$ with radius R = 9.90 km (for internal magnetic field 8×10^{17} G) which is consistent with the observed value for PSR J0348 + 0432.

Based on the idea massive neutron star arises because of the pressure from its strong internal magnetic field, Watanabe C, et al. [30] studied mass-radius relationship considering various equation of states and surface magnetic field $B_{surface} = 10^{12}$ G and central magnetic field Bo = 2.5×10^{18} G, respectively. They used known observed surface magnetic field of neutron star = 10^{12} and estimated internal magnetic field using eqn. (2) and found maximum mass of neutron star (i.e., magnetar) with free parameter α = 0.06, γ = 1,2,3,4, core magnetic field 2.5×10^{18} G are 2.227 $M_{\odot}$, radius $R_{1.4}$ $M_{\odot}$ = 13.98 ; 2.409 $M_{\odot}$, radius $R_{1.4}$ $M_{\odot}$ = 13.88 ; 2.731 $M_{\odot}$, radius $R_{1.4}$ $M_{\odot}$ = 13.94 ; and 2.997 $M_{\odot}$ with radius $R_{1.4}$ $M_{\odot}$ = 14.04, respectively. According to Watanabe C, et al. [30] for used equation of state (EoS) the credibility is 68% w.r.t. maximum mass and radius at 1.4 $M_{\odot}$ in the cases:
γ = 2 , α = 0.03, 0.04, 0.05 and 0.06
γ = 3 , α = 0.01, 0.02, 0.03 and 0.04
γ = 4 , α = 0.01

Triaxiality and Magnetar's Tilt Angle

It is believed that in new born or young magnetars that rotation axis and magnetic axis are not aligned. Due to this magnetic field induced deformation magnetars are considered as strong source for continuous gravitational waves emission. As the rotation axis and the magnetic axis are not aligned, the magnetar (i.e., neutron star) have some precession. The amplitude of gravitational wave signal emitted by such a magnetar can be expressed as [37,38].

$$h_o = \left(4G / dc^4 \right) \Omega^2 I \in sin\alpha \qquad (2)$$

Where,
d = distance of the magnetar
c = speed of light
Ω = the rotational velocity,
I = Moment of Inertia
ϵ = ellipticity
α = the angle between the rotation and magnetic axes

Analysis of observational parameters of the magnetar favors the existence of the magnetic inclination "α" in new born phase of magnetars (i.e., neutron stars). The observed data are very less because of poor observability as the new born magnetars (i.e., neutron stars) are surrounded by opaque materials [39].

Theoretical investigations on the stability of the field consisting of toroidal, poloidal and mixed of toroidal-poloidal i.e. 'twisted-torus' suggest that

i. $\alpha = 0^o$ — both the purely toroidal and the combined toroidal-poloidal i.e., 'twisted- tous' show the same stabilizing effect on the rotation quantitatively;
ii. $\alpha = 90^o$ — A much less stabilizing effect of rotation in the presence of purely toroidal field;
iii. $\alpha = 45^o$ — A sufficiently fast rotating new born magnetars (i.e., neutron stars) with period $P \leq 6$ ms retain their magnetic field strength ~ 10^{15} G as magnetar [40,41].

Deformation of Magnetar due Internal Strong Magnetic Field

The external magnetic field of a neutron star is usually derived from its spin down rate (which is estimated from the observed period). But its internal magnetic field is not observable. Thus, clues for existence of strong internal magnetic fields come from the phenomena like giant flares (x-rays, gamma rays) associated with the magnetars (i.e., neutron stars). The energy released due to giant flares is related to the spin down rate of the magnetar. Measuring the flare emitted energy the external magnetic field of the neutron star (i.e., Magnetar) is calculated and then the possible strength of the internal magnetic field of the magnetar is estimated using the calculated value.

Neutron stars and magnetars are the most observable relativistic astrophysical sources. Studies of magnetars indicated an extended toroidal magnetic field, beyond the stellar crust, into the stellar magnetosphere. This implies that magnetars have a strong but localized toroidal magnetic field ~ 10^{19} G [42].

Theoretical models considering magnetars (i.e. neutron stars) with both poloidal and toroidal magnetic fields hint that [43,44]

a) simultaneous presence of poloidal and toroidal magnetic field components should be considered for realistic case;
b) the general implication of the presence of strong toroidal magnetic field is for stellar stability;
c) the sources of magnetic field generation in neutron stars, magnetars must be in stellar interior;
d) a strong internal magnetic field can deform a star (i.e., neutron star, magnetar);
e) stellar ellipticity (ϵ) can be used to constraint the strength of a star's (i.e. neutron star, magnetar) internal magnetic field;
f) this ellipticity (ϵ) is roughly proportional to the magnetic energy;
g) neutron star, especially magnetars with their strong internal magnetic field possess significant ellipticities that turn them as a good candidate for continuous gravitational waves.

Numerical simulation studies with poloidal- toroidal magnetic field configurations showed the following important properties [45,46]:

- the field is axially symmetric around z-axis,
- the poloidal component is continuous with a dipole field extending outside the star,
- the toroidal component is confined within the star, in particular, to the region closed to poloidal field.

As the magnetar (i.e. neutron star) possess strong magnetic field, so this magnetic field leads to non-negligible effect i.e. deformation. Recent magneto-hydordynamics simulation study hints the magnetic field scenario inside the magnetar could possibly be much more complicated. For example, in the case of axisymmetric poloidal field, which extends from interior of the star to the exterior and the toroidal field which remains confined within the star, the combination of these two magnetic fields form a torus shaped region inside the star. This configuration is known as the "twisted-torus" [47]. The deformation of a magnetic star i.e., magnetar, under this "twisted-torus" with internal magnetic field strength ~ 10^{16} G is ~10^{-3} – 10^{-4}.

Deformation due Purely Poloidal Configuration

The deformation parameter i.e., ellipticity (ϵ) of a magnetar (i.e., neutron star) can be expressed as [37].

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$$\in = \beta\left(B^2R^2/4GI^2\right) \quad (3)$$

Where,

- B = the magnetic field associated with the magnetar, I = the moment of Interia
- R = radius of the magnetar
- β = a dimension

less parameter taken into account the equation of state (EoS) and the magnetic field geometry.

Regarding the deformation of magnetar (i.e., neutron star) Yanase K, et al. [48] showed that the anisotropic effects (i.e., deformation) of the poloidal magnetic fields are found when the magnetic field strength at the center of the magnetar is more than 3×10^{18} G.

Deformation due "Twisted-Torus" Configuration

It is argued that deformation of a magnetar (i.e., neutron star) may be induced by strong internal magnetic field (B_{int}) in the stellar core instead of the dipole magnetic field through the relation [49].

$$\in \approx 10^{-8}\left(B_{int}/10^{12}\,G\right) \quad (4)$$

The above relation hints

a) the possession of very strong magnetic field i.e., $B_{int} \sim 10^{16} - 10^{17}$ G is needed for gaining the ellipticity $\epsilon \sim 10^{-3} - 10^{-4}$;
b) the strength of the internal core magnetic field should be at least (1 – 2) order of magnitude greater than the surface (i.e., external) magnetic field ($B_{dipole} \sim 10^{15}$ G).

Numerical simulation study of the magnetized deformation of a neutron star (i.e., magnetar) Rizaldy R, et al. [50] showed an interesting consequence for neutron star with low masses that the effect of magnetic field is more " prominent" for internal magnetic field $B_{int} > 4 \times 10^{18}$ G. This means that in the case of massive neutron star (i.e., magnetar) the oblate shape is very much less in comparison to that of less massive ones. In other words, we can say the internal toroidal magnetic field is more effective than the poloidal field. Hence, the deformation associated to the poloidal field ($B_{poloidal} \approx 10^{14}$ G and 10^{15} G) and the corresponding correction in ellipticity (i.e., $\sim 10^{-4} - 10^{-2}$, respectively) are negligible [51].

Magnetic Field Induced Deformation and Observable Limit on Ellipticity

It is claimed that twisted-torus magnetic field configuration is applicable for realistic situation inside a magnetar, instead of pure poloidal field. Based on the idea the dependence of magnetar's deformation on the magnetic field Braithwaite J, et al. [52] showed that huge amount deformation is possible if the magnetic field is strong enough during its early phase.

The reason is that (i) the toroidal magnetic field is closed in the twisted-torus field in the interior of the magnetar, and (ii) for becoming stable the poloidal field is twisted by the toroidal field.

In this case, the ellipticity is expressed as [53]

$$\epsilon = k\,(B / 10^{15}\,G)\; 2 \times 10^{-6} \quad (5)$$

where,
B = the interior magnetic field of the magnetar,
k = a dimensionless parameter depends only on the EoS and interior field geometry.

The value ' k' , according to Ciolfi R, et al. [54] , for compact stars i.e., magnetars having inside "twisted-torus" configuration under realistic regime lies in the range $4 \leq k \leq 9$. For low compactness k = 4 and for significant compactness k = 9. Further studies, the precise variation of ellipticity (ϵ) for different values of magnetic field (B) of a realistic compact star (presence of toroidal and poloidal and twisted-torus magnetic fields) are

i. $0.0402 \leq \epsilon \leq 0.0905$ for $B = 1.0 \times 10^{17}$ G
ii. $0.0102 \leq \epsilon \leq 0.0227$ for $B = 0.5 \times 10^{17}$ G
iii. $0.0037 \leq \epsilon \leq 0.0082$ for $B = 0.3 \times 10^{17}$ G

Note that the dimensionless parameters 'β' and 'k' are effectively very low for very small values of 'ϵ' < 10^3.

This clearly indicates that in a realistic case with internal twisted torus configuration a magnetar requires to possess a higher magnetic field for large (higher) deformation.

Discovery of GW190814

The gravitational wave signal GW190814 was observed by LIGO and VIRGO detector on 14th August 2019 at 21:10:39 UTC [55]. This signal was associated with the astronomical super-event S190814 bv which was located at 241^{+45}_{-41} Mpc (or 790 million light years) distance from Earth. The designated event involved a binary coalescence i.e. the gravitational wave signal GW190814 was generated by the merger of a binary system whose primary component was a black hole with mass (m_1) = $23^{+1.1}_{-1.0}\,M_\odot$ and the secondary component was with mass (m_2) = $2.59^{+0.08}_{-0.09}\,M_\odot$.

The other important features are:

- Asymmetric mass ratio = $0.112^{+0.008}_{-0.009}$ (the most asymmetric mass ratio to date),
- Dimensionless spin $\chi 1 \leq 0.07$,
- Absence of an electromagnetic (EM) counterpart,
- Tidal deformation measured — uncertain

Uncertainty in tidal deformation measurement adds further uncertainty to the nature of the secondary component to be a black hole, or neutron star, or something more exotic [56].

Before the detection of GW190814 the earlier detected signal was GW170817 and measured parameters were reliable (at 90% confidence) [57]. Astronomers tried to resolve this problem arises in the nature of secondary component of GW190814 by using the measured and estimated data of GW170817 as well as observed pulsar data as reference. For example, measurement of electromagnetic (EM) and gravitational waves spectra of GW170817 inferred the maximum mass of neutron star $M^{sph}_{max} \leq 2.17\ M_{\odot}$ suggesting the remnant of GW170817 'most probably' was an high mass neutron star (HMNS) or a very short lived supra-massive remnant. Using different argument i.e., quasi-universal relation, Rezzolla L, et al. [58] found $2.01^{+0.04}_{-0.04} \leq M^{sph}_{max} \leq 2.16^{+0.17}_{-0.15}\ M_{\odot}$ with an absolute upper limit of $M^{sph}_{max} \leq 2.33\ M_{\odot}$ (assuming the core collapse exactly at the maximum mass shedding limit). But Shibata M, et al. [59,60] argued that this upper limit can only be weakly constrained to be $M^{sph}_{max} <\sim 2.3\ M_{\odot}$.

On the other side, different measurements of pulsar masses to date suggest that the absolute limit for the maximum mass of spherical neutron stars is

a. $M^{sph}_{max} \leq 2.51\ M_{\odot}$ if GW170817 was composed of low spin neutron star, and
b. $M^{sph}_{max} \leq 3.01\ M_{\odot}$ if composed by high speed ones.

However, in the light of GW170817 reference data the nature of companion of GW190814 remains unsolved.

Recent Work Considered in this Study

Discovery of other Compact Binary mergers: The main target sources of ground – based gravitational wave observation are black hole binaries (BH – BH) , black hole neutron star binaries (BH – NS) and neutron star binaries (NS – NS). The first observation of gravitational wave (GW) by the LIGO- Virgo collaboration was GW150914 event whose signals came from merging of black hole binary. The second event was GW170817 where gravitational waves were generated from the merging of (NS – NS) binary [61]. These two events made a significant contribution that GW astrophysics is real. Observation of neutron star mergers provide information about the origin of heavy elements produced through r- process nucleosynthesis, equation of state (EOS) of neutron star, short gamma ray bursts, etc. But the issue of merger (BH – NS) remains uncertain and undetectable.

The detection of the event GW190814 was thought to the astronomers initially as a (BH – NS) binary system. Later the low mass companion creates a puzzle indicating uncertainty in its nature i.e. it may be a highest mass neutron star or a lightest mass black hole. This dispute in nature of the low mass secondary component still remains today.

Recently, the detection of two (BH – NS) merger events i.e., GW200105 and GW200115 Abbott R, et al. [61,62] provides the confirmed evidence of (BH – NS) binary merger. Using the observed parameters of these two events and the properties of other two possible (BH – NS) candidates GW190425 and GW190814 Broekgaarden PS, et al. [63] found a significant result that the properties of GW190425 and GW190814 do not match with the prediction of (BH – NS) population implying that the GW190814 more likely to be a (BH – BH) merger.

Recently, D'Orazio DJ, et al. [64] studied the multi-messenger constraints on magnetic fields in (BH – NS) binaries concentrating on the overlooked area mainly the lack of a neutron star disruption does not the lack of a brightness of electromagnetic (EM) counterpart. This means that a bright EM emission is possible and even also possible from a non-disrupting binary system. The reason is that locking up of magnetic energy in the neutron star's magnetosphere can arise without breaking apart the neutron star. The similar manifestations that can be observed in the pulsars, anomalous x-ray pulses, soft gamma ray repeaters, etc. [65].

In their studies they considered the features of the predicted (BH – NS) magnetospheric emission, along with GW observation and EM upper limit for LIGO-VIRGO-KAGRA (LVK) detectors for detected events GW200105, GW200115, and GW190814. In fact, they used Black Hole (BH) battery powered magnetosphere model into two stages [66]: (a) in the first stage they apply the known binary parameters obtained from GW observation for consistent with a non- disrupting system, then (b) EM observation consistent with a BH battery powered event, so that information on neutron star magnetic field has been used as probe for insights into the BH-NS magnetosphere physics. The significant results are:

- Short – hard burst of gamma ray within ~ 1s after the merger;
- The strength of surface dipolar magnetic field of neutron star is constrained to be $\lesssim 10^{15}$ G ;
- The upper limit for future detection of GW plus gamma ray flux constraints to as low as $10^{13} - 10^{14}$ G, depending upon distance, battery parameters and EM flux upper limits.
- In the case joint GW detection and EM upper limits for neutron star surface dipolar magnetic field $\gtrsim 10^{15}$ G until merger is ruled out.
- It is also ruled out the formation scenarios where strongly magnetized magnetars quickly merge with black holes.

- Pre-merging scenarios, neutron star with strong magnetic field (i.e. magnetar) formation takes place, a time lapse is there before the marger takes place. In other words, **presence of neutron star with strong magnetic field in the form of "Magnetar" exists before the 'coalescence'**

Regarding time evolution of neutron star in BH – NS binaries, if it is assumed that magnetar can be formed in binary merger system and neutron star can only hold large magnetic fields for the magnetar's life time (i.e., ~ 10^3- 10^4 years) then

- ~ 10^3 BH-NS mergers formed through isolated binary evolution which required a detectable EM horizon ;
- ~ 10 BH-NS merger for GWs within detectable EM horizon but no EM counterparts.

This means that for the above mentioned two formation scenarios , the magnetar's life span should be a continuous period ranging from NS formation to merger [67].

In their calculations D'Orazio DJ, et al. [64] they estimated the maximum allowed NS surface magnetic field strength for different GW sources in the range of "optimistic (opt)" and "pessimistic (pesi)" choices for flux upper limit and BH spins. For the highest spins allowed by the GW observations the obtained values kept in 'opt' column and zero spin in the 'pesi' column for the events GW190814, GW200105, GW200115 as shown below:

Events	**Surface magnetic field strength B_{max}**	
	'opt'	**'pesi'**
GW200105 [68]	6.3×10^{14} G — 2.2×10^{15} G	
GW200115 [69]	4.4×10^{14} G — 2.3×10^{15} G	
GW190814 [70]	1.3×10^{15} G — 4.2×10^{15} G	

Need of High Magnetic Neutron Stars in Binaries

It is believed that (NS – BH) binary system is formed through two main possible ways: (a) the "isolated binary evolution " and (b) the "dynamical interaction". In "isolated binary evolution" process the stars having masses such that at the end of their lives, they eventually explode via supernova explosions resulting which one star living behind a black hole and the other one leaving a neutron star. Finally, this black hole and neutron star form a (BH – NS) binary system. In the case of other one, i.e. dynamical interaction, the neutron star and black hole form separately through unrelated supernova explosions and later find each other, forming the (BH – NS) binary system. These binaries are created in the dense stellar environments such as "globular clusters".

Studies of high mass x-ray binaries (HMXBs) and low mass x-ray binaries (LMXBs), ultra- luminous x-ray pulsars (ULXPs) suggest that

i. An accretion column might be formed when accretion takes place onto a neutron star which have a large magnetic field only.
ii. Analysis of observational data of several ultra-luminous x-ray pulsars hints that dipolar fields do not favour very strong magnetic field but suggest an upper limit of the dipolar field (B) ≤ 10^{13} G [71,72].
iii. Measured neutron star spin and its derivative based different models (including settling accretion approach) suggest that a neutron star can reach large spin periods even with a standard (i.e., normal) magnetic field (B) ~ 10^{12} – 10^{13} G [73].
iv. Considering the slow winds with velocity << 10^8 cm.s^{-1} and observed spin ~ few hundred seconds it is shown that the dipole magnetic field for X-ray pulsar (for example, Pulsar GX301–2) can reach >> 10^{13} G [74,75].
v. In another calculation, using equilibrium period approach in the disc accretion model for many Be / x-ray system, Shi CS, et al. [76] obtained surface dipolar fields, in most cases, above 10^{14} G, even up to ~ 10^{16} G.

Long-lived High Magnetic Neutron Star in a Binary: Study of compact stellar binary systems indicates that spiral orbit shrinks slowly due to emission of gravitational wave radiation. For example, in the case of a binary neutron star it is expected to take million of years or more to merge [77,78]. This expected time depends on the orbital parameters of the binary i.e. just after the final gravitational collapse and the formation of the final neutron star (i.e., compact object produced). In the case of ultrafast compact binary mergers (i.e., a non-negligible fraction of neutron star binaries) this merger will occur on a time scale as short as 10 Myr while for a small fraction it will merge even on a time scale less than 10 Kyr [79]. It is noteworthy that the above merger time scale is applicable for different types of compact binaries.

Normally, magnetars are considered as high magnetic neutron stars having surface magnetic fields larger than 4.4 x 10^{13} G (i.e., quantum critical or Schwinger limit $B_{cr} = m^2 c^3 / e\hbar$) [80]. Observational correlation between the characteristic ages and dipole surface magnetic field strengths of all pulsars indicates magnetic field decay arises with core temperature of 2 x 10^8 K, 2 x 10^7 K, and ~ 10^5 K for magnetars, normal radio pulsars and millisecond pulsars. Magnetar's life span is 10^3 – 10^4 yrs. So, the magnetic field decay in the case of magnetar is much shorter than typical ages of known neutron stars in binary systems. Studies of magnetic field decay in neutron star cores hint at three involved separate processes — ohmic dissipation, ambipolar diffusion and Hall drift that affect the evolution and dissipation of magnetic fields in the magnetar interior [81,82]. Among these, in particular, ohmic dissipation and ambipolar diffusion are directly active in dissipation, while Hall drift is active indirectly.

Pons JA, et al. [82] found a significant result regarding ambipolar diffusion at high temperature in neutron star (i.e., magnetar) core that the magnetic field decay follows a power law and is dominated by the solenoidal component of the ambipolar diffusion mode. The temperature of the magnetar core material will be > 10^9 K because neutron star (i.e., magnetar) core magnetic field <~ 10^{18} G (which is >~ 10^{16} G). In this stage, the field decay is not frozen implying that an equilibrium condition between heating and cooling in the high temperature regime may appear [44]. This means, in particular, that core magnetic fields of magnetar larger than that would be able to

i) Dissipate enough energy;
ii) Balance neutrino cooling in the early phase, when the effective solenoidal mode and irrotational modes are still degenerate.

So, it can be said that magnetic field decay is negligible as long as the temperature is high enough (i.e. > 10^9 K) when the time-scale of field decay occurs on the same time scale in both modes. The significance of ambipolar diffusion is that

a) it becomes active soon after the formation of a magnetar; and
b) can prevent the cooling of the magnetar core below a temperature ~ 10^9 K for a period of thousands of years (i.e., at least 10^3 yrs).

In other words, the decay of an internal magnetic field >~ 10^{16} G couples with the magnetar cooling at the early phase.

In another study of magnetic field decay in the case of magnetars operating on the time scale ≤ 10^4 years Popov SB [83] considered two processes i.e. Hall cascade and ohmic decay due scattering of phonons and showed that

a. the Hall attractor is an absolute necessary ingredient to overcome the field significantly decay.
b. This Hall attractor inclusion ultimately allows to obtain
- magnetic field ~ 10^{14} G at ages ~ few Myrs for initial magnetic field B_o ~ 10^{15} G
- magnetic field ~10^{14} G at ages ~10 Myr for initial magnetic field B_o ~10^{16} G.

It is believed that soft gamma repeater (SGR) and Anomalous x-ray pulsar (AXP) activities are fuelled by their extreme magnetic fields i.e. magnetars associated with this SGR / AXP are responsible to power the giant flares. But discovery of SGR 0418+5729 with very low surface magnetic field shows that its dipolar magnetic field can not be greater than 7.5 x 10^{12} G [84]. This indicates that a high / strong surface dipolar magnetic field is not essential for magnetar like activities. On the other hand, magnetar population study (including this SGR 0418 + 5729) indicates a wider range of magnetic fields and ages. Adopting the magnetar field decay models for magnetars, normal pulsars and millisecond pulsars Xie Y, et al. [85] showed that

i) magnetars were born much hotter than normal pulsars;
ii) a magnetar possesses higher surface magnetic field strength in comparison to the same ages of normal pulsar although magnetars have much longer magnetic field decay time scale,
iii) the surface and the core temperature of magnetar are the highest that remain constant for at least 24 Myr.

This implies that high magnetic neutron star with the highest surface and core temperatures that remain constant for at least 24 Myr can survive in a binary system. Thus, one can expect that in a binary **syst**em it is possible the survival of a high magnetic neutron star i.e. magnetar with the highest surface and core temperatures that remain constant for 10 Myr and even more at least 24 Myr [85].

Systematic study of the Properties of Magnetic Stars

The gravitational wave event GW190814 was observed with its secondary component mass (2.50 – 2.67) $M_\odot$ that lies in the lower mass gap region (2.5 – 5) $M_\odot$ it raised the question whether the secondary component object is a lighter black hole or a very massive neutron star. Different theories offer various masses and radii of neutron stars based on their analysis related to the composition of matter, appearance of exotic degrees of freedom and also magnetic field energy in the interior of neutron star.

Observation of various activities of neutron stars, pulsars suggest the solid crust, superconductor, super fluid are existed inside the neutron star. But was it exactly at the neutron star core not yet fully known.

90% of the neutron star's mass comes from the contribution of core compositions. As the neutron star core is not observable directly, different theoretical models arise depending on the equation of state of neutron star matter inside the core. With increasing density, the appearance of exotic degrees of freedom inside the neutron star is possible [86]. Heavy neutron stars are expected to contain exotic matter in their interior, even if they are rotating fast [87].

Deconfined Strange Quark Matter: Assuming the true ground state of strongly interacting strange quark matter instead of ^{56}Fe , i.e., the deconfined mixture of "u" (up), "d" (down) and "s" (strange) quarks Bombaci I, et al. [88] considered the low mass companion star is entirely composed of deconfined u, d, s quark matter. Using only lowest order perturbative interactions between quarks they estimated the maximum mass of quark star that could reach the value

$M^{quark}_{max} \sim 2.75\ M_\odot$ without the need for sound velocity close to the causal limit [89]. In this case, their argument was to consider two family scenario, i.e., coexistence of neutron star and quark star, for obtaining the radius $R_{1.4} \leq 11.5$ km.

This means that

a) if only one family of compact star exists (i.e., neutron star or quark star) then the radius of the compact star $R_{1.4} \geq (11.6 – 11.8)$km due to causal limit ;

b) if two families of compact stars considered, in that case the requirement i.e., the maximum mass $M_{max} \sim 2.6\ M_\odot$ and radius $R_{1.4} \leq 11.6$ km will be satisfied.

In other words, the conclusion of the investigation done by Bombaci I, et al. [88] is that the possibility of the “low mass companion of GW190814 was a strange star”.

Ellipticity and Internal Magnetic Field: Recently, Biswas B, et al. [90] studied the properties of the secondary or companion star of GW190814 using Bayesian frame work with a hybrid equation of state (EoS) in piecewise polytropic model at high densities. They considered two situations — one for properties assuming slow motion scenario of neutron star, and the other one for rapidly rotating scenario of neutron star.

In the case of slow motion scenario they found secondary compact object with radius and tidal deformation as $R_{1.4}= 13.3^{+0.5}_{-0.6}$ km and $\Lambda_{1.4} = 795^{+151}_{-194}$, (90% C.I.) respectively, with a stiff EoS at high density region that can support an $\sim 2.6\ M_\odot$ neutron star i.e., GW190814 is in a place of very tight constraint on the high-density part of the EoS. While for rapidly rotating neutron star case their obtained results are: $R_e = 14.1^{+1.5}_{-2.0}$ km and ellipticity $(\epsilon) = 0.60^{+0.07}_{-0.23}$.

Comparing their estimated values with the data of pulsars PSR J1748 – 2446a, PSR J0740 + 6620 they suggested that the companion would definitely be a fastest rotating neutron star observed so far under rapidly rotating scenario ,i.e., if the secondary of GW190814 is indeed a rapidly rotating neutron star.

Interior Magnetic Fields: We know that very massive and / or fast rotating stars could be the result of accretion or stellar merger, both processes ultimately enhance the stellar magnetic fields [73-76]. As a result, various effects in compact object can appear. Such as

a) interior core magnetic field ≈ 10^{18} G is attainable in high density matter at the center of a massive neutron star [91-93];

b) surface magnetic fields of magnetars (i.e. AXP and SGR) can be considered ~ $10^{14} – 10^{15}$ G [94,95];

c) Fast Radio Bursts (FRB) appear in magnetars [96,97] etc.,.

As the magnetic fields in the interior of the magnetars is not possible to measure directly, field strengths can be estimated theoretically from the observed effects. Our present understanding of the magnetar’s interior are:

- the magnitude of the gravitational potential energy must be greater than the magnetic field energy, implying that magnetar’s interior magnetic field at the center is ≈ 10^{18} G [98].
- Strength of this magnetic field at the center can be possible up to $10^{19} – 10^{20}$ G [99].
- Due to interior ultra-strong magnetic fields deformation in the shape of the massive neutron star, the internal toroidal magnetic field is more than the poloidal field. Thus, the deformation associated to the poloidal field ($B_{poloidal} \approx 10^{14}$ G and 10^{15} G) and the corresponding correction in ellipticity (i.e., $10^{-4} – 10^{-2}$, respectively) are negligible [100].
- In a purely toroidal configuration the magnitude of internal magnetic field does not increase much beyond one order of magnitude than its surface magnetic field, regardless of the equation of state or magnetic field configuration [101,102]. This implies in order to reach a magnetic field ≥ 10^{17} G or higher in the center, the star would have a surface magnetic field ≥ 10^{16} G.

To investigate the effect of strong internal magnetic field on the properties of neutron star Rather IA, et al. [103] applied density dependent relativistic mean field (DDRMF) data on hyperon model for reproducing hyperon-hyperon potentials and different couplings and finally the possibility of a star with a strong magnetic field in its interior. A summary of their findings is tabulated in Table 3.

Applied dipole magnetic moment (μ) Am^2	Nucleonic Star				Hyperonic Star			
	Magnetic field produced at		Maximum Mass M_{max} ($M_\odot$)	Radius (Km)	Magnetic field produced At		Maximum Mass M_{max} ($M_\odot$)	Radius (Km)
	Surface $B_{surface}$ (G)	Center B_{center} (G)			Surface $B_{surface}$ (G)	Center B_{center} (G)		
0			2.575	12.465			2.183	12.506
5 x 10^{30}	1.01 10^{15}	2.59 x 10^{16}	2.58	12.536	6.65 10^{15}	1.96 10^{16}	2.224	12.506
5 x 10^{31}	8.98 10^{16}	2.28 x 10^{17}	2.632	13.024	5.83 10^{16}	1.89 10^{17}	2.325	13.269
10^{32}	1.79 10^{17}	4.55 x 10^{17}	2.711	13.474	1.12 10^{17}	3.77 10^{17}	2.463	13.894

Table 3: Estimated magnetic field produced in a star as obtained by Rather IA, et al. [103].

Rather IA, et al. [103] used magnetic dipole moments (μ)= 5 x 10^{30} Am^2, 5 x 10^{31} Am^2 and 10^{32} Am^2 and their results show that

1. In the case of magnetic dipole moment greater than 10^{31} Am^2 the magnitude of magnetic field produced at the center of the star with large densities is larger than 10^{17} G which is strong enough to cause a large deformation in the neutron star structure.
2. For a magnetic dipole moment μ = 10^{32} Am^2, the magnetic field produced at large densities is greater than 4 x 10^{17} G for both nucleonic and hyperonic stars.
3. For central magnetic fields ≈ 7 x 10^{16} G and ≈ 4 x 10^{16} G, produced in pure nucleonic matter and hyperonic matter, respectively, satisfy the radius constraints from NICER measurement in both cases.
4. For low magnetic fields, pure nucleonic stars satisfy the possible maximum mass constraint arises from the GW190814. This indicates the possibility that the secondary component of GW190814 to be a "Magnetar".
5. Both the nucleonic and the hyperonic stars satisfy the constraints of the mass-radius limits from NICER observed values and also the tidal deformability constraints inferred from the LIGO and VIRGO detectors.

The most significant findings of Rather IA, et al. [103] is the presence of somehow realistic internal magnetic fields ≈ 10^{17} G inside a neutron star and consequences of this are — stiffen hyperonic EoS, generation of more massive neutron star (possibility to satisfy the GW190814 mass constraint), large deformation w.r.t. spherical symmetry.

Cosmic Baby and its Triaxial Nature

In 1969 Chandrasekhar S [6] first proposed the idea of "Triaxially deformed" star or simply "Triaxial Star". More than 50 years passed but no triaxial star has been detected till date. On 12th March 2020 the Swift Burst Alert Telescope (BAT) detected a typical characteristics of short bursts from magnetar [104,105] and finally spotted a new un-cataloged x-ray source, Swift J1818.0-1607 which is presently known as "Cosmic Baby". At the time of discovery the observed and estimated parameters are [106-108]:

Characteristic age ~ 240 years
Surface magnetic field at poles ≈ 2.7 x 10^{14} G
Dipolar magnetic field at poles ≈ 7 x 10^{14} G
Initial Periodicity (coherent periodicity of x-ray signal) =1.36 s
Period derivative ~ 9 x 10^{-11} $s.s^{-1}$
Spin period derivative ~ 8.2 x 10^{-11} s. s^{-1}
Spin down luminosity ~ 1.4 x 10^{36} $erg.s^{-1}$

A magnetar is a slowly rotating isolated neutron star with an extremely strong magnetic field in its interior (i.e. at the center) ranging from (10^{16} – 10^{18}) G [30]. A magnetar, in general, is a triaxial stellar body, especially in its new born phase [109,110]. The geometric distortion of the neutron star (i.e. Magnetar) generated by strong toroidal magnetic field (effect of poloidal magnetic field is negligible for massive neutron star), is used to estimate its internal ultra-strong magnetic field.

Recently, Parui RK [10,111] estimates the deformation i.e., ellipticity (ϵ) and internal strong magnetic field ($B_{toroidal}$) of the cosmic baby which are ~ 9 x 10^{-3} and 8.9424 x 10^{17} G, respectively. Considering the ambipolar diffusion is active in the core of neutron star which prevents both the decay of interior magnetic field and cooling of the neutron star, i.e., magnetar (as the effect is the same and applicable for magnetars as well as neutron stars also) Parui shows that the magnetar core temperature stays higher than several times 10^8 K for a period of few thousand years (at least 10^3 years). Precisely, the estimated ellipticity of this cosmic baby lies within the range of triaxiality and its ellipticity will remain almost at that value for exhibiting a triaxial nature for at least 700 – 760 years.

Methodology Used in the Present Investigation

Data used and Calculations

Rather IA, et al. [103] showed that the secondary compact object of GW190814 has a possibility to be a magnetar with internal magnetic field ~ 10^{17} G. For central magnetic field valued ≈ 7 x 10^{16} G and ≈ 4 x 10^{16} G for nucleonic matter and hyperonic matter stars, respectively, satisfy the mass- radius constraints inferred from NICER observation. Magnetic field produced at the center of nucleonic star and hyperonic star by the application of magnetic dipole moment 5 x 10^{31} Am^2 and 10^{32} Am^2 and the corresponding ellipticity are shown in Table 4. The estimated values of internal / core magnetic field strength of secondary component of GW190814 and its corresponding ellipticity (using the BH battery powered magnetospheric model proposed by D'Orazio, et al. [64] and Parui RK [10] model) are included in the present work column.

Regarding estimation of ellipticity I use the formula i.e. the best fitting relation (for details see Parui RK [10])

$\log \epsilon = -22.50^{+2.15}_{-2.22} + (1.29^{+0.15}_{-0.14}) \log B_{dipole}$ (6), eqtn (4)

and apply the above mentioned parameters of B_{max}, dipole. The estimated values of internal magnetic field strength and the corresponding ellipticities are noted in Table 4.

Results

As mentioned above the calculated values of various parameters are shown in Table 4.

Model	Magnetic field produced at the center	Estimated ellipticity of the secondary compact object of GW190814	Model proposed by / Reference
Hyperonic Star	1.89×10^{17} G	1.9×10^{-3}	Rather IA, et al. [103]
	3.77×10^{17} G	3.8×10^{-3}	
Nucleonic Star	2.28×10^{17} G	2.3×10^{-3}	Rather IA, et al. [103]
	4.55×10^{17} G	4.6×10^{-3}	
Cosmic Baby as Triaxial Star	8.9424×10^{17} G	9×10^{-3}	Parui RK [10]
Secondary companion of GW190814 as Triaxial star	1.861526×10^{18} G ('opt')	1.00696×10^{-3} ('opt')	Present work
	3.459707×10^{18} G ('pesi')	2.218239×10^{-2} ('pesi')	

Table 4: The estimated ellipticity of the secondary compact object of GW190814 using the triaxial model proposed by Parui RK [10,86].

Theoretical values (minimum) for neutron star or magnetar must have to be a triaxial star Surface magnetic field ~ 10^{14} – 10^{15} G.

- Internal magnetic field (at the center) ~ 10^{17} G
- Minimum rotation period ~ (0.3 – 0.5) ms
- llipticity ~ 10^{-3} – 10^{-4}
- Initial Period Po ~ 4.9 ms

It is clearly seen from table 4 that internal magnetic field generated inside the companion compact star of GW190814 varies ranging 1.89×10^{17} G to 1.861×10^{18} G (physically possible) and the corresponding ellipticity whose magnitudes also changes from (1.9 to 4.6) x 10^{-3}, if it becomes a hyperonic or nucleonic star [112,113]. If compared with the cosmic baby's, i.e., swift J 1818.0 – 1607 ellipticity, the magnitude of the highest values of ellipticity i.e., 4.6×10^{-3} for nucleonic star or 3.8×10^{-3} for hyperonic star which is half (51.1%) or almost half (42.2%) of the value of magnitude of the cosmic baby's ellipticity respectively.

Whereas in the case of high magnetic companion neutron star (i.e. Magnetar) this ellipticity value shows 1.00696×10^{-3} implying that this value also satisfy the condition that can be considered as a triaxial star.

Not only that, comparing with the theoretical values required for a compact star to be a triaxial star the magnitude of the ellipticity of the companion star of GW190814 (i.e., 1.00696×10^{-3}) lies within the required values for becoming a triaxial star. In other words, the companion compact object of GW190814 can be considered as a triaxial star.

Conclusion

Considering BH battery powered magnetosphere model the recent investigation on the survival of a magnetic neutron star as secondary companion of the event GW190814 by D'Orazio, et al. [64] showed that a normal neutron star (with radius 10km) follows a continuous path from its birth to before coalescence to Black Hole in the case of GW190814 and acquired a super-strong magnetic fields ~ 10^{18} G i.e. turned into a magnetar, stayed some period (not instantly) and finally merged with Black Hole. Based on their estimated values of surface dipole magnetic fields strength of a non-disrupted neutron star the calculated internal / core magnetic fields and the corresponding ellipticity of the neutron star (i.e. turned into magnetar) in the BH – NS binary system for the event GW190814 :

A highly magnetized neutron star have surface dipolar magnetic field ranging 10^{14} – 10^{16} G and core internal magnetic field ≥ 10^{15-18} G. Ambipolar diffusion with solenoidal mode takes a leading role for keeping neutron star core and surface temperatures at the highest, remain constant for the period at least 24 Myr. This means in a binary system a long lived, high magnetic neutron star in the form of magnetar is possible. The strong magnetic field of magnetar (i.e. neutron star) could induce non-axisymmetric distortions of the magnetar directly. It is believed that magnetars are born with a large magnetic fields. As a result, young magnetars likely to possess large ellipticities. Analyzing the observed data of GW190814 event the estimated deformation i.e. ellipticity, lies within the range of becoming a triaxial star. On the other

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hand, the estimated internal core magnetic field ~ 1.861526 x 10^{18} G which is necessary for deformation i.e. ellipsoidal shape. This author Parui RK [6,10] thus, concludes that the secondary/ companion compact object of GW190814 was a "triaxial star".

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