

## Original Research Article

### A New Compact Star—the "Triaxial Star"—and the Detection of a Cosmic Baby: A Possibility

#### Cosmic Baby and the detection of New Compact Star—the "Triaxial Star": A Possibility

**Abstract :** The "Triaxial Star" was first proposed by S. Chandrasekhar in 1969, but to date it has not been detected. The Cosmic Baby, i.e. Swift J1818.0-1607, is the youngest magnetar. Its characteristic age is ~300 years, with a superfast spin period ~ 1.36 s and a strong surface dipole magnetic field ~  $3 \times 10^{14}$  G. Taking into account three facts: The "Triaxial Star" first proposed by S. Chandrasekhar in 1969 but till date this is not yet detected. The Cosmic Baby i.e. Swift J1818.0-1607 is the youngest magnetar. It's characteristic age is ~300 years having superfast spin period ~ 1.36 s and strong surface dipole magnetic field ~  $3 \times 10^{14}$  G. Taking into account three facts:

- i) The ambipolar diffusion in the neutron star core is expected to be the dominant mode of field decay in the early evolution of magnetar( as long as the age is much less than ~  $10^4$  yrs) ;
- ii) Magnetars's field decay is negligible as long as the core temperature is a few times that is few times of  $10^8$  K (i.e.  $< 10^9$  K) ;
- iii) The coupling between the decay of the internal magnetic field and the neutron star cooling is so strong at the early phase of Magnetar that it significantly slows down both processes, but interior magnetic fields remain so strong that the core temperature stays higher than several times  $10^8$  K for thousands of years (at least  $10^3$  yrs), as proposed by Dall'Osso et al [40].
- iii) The coupling between the decay of internal magnetic field and the neutron star cooling is so strong at the early phase of Magnetar that it significantly slows down both processes but interior magnetic fields remain so strong that core temperature stays higher than several times  $10^8$  K for thousands years (at least  $10^2$  yrs) as proposed by Dall'Osso et al [40]
- iv)

We suggest Swift J1818.0-1607 is a triaxial magnetar, i.e., just a triaxial star. The baby magnetar's fast spin period and interior ultra-strong magnetic field transform it into a unique compact object with spontaneously broken axial symmetry, making it a potential source for detecting and measuring the properties of a triaxially deformed neutron star (i.e., magnetar) or triaxial star. The significance of our research is that continuous observation allows us to (a) detect the physical existence of a triaxial star, (b) understand the evolution of the magnetic field

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of a neutron star and a magnetar from a strong magnetic field to an ultra-strong magnetic field, and (c) learn about the strange properties of a new baby magnetar. This author invites the GW community to look for electromagnetic analogues to compact objects when observing them. The significance of our study is that continuous observation allows us to (a) detect the physical existence of a triaxial star, (b) understand the evolution of the magnetic field of a neutron star and a magnetar from a strong magnetic field to an ultra-strong magnetic field, and (c) learn about the strange properties of a new baby magnetar. This author encourages the GW community to look for electromagnetic analogues when observing compact objects.

~~we suggest swift J1818.0-1607 is a triaxial magnetar i.e. simply Triaxial Star. The fast spin period and interior ultra-strong magnetic field turn this baby magnetar as a unique compact object having spontaneously broken axial symmetry and offer it to the astronomers as a potential source for detecting and measuring the properties of triaxially deformed neutron star (i.e. Magnetar) or triaxial star. Significance of our study is — continuous observation thus provides an opportunity for (a) detection of physical existence of Triaxial Star (b) understanding the evolution of the magnetic field from strong magnetic field to ultra-strong magnetic field of a neutron star and a magnetar and (c) the bizarre properties of new baby magnetar. This author encourages the GW community to search the electromagnetic counterparts during their observation of compact objects.~~

Key Words: **Gravitational Waves, Triaxial star, Neutron Star, Pulsar, Magnetar**

## **1. Introduction**

Chandrasekhar proposed the concept of a "triaxially deformed" star in 1969 [1]. The classical solution of Maclaurin spheroids and Jacobi ellipsoids for self-gravitating and uniformly rotating incompressible fluids in equilibrium yields two models of rapidly spinning stars. When the rotation of an equilibrium configuration is increased, the sequence of triaxial Jacobi ellipsoids diverges from that of the axisymmetric Maclaurin spheroids, and the ratio of kinetic (T) to gravitational (W) energy reaches  $T / |W| > 0.14$ . [2] Because the configurations are no longer a precise ellipsoid in relativistic gravity or for compressible fluids, triaxially deformed rotating compact stars (or simply triaxial stars) are rather than ellipsoids. This triaxial model is very important in relativistic astrophysics because 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 [3, 4]. Because the configurations are no longer a precise ellipsoid in relativistic gravity or for compressible fluids, triaxially deformed rotating compact stars (or simply triaxial stars) are rather than ellipsoids. This triaxial model is very important in relativistic astrophysics because 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 [3, 4].

The idea of “Triaxially deformed” star was first proposed by S. Chandrasekhar in 1969 [1]. The classical solution of Maclaurin spheroids and Jacobi ellipsoids for self-gravitating and uniformly rotating, incompressible fluids in equilibrium provide us two models of rapidly rotating stars. When the rotation of an equilibrium configuration is increased, the sequence of triaxial Jacobi ellipsoids branches off from that of the axisymmetric Maclaurin spheroids such that the ratio of kinetic (T) to gravitational (W) energies reaches  $T/|W| = 0.14$ [2]. This means that triaxially deformed rotating compact stars (or simply triaxial stars) are rather than ‘ellipsoid’ because the configurations are no longer an exact ellipsoid in relativistic gravity or for compressible fluids. In the view of relativistic astrophysics this triaxial model is very important by including compressibility of the fluid, for modeling the realistic neutron star as an axisymmetric and uniformly rotating configurations associated with equation of state (EoS) of high density nuclear matter [3, 4].

Ury et al. [5] discovered supra-massive triaxial solutions for relatively stiff (piecewise) polytropic equations of state (EoS) with tri-planar symmetry w.r.t. three orthogonal x, y, and z planes, the masses of which exceeded the maximum mass of the spherical solution but were always lower in comparison to those of axisymmetric equilibrium. They obtained the following results:

Considering the triaxial configurations possessing the tri-planar symmetry w.r.t. three orthogonal x, y, z planes for relatively stiff (piecewise) polytropic equation of state (EoS) Uryū et al [5] found supra-massive triaxial solutions the masses of which exceed the maximum mass of the spherical solution but are always lower in comparison to those of axisymmetric equilibrium. The fact to be noted they obtained are:

- a) The difference in the maximum masses of triaxial and axisymmetric equilibrium solutions depends sensitively on the equation of states (EoSs) ;
- b) In the case where this difference turns out to be only 10%, then it will be treated as strong evidence that the EoS of high-density matter in the core of neutron stars becomes substantially softer [5].
- b) In the case when this difference turns out to be only 10%, then it will be treated as a strong evidence that the EoS of high density matter in the core of neutron stars becomes substantially softer [5].

Another crucial information about the conditions for a star collapsing into a black hole [7] is that supernova fallback accretion can spin up a freshly formed neutron star with a strong magnetic field (B) of  $5 \times 10^{14}$  G as rapidly as  $T/W \sim 0.14$  for 50-200 s before the star collapses into a black hole. This suggests that a triaxially deformed compact star, such as the recently formed neutron star discussed above, could form transiently from enormous stellar core collapse. Once such a triaxial star is produced, the massive volume of gravitational waves emitted allows us to extract attributes from high-density nuclear materials. Using a realistic excess cross-power search technique and the typical value [6] of the amplitude of gravitational waves produced by triaxial stars. Once such a triaxial star is produced, the massive volume of gravitational waves emitted allows us to extract attributes from high-density nuclear materials. Using a realistic excess cross-power search technique and the typical value [6] of the amplitude of gravitational waves produced by triaxial stars.

~~Another important fact regarding the criteria for the star collapsing to black hole [7] is that the supernova fall back accretion may spin up a newly born neutron star having a strong magnetic field  $(B) \leq 5 \times 10^{14}$  G as fast as  $T / |W| \sim 0.14$  for 50 – 200 s until the star collapses to a blackhole. This means there is a possibility that a triaxially deformed compact stars, like above mentioned newly neutron star, may be formed transiently from massive stellar core collapse. Once such triaxial star is formed, emission of enormous amount of gravitational waves then provides us an opportunity to extract properties of high density nuclear matter. Considering the typical value [6] of the amplitude of gravitational waves produced from triaxial stars and using a realistic excess cross power search algorithm~~

$$h \sim 9.1 \times 10^{-21} (30 \text{ Mpc} / D) (M / 1.4 M_{\odot})^{3/4} (R / 10 \text{ Km})^{1/4} f^{-1/5} \dots\dots\dots(1)$$

where D, M, R and f are the distance to source, the source mass, the mean radius, and the wave

(2)

frequency in Hz , respectively. Piro and Thrane[8] estimated the detectability of gravitational waves produced by triaxially compact stars under the fall back accretion scenario for Advanced LIGO detector [ 9]  $\sim 17$  Mpc.

A neutron star or magnetar can be deformed into a triaxial compact star by its intrinsic ultra-strong core magnetic field [10-12]. In this research, we investigate the triaxiality of the magnetar Swift J1818.0-1607, taking into account the ellipticity's stability and the effect of an internal strong core magnetic field.

Deformation of neutron star or magnetar by its internal ultra-strong core magnetic field can offer it as a triaxial compact star [10–12]. In this paper we study the triaxiality of the magnetar Swift J1818.0–1607 considering the stability of its ellipticity and the effect of internal strong core magnetic field.

## 2. Cosmic Baby

The Swift Burst Alert Telescope (BAT) on board the Neil Gehrels Swift Observatory [13] detected a typical brief burst from a magnetar [14] on March 12, 2020, at 21:16:49 UT. The Swift X-ray Telescope (XRT) ultimately spotted a new uncatalogued x-ray source, Swift 1818.0–1607, which is now known as Cosmic Baby, 64 seconds later. Table I shows the main parameters of this cosmic infant derived from the timing analysis of early data at the moment of discovery.

On 12<sup>th</sup> March 2020 at 21:16:49 UT the Swift Burst Alert Telescope (BAT) on board the Neil Gehrels Swift Observatory [13] detected a typical characteristics of short burst from magnetar [14]. 64 seconds afterwards observation by the Swift X-ray Telescope (XRT) finally detected a new uncatalogued x-ray source, so called Swift 1818.0–1607 which is presently known as Cosmic Baby. The important parameters of this cosmic baby, obtained from the timing analysis of early observations at the time of discovery, are shown in table I.

**Table I** : Various early observed / measured parameters of Swift J1818.0 – 1607

Instruments	Observation based on	Typical properties	Value	Reference
BAT Radio Telescope	9 ms hard X-ray burst and long-lived outbursts	Characteristic age (shortest known)	$\sim 240$ years	Esposito et al [15]
		Surface magnetic field	$\sim 2.7 \times 10^{14}$ G	
		Dipolar magnetic field at poles	$\approx 7 \times 10^{14}$ G	
		Spin down Luminosity ( $\dot{E}_{\text{rot}}$ )	$\sim 1.4 \times 10^{36}$ erg.s <sup>-1</sup>	
XMM Newton Telescope		Luminosity	$\sim 8 \times 10^{34}$ erg.s <sup>-1</sup>	Enoto et al [16]
		Coherent periodicity of x-ray signal	1.36 s	
Sardini Radio Telescope	Radio observation	Spin period derivative	$\sim 8.2 \times 10^{-11}$ s.s <sup>-1</sup>	Champion et al [17]
		Period derivative	$\sim 9 \times 10^{-11}$ s.s <sup>-1</sup>	
		Spin Period	0.7333920 s	

Following a series of observations at multiple telescopes (including TMRT and NICER), some confirmed parameters of the cosmic baby magnetars were accessible till July 27, 2020. The rotation/spin period derivative, for example, is  $3.74 \times 10^{-11} \text{ s}^{-2}$ , the surface dipole magnetic field is  $3 \times 10^{14} \text{ G}$ , the spin-down luminosity is  $1.1 \times 10^{36} \text{ erg. S}^{-1}$ , and so on. Although Chandra Observatory [18] began observing Swift J1818.0-1607 less than a month after its discovery, its observations provided astronomers with the first high-resolution x-ray picture of the cosmic baby. Nonetheless, practically all characteristics of the cosmic infant qualities vary greatly.

~~After a series of observations through various telescopes (such as TMRT, NICER ) at several~~

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~~wavelengths till July 27, 2020 some confirmed parameters of the cosmic baby magnetars were available. For example: Rotation / spin period derivative is  $3.74 \times 10^{-11} \text{ s}^{-2}$ , surface dipole magnetic field  $3 \times 10^{14} \text{ G}$ , spin down luminosity  $1.1 \times 10^{36} \text{ erg. S}^{-1}$ , etc. Although Chandra Observatory [18] began its observation to swift J1818.0 - 1607 less than a month after the discovery of cosmic baby but its observations gave the astronomers the first high resolution view of the cosmic baby in x rays. Still there is a lot of variation almost in all parameters of the cosmic baby properties.~~

### **3. Ellipticity of Cosmic Baby Magnetar Swift J1818.0-1607**

In 1992, Robert Duncan and Christopher Thompson [19] postulated the existence of magnetars to explain the features of transient sources of gamma rays, i.e., soft gamma repeaters (SGRs). Magnetars are isolated young neutron stars with powerful magnetic fields that generate a wide range of high-energy emissions, from huge flares to quick radio bursts. The underlying hypothesis behind these unusual high-energy sources is that they could be ultra-strong magnetized neutron stars, magnetars with surface (dipole) fields in the  $10^{14}$ - $10^{16} \text{ G}$  range and core magnetic fields  $>10^{16} \text{ G}$  (at least one order of magnitude greater) [20, 21]. Because the density of the neutron star core is larger than or equal to  $10^{15} \text{ g/cm}^3$ , the compact object has an anisotropic character [22], which means that the internal pressure can be divided into two parts: radial pressure ( $p_r$ ) and transverse pressure ( $p_t$ ), where  $p_t$  is orthogonal to  $p_r$ . The physical properties, stability, and structure of stellar matter are all affected by pressure anisotropy [23]. The ultra-strong internal magnetic field of stellar matter can also produce anisotropic pressure, which is the deformation of a rotating neutron star's spheroidal shape and the emission from it as a result of that deformation.

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Cutler [24] initially identified the internal field structure of a neutron star as an effective and efficient source of GW emission when looking for strong gravitational wave (GW) emission. According to him, a magnetically distorted neutron star, that is, a neutron star with a strong internal toroidal field, forms a prolate shape, which has the best probability of being a strong GW emitter. As a result, the ellipticity of magnetic deformation ( $B$ ) in the shape of a star object is critical in the powerful GW source. In other words, the stellar body's triaxiality is determined by its reliance on an internal strong magnetic field, the decay of the field strength, and the dynamical shape transition to a triaxial ellipsoid form.

In searching the strong Gravitational Wave (GW) emission Cutler [24] first pointed out the internal field structure of a neutron star becoming an effective, efficient source of GW emission. According to him a magnetically distorted neutron star, i.e. a neutron star with a strong internal toroidal field, turn into a prolate shape that offer the best chance of being a strong GW emitter. Thus, the ellipticity of the magnetic deformation ( $\epsilon_B$ ) in the shape of stellar object has crucial role in the strong GW source. In other word, the triaxiality of the stellar body—its dependence on the internal strong magnetic field strength, decay of the field strength, dynamical shape transition to a triaxial ellipsoid configuration.

A magnetar is a slowly revolving solitary neutron star with an extremely strong magnetic field in its interior ranging from 1016-1018 G and even up to 1020 G [25]. A magnetar, in general, is a triaxial stellar body [26], especially in its newborn period. The geometric distortion of the neutron star (or magnetar) generated by the strong toroidal magnetic field is used to estimate its internal ultra-strong magnetic field (i.e., the toroidal magnetic field is larger than at least one order of magnitude greater than its surface dipolar magnetic field). As a result, magnetar ellipticity limitations can be employed to A magnetar is a slowly rotating isolated neutron star having very strong magnetic field ranging  $10^{16}$ — $10^{18}$  G and even more upto  $10^{20}$  G [25] in its interior. In general, a magnetar is a triaxial stellar body [26], particularly in new born phase. Its internal ultra-strong magnetic field (i.e. the toroidal magnetic field is greater than at least one order of its surface dipolar magnetic field) is estimated by inferring from the geometric distortion of the neutron star (or magnetar) caused by strong toroidal magnetic field. Therefore, limits on the ellipticities of magnetars can be used to

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As a time or duration of GW emission, restrict the toroidal magnetic field. So, if the field is dipolar, then hydro-magnetic stresses arising from non-radial gradients of the super-strong internal magnetic field deform the magnetar (that is, between the magnetic poles and the equator), and the fractional difference ( $\epsilon$ ) between the principal moments of inertia can be expressed as [26, 27, 28].

constrain the toroidal magnetic field as a period or duration of GW emission. So, if the field is dipolar, then hydro magnetic stresses, arising from non radial gradients of the super strong internal magnetic field, deform the magnetar (i.e. between the magnetic poles and the equator) and the fractional difference ( $\epsilon$ ) between the principal moments of inertia can be expressed as [26,27,28]

$$\epsilon \sim \delta p R^5 / I_1 \approx 2 \times 10^{-9} (B_{\text{int}} / 10^{10} \text{ T})^2 \dots\dots\dots (2)$$

where  $\delta\rho$  = induced matter-density perturbation

$$\sim B_{\text{int}}^2 / \mu_0 C_s^2,$$

R = the stellar radius,

$C_s$  = the isothermal sound speed ( $= 3^{-1/2} c$ ,  $c$  being the velocity of light),

$B_{\text{int}}$  = the characteristic magnitude of the internal magnetic field

- i)  $\approx B_o$ , if the internal magnetic field is confined to the stellar crust,
- ii)  $> \sim B_o$ , if it is generated deep inside the star (i.e. convective dynamo model [29],
- iii)  $B_{\text{int}} < \sim 10^9$  T in the case of rotation powered pulsars

According to Melatos [26], a) the hydrodynamic deformation in a magnetar is much larger in comparison to the elastic deformation arising from shear stresses in the crystalline stellar crust of a rotating neutron star; b) the principal axes of inertia in a rotating neutron star are oriented arbitrarily w.r.t. the magnetic axis of the external magnetic dipole field, whereas in the case of a magnetar, the magnetic axis is approximately parallel to one of the principal axes of inertia (say,  $e_3$ ), the magnetic axis of inertia (say,  $e_3$ ), the magnetic axis. According to Melatos [26] a) the hydrodynamic deformation in a magnetar is much larger in comparison to the elastic deformation arising from shear stresses in the crystalline stellar crust of a rotating neutron star; b) the principal axes of inertia in a rotating neutron star are oriented arbitrarily w.r.t. the magnetic axis of the external magnetic dipole field where as in the case of magnetar the magnetic axis is approximately parallel to one of the principal axes of inertia (say  $e_2$ ) i.e. the alignment of magnetic axis is not exact to inertia axis due to the complicated structure of the internal field near its generation site (i.e. in other word, a non-axisymmetry state remains).

#### 4. Origin and decay of core magnetic field of Swift J1818.0-1607

Idealizing the magnetar as a neutron star with the shape of slightly deformed, homogeneous ellipsoid and having a small ellipticity

$$\epsilon = (I_1 - I_2) / I_3 \dots\dots\dots (3)$$

where  $I_1, I_2, I_3$  are the principal moments of inertia of the neutron star such that  $I_3$  is assumed to be aligned with the spin axis then using eqn. (3) we obtain the following constraint on the magnetar ellipticity [30] as

$$(5)$$

$$|\epsilon| < (5/3G)^{1/2} \{ C R^3 P_o B_{\text{dipole}} / 2^4 \pi I \}$$

$$\cong 3 \times 10^{-4} ( B_{\text{dipole}} / 10^{14} \text{ G} ) ( P_o / 1\text{ms} ) \dots\dots\dots(4)$$

with fiducially standard neutron star properties of  $I=10^{45} \text{ g.cm}^2$ ,  $R = 10 \text{ km}$ ,  $P_o =$  initial spin period and the angle between the spin axis and the principal axis of the neutron star distortion =  $\pi/2$  [31].

If we assume that magnetar’s internal toroidal magnetic field component ( $B_{\text{toroidal}}$ ) is the main cause of neutron star deformation then we can constrain the average value of this component by the relation [24]

$$|\epsilon| \sim 1.6 \times 10^{-4} ( B_{\text{toroidal}} / 10^{16} \text{ G} )^2 \dots\dots\dots(5),$$

and  $B_{\text{toroidal}}$  as [30]

$$B_{\text{toroidal}} < \sim 1.4 \times 10^{16} \text{ G} ( B_{\text{dipole}} / 10^{14} \text{ G} )^{1/2} ( P_o / 1 \text{ ms} )^{1/2} \dots\dots\dots(6)$$

Considering the observed dipolar magnetic field strength  $B_{\text{dipole}} = 7 \times 10^{14} \text{ G}$  and spin period  $P_o = 1.36\text{s}$  of the Swift J1818.0-1607 we estimate the ultra-strong internal toroidal field strength  $B_{\text{toroidal}} < \sim 10^{18} \text{ G}$ . This value is consistent with the value  $10^{17} - 10^{18} \text{ G}$  in the case of newly born proto-neutron stars [32 – 34] and also supports the model proposed by Dall’Osso et al [35] that the internal magnetic field must be a very large initial value ( $> \sim 10^{16} \text{ G}$ ) for the internal magnetic field decay.

The decay of Core Magnetic field

Studies of magnetic field decay in the neutron star core [36, 37] point to three distinct mechanisms that affect the evolution and dissipation of magnetic fields in the magnetar interior: ohmic dissipation, ambipolar diffusion, and Hall drift. Specifically, ohmic dissipation and ambipolar diffusion are directly active in dissipation, whereas Hall drift is indirectly active. Further research [38, 39] shows that total energy conservation remains nearly the same after Hall drift, implying that due to Hall diffusion, a new equilibrium configuration with lower total energy will arise in the magnetar interior. According to their findings, initial stable magnetohydrodynamic configurations remain close to the new equilibrium configuration. Even yet, ambipolar diffusion in the neutron star core is projected to be the primary mechanism of internal field decay as long as magnetars are in their early phase evolution (i.e., ages less than 104 years).

~~Studies [36,37] of magnetic field decay in neutron star core hint three separate processes— ohmic dissipation, ambipolar diffusion and Hall drift are involved which affect the evolution and dissipation of magnetic fields in magnetar interior .In particular, ohmic dissipation and~~

~~ambipolar diffusion are directly active in dissipation while Hall drift is active indirectly. Further studies [38,39] also indicate the conservation of total energy remains almost same after the Hall drift i.e. due to Hall diffusion a new equilibrium configuration with smaller total energy will appear in the magnetar interior. But initial stable magneto hydrodynamic configurations remain close to the new equilibrium configuration as per results found in their studies. Even, the ambipolar diffusion in the neutron star core is expected to be dominant mode of interior field decay as long as early phase evolution (i.e. ages much less than  $\sim 10^4$  yrs) of magnetar is concerned.~~

Another significant result was found in ref [38,39] about ambipolar diffusion at high temperature in the core of a neutron star (i.e. magnetar). Ambipolar diffusion actually drives a slow motion of charged particles (located amid neutrons in the core of a neutron star) that is in opposition to the stable neutron star medium, particle friction and chemical potential gradients work together. Inside the core, two forms of ambipolar diffusion are active, depending on their effect on chemical composition. Inside the core, two forms of ambipolar diffusion are active in terms of chemical composition: a) Solenoid mode—only particle friction is used to counteract without disrupting chemical equilibrium. b) irrotational mode: disrupts the chemical equilibrium but does not evolve on time scales less than the  $\beta$ -reaction time scale. Because the core magnetic field of the neutron star (i.e., magnetar) is  $10^{18}$  G (which is greater than  $10^{16}$  G), the temperature in the magnetar core material will be greater than  $10^9$  K. The field degradation is not frozen in this scenario. This means that in the high-temperature zone, an equilibrium condition between heating and cooling may develop.

~~Another important result was obtained in ref [38,39] regarding ambipolar diffusion at high temperature in neutron star (i.e. magnetar) core. Ambipolar diffusion actually drives a slow motion of charged particles (situated among neutrons in the neutron star core) which is opposed~~

(6)

~~by both particle friction and chemical potential gradients in the stable neutron star medium. Depending on their effect on chemical composition two modes of ambipolar diffusion are active inside the core : a) solenoid mode—counteracting only by particle friction without perturbing chemical equilibrium b) irrotational mode—perturbing the chemical equilibrium but can not evolve on time scales shorter than the  $\beta$  reaction time scale. As the neutron star (i.e. magnetar) core magnetic field  $< 10^{18}$  G (which is  $> 10^{16}$  G) the temperature in the magnetar core material will be  $> 10^9$  K. In this case the field decay is not frozen. This means an equilibrium condition between heating and cooling in the high Temperature regime may appear.~~

Using the relation for heating rate per unit volume through field decay

$$dU^+ / dt = (B^2 / 4\pi t_{\text{decay}}^{\text{(early)}}) \approx 3.69 \times 10^{19} \{ B_{16}^4 / T_9^2 (\rho_{15})^{2/3} \} \text{ erg.cm}^{-3} \cdot \text{s}^{-1} \dots\dots (7)$$

and the relation for cooling rate per unit volume through modified URCA reaction

$$dU^- / dt \cong 9.6 \times 10^{20} \cdot (T_9)^8 \cdot (\rho_{15})^{2/3} \text{ erg.cm}^{-3} \cdot \text{s}^{-1} \dots\dots\dots(8)$$

and then equating the two rates Dall'Osso et al [40] found the equilibrium temperature as

$$T_{\text{eq}} \cong 6.6 \times 10^8 \cdot (B / 10^{16} \text{ G})^{2/5} \cdot (\rho_{15} / 0.7)^{2/3} \cdot (L / 2 \text{ km})^{-1/5} \text{ K} \dots\dots\dots(9)$$

Where  $B_{16}$ ,  $T_9$ ,  $\rho_{15}$  are in their usual notations, 'L' and 'a' are the characteristic scale of variation of the Lorentz force and the chemical potential, respectively, with  $(L/a) \approx 9.6 T_9^4 (\rho_{15})^{-1/3} (L / 2 \text{ km})$  [37]. Comparing the obtained  $T_{\text{eq}}$  with the transition time  $T_{\text{tr}} \approx 5.73 \times 10^8 (\rho_{15} / 0.7)^{1/12} \text{ K}$  (i.e. when  $\beta$ -reaction are very efficient in deleting the chemical equilibrium imbalance) they found  $T_{\text{eq}}$  is higher than  $T_{\text{tr}}$  (i.e.  $T_{\text{eq}} > T_{\text{tr}}$ ) at magnetar interior core field environment where field decay occurs on the same time scale in both active modes. This means that magnetar core fields larger than that would be able to i) dissipate enough energy and ii) balance neutrino cooling in the early phase under the effective solenoidal and irrotational modes, which are still degenerate. It can be said that the field decay is negligible as long as the temperature is high enough (ergy and ii) balance neutrino cooling in the early phase under the effective solenoidal and irrotational modes, which are still degenerate. It can be said that the field decay is negligible as long as the temperature is high enough (e.g.,  $> T_9$ ) and when the time scale of field decay occurs on the same time scale in both two modes. The significance of ambipolar diffusion is that it becomes active soon after the formation of magnetar and can prevent the cooling of the magnetar core below a temperature of  $10^9 \text{ K}$  for a period of thousands of years (at least  $10^3$  years) [40]. This means the decay of an internal magnetic field  $\geq 10^{16} \text{ G}$  couples with the magnetar cooling at the early stage. ~~This means that magnetar core fields larger than that would be able to i) dissipate enough energy as well as ii) to balance neutrino cooling in the early phase under the effective solenoidal and irrotational modes are still degenerate. It can be said that the field decay is negligible as long as the temperature is high enough (e.g.  $> T_9$ ) when the time scale of field decay occurs on the same time scale in both two modes. The significance of ambipolar diffusion is that it becomes active soon after the formation of magnetar and can prevent the cooling of magnetar core below a temperature  $\sim 10^9 \text{ K}$  for a period of thousands yrs (at least  $10^3$  yrs) [40]. This means the decay of an internal magnetic field  $> 10^{16} \text{ G}$  couples with the magnetar cooling at the early stage.~~

### 5. Ellipticity and Triaxiality of Swift J1818.0-1607

Theoretically, a rotating neutron star will break its axial symmetry spontaneously when the rotational kinetic energy to gravitational binding energy ratio, i.e.,  $T/W$ , exceeds the critical value. When a rotating compact star is born from a core collapse supernova, it can also have a larger value of  $T$  or  $|W|$ . The

ratio  $T/W$  of a triaxial neutron star is basically constant, as is the triaxial sequence for increased compactness [41]. Except for J1818.0-1607, thirty magnetars have been detected to date. The spin or rotational durations of these 30 magnetrons range from 2 to 10 s, and their surface dipolar fields (derived from the periods, period derivatives) are 10<sup>13</sup>-10<sup>15</sup> G [42]. However, Jawor and Tauris [43] demonstrated that the magnetar's initial period must be shorter than 2s. According to data analysis, magnetars are young, with most of them having characteristic spin-down ages of less than a million years. Except for J1818.0-1607, thirty magnetars have been detected to date. The spin or rotational durations of these 30 magnetrons range from 2 to 10 s, and their surface dipolar fields (derived from the periods, period derivatives) are 10<sup>13</sup>-10<sup>15</sup> G [42]. However, Jawor and Tauris [43] demonstrated that the magnetar's initial period must be shorter than 2s. According to data analysis, magnetars are young, with most having distinctive spin-down ages of fewer than 10<sup>4</sup> years [44]. Because they are slow rotators, spin-down energy losses are insufficient to power their emissions. The dissipation and re-arrangement of their magnetic energy is thought to be another source. Magnetar internal structure, particularly the equation of state (EoS), and cooling process in the presence. According to data analysis, magnetars are young, with most having distinctive spin-down ages of fewer than 10<sup>4</sup> years [44]. Because they are slow rotators, spin-down energy losses are insufficient to power their emissions. The dissipation and re-arrangement of their magnetic energy is thought to be another source. Magnetar inner structure, particularly the equation of state (EoS), and the cooling process in the presence of high density, strong gravity, and a strong magnetic field are significant in defining magnetar shape deformation and triaxial value [45-47].

Theoretically, a rotating neutron star will break its axial symmetry spontaneously when rotational kinetic energy to gravitational binding energy ratio i.e.  $T/|W|$  exceeds the critical

(7)

value. A newly born rotating compact star can also achieve higher value of  $T/|W|$  when it is born from core collapse supernova. In the case of triaxial neutron star the ratio  $T/|W|$  is essentially constant along with the triaxial sequence for higher compactness [41]. Till date thirty magnetars have been discovered excluding this swift J1818.0-1607. For these 30 magnetars their spin / rotational periods range 2—10 s and surface dipolar fields (calculated from the periods, period derivatives) are 10<sup>13</sup>—10<sup>15</sup> G [42]. But Jawor and Tauris [43] showed that initial period of magnetar must be less than 2s. Analysis of observed data indicates magnetars are young and most of them having characteristic spin down ages of less than 10<sup>4</sup> years [44]. Since they are slow rotator, so spin down energy losses can not power their emission. Alternate source is believed to be the dissipation and re arrangement of their magnetic energy. Magnetar interior structure specially equation of state (EoS) and the cooling process in the simultaneous presence of high density, strong gravity, and strong magnetic field is important in determining the deformation in shape as well as triaxial value of the magnetar [45—47].

According to numerical calculations, a newly created magnetar will have a strong magnetic field and a rapid rotation, resulting in stellar deformation [48, 49]. As a result, a magnetar can release detectable gravitational waves; for example, a baby magnetar will spin down due to magnetic dipole torque and gravitational wave quadrupole radiation. Electro-magnetic radiation is also produced by the magnetar's spin-down evolution. In other words, the dynamic evolution of magnetar spin down is related to the theoretical breaking index (n) in such a way that

~~Numerical simulations show a newly born magnetar will be born with a strong magnetic field and a rapid rotation [48,49] which lead to the stellar deformation. As a result a magnetar can emit observable gravitational waves i.e. a baby magnetar will spin down due to a magnetic dipole torque as well as gravitational wave quadrupole radiation. Spin down evolution of the magnetar also produces electro magnetic radiation. In other words, the dynamic evolution of magnetar spin down provides a relation to the theoretical breaking index (n) such that~~

- a)  $n = 3$  when magnetic dipole radiation (i.e. electromagnetic phenomena ) dominates the spin down of the magnetar ;
- b)  $n = 5$  when the GW radiation dominates the magnetar spin down.

The comparison of the observed spin-down light curves and their related models, on the other hand, allows us to restrict the neutron star's initial spin period ( $P_0$ ), dipole magnetic fields ( $B_{dipole}$ ), and ellipticity ( $\epsilon$ ). (i.e., magnetar). Magnetars with an initial period of  $P_0$  1 ms and a surface dipole magnetic field of  $B_{dipole}$  10<sup>14</sup>-10<sup>15</sup> G, for example, often have an ellipticity of 10<sup>-3</sup>. However, the magnetar's theoretical minimum rotation period is 0.3-0.5 ms [50]. The most appropriate relationships [51] include

~~On the other hand, the comparison between the observed spin down light curves and their related models provide us an opportunity to constrain the initial spin period ( $P_0$ ), dipole magnetic fields ( $B_{dipole}$ ) and the ellipticity ( $\epsilon$ ) of the neutron star (i.e. magnetar). For example, magnetars with initial period  $P_0 \sim 1$  ms and surface dipole magnetic field  $B_{dipole} \sim 10^{14} - 10^{15}$  G usually have the ellipticity  $\epsilon \sim 10^{-3}$ . But theoretical value of the minimum rotation period of the magnetar is 0.3 - 0.5 ms [50]. The best fitting relations [51] are~~

$$\log \epsilon = 3.79^{+0.52}_{-0.43} + (2.19^{+0.17}_{-0.15}) \log P_0 \dots\dots\dots (10)$$

$$\text{and } \log \epsilon = -22.50^{+2.15}_{-2.22} + (1.29^{+0.15}_{-0.14}) \log B_{dipole} \dots\dots\dots (11)$$

suggest that

- a) magnetar having a stronger magnetic field and / a slower spin period corresponds to the longer ellipticity;

b) a longer rotation period corresponds to possession of a stronger magnetic field;

(8)

c) the neutron star deformation is related to its surface dipole magnetic field to some extent.

But it is argued [52,53] instead of dipole magnetic field neutron star deformation may be induced by a strong internal magnetic field ( $B_{\text{int}}$ ) in the stellar core through the relation

$$\epsilon \approx 10^{-8} (B_{\text{int}} / 10^{12} \text{ G}) \dots\dots\dots (12)$$

This relation hints the possession of a very strong internal magnetic field (i.e.  $B_{\text{int}} \sim 10^{16} - 10^{17}$  G) is needed in order to obtain the ellipticity  $\epsilon \sim 10^{-3} - 10^{-4}$  and also the required strength of the internal core magnetic field which should be at least 1 – 2 order of magnitude greater than the surface (i.e. external ) magnetic field ( $B_{\text{dipole}} \sim 10^{15}$  G).

The Triaxiality of Swift J1818.0-1607

At the time of its discovery on 12<sup>th</sup> March 2020 the Swift J1818.0 – 1607 was appeared to the astronomers as a new un-catalogued x-ray source. Presently it is a confirmed magnetar [52]. The follow up observations suggest the following properties :

- i) rotational period = 1.36 s
- ii) surface dipolar magnetic field =  $3 \times 10^{14}$  G
- iii) surface magnetic field at poles =  $7 \times 10^{14}$  G
- iv) spin down luminosity  $\sim 1.1 \times 10^{36} \text{erg.s}^{-1}$
- v) characteristic age  $\sim 300$  years

Using equ. (4), (5), (6) and (12) and with the above parameters as input we calculate the ellipticity, internal core magnetic field of Swift J1818.0-1607 and found  $\sim 9 \times 10^{-3}$  and  $8.9424 \times 10^{17}$  G, respectively.

Comment [Bs1]: Use mathematical equation formats

[A numerical study \[53\] of the magnetized deformation of neutron stars shows an interesting consequence for neutron stars with low masses, i.e., the effect of the magnetic field is more prominent for internal magnetic fields  \$> 4 \times 10^{18}\$  G. The equilibrium between gravity and magnetic field is notably different for different directions in the case of a modest mass rather than a big neutron star, according to Rizaldy and Sulakseno \[53\]. Even the magnetic field's gravitational force on the z-axis is substantially larger than on the other axes, resulting in the oblate shape seen in low mass neutron stars. This oblate form is quite tiny in the case of a large neutron star compared to a less massive one. To put it another way, the internal toroidal magnetic field outperforms the poloidal field. The poloidal field's deformation \( \$B\_p\$  1014 and 1015 G\) and the accompanying adjustment in ellipticity \(i.e., 10-4 and 10-2, respectively\) are negligible \[54\].](#)

. The equilibrium between gravity and magnetic field is notably different for different directions in the case of a modest mass rather than a big neutron star, according to Rizaldy and Sulakseno [53]. Even the magnetic field's gravitational force on the z-axis is substantially larger than on the other axes, resulting in the oblate shape seen in low mass neutron stars. This oblate form is quite tiny in the case of a large neutron star compared to a less massive one. To put it another way, the internal toroidal magnetic field outperforms the poloidal field. The poloidal field deformation (Bp 1014 and 1015 G) and the related ellipticity correction (i.e., This oblate form is quite tiny in the case of a large neutron star compared to a less massive one. To put it another way, the internal toroidal magnetic field outperforms the poloidal field. The poloidal field's deformation (Bp 1014 and 1015 G) and the accompanying adjustment in ellipticity (i.e., 10<sup>-4</sup> and 10<sup>-2</sup>, respectively) are negligible [54].

~~Numerical study [53] of magnetized deformation of neutron stars shows an interesting consequence for neutron stars with low masses i.e. the effect of magnetic field is more prominent for internal magnetic field  $B_{int} > 4 \times 10^{18}$  G. According to Rizaldy and Sulakseno [53] the balance between the gravity and magnetic field is significantly different for different directions in the case of small mass rather than massive neutron star. Even the gravity pull of magnetic field on the z axis is significantly more than for the other axes resulting which oblate shape appears in the low mass neutron stars. In the case of massive neutron star this oblate shape is very less in comparison to that of less massive. In other words, we can say internal toroidal magnetic field is more effective than the poloidal field. The deformation associated to the poloidal field ( $B_p \approx 10^{14}$  and  $10^{15}$  G) and the corresponding correction in ellipticity (i.e.  $10^{-4}$  -  $10^{-2}$ , respectively) is negligible [54].~~

~~In this study we consider the effect of toroidal magnetic field only although the recent view of magnetized deformation of neutron stars (i.e. magnetars ) is due to the effect of both the~~

(9)

Although the contemporary perspective of magnetized deformation of neutron stars (i.e., magnetars) is owing to the action of both the toroidal and poloidal magnetic fields, i.e., a mixed magnetic field, we only investigate the effect of a toroidal magnetic field in this study. Our primary goal is to examine the ellipticity and stability of the deformed neutron star, magnetar Swift 1818.0-1607. Heras [55] discovered that in a realistic instance, the initial magnetic fields in the interior of young neutron stars lay in the range 1014-1016 G in a comparative investigation of pulsars and magnetars. Because ambipolar is active, it inhibits both the decay of inner magnetic fields and the cooling of the neutron star, i.e., the magnetar (because the effect is the same for magnetars and neutron starsal magnetic fields, i.e., a mixed magnetic field). Our primary goal is to examine the ellipticity and stability of the deformed neutron star, magnetar

Swift 1818.0-1607. Heras [55] discovered that in a realistic instance, the initial magnetic fields in the interior of young neutron stars lay in the range 1014-1016 G in a comparative investigation of pulsars and magnetars. Because ambipolar is active, it prevents both the decay of interior magnetic fields and the cooling of the neutron star, i.e., the magnetar (because the effect is the same and applies to both magnetars and neutron stars), causing the magnetar core temperature to remain higher than several times 10<sup>8</sup> K for thousands of years. (at least 10<sup>3</sup> years). This ellipticity of newly born magnetar may not vary significantly during the following thousand years. Because the Swift J1818.0-1607's characteristic age is just 300 years, i.e., the baby phase compared to thousands of years, it will very certainly exhibit triaxiality, i.e., triaxial behavior, at least up to the age of 1000 years.

In a realistic situation, Heras [55] discovered that the first magnetic fields in the interior of embryonic neutron stars are in the range 1014-1016 G. Because ambipolar is active, it inhibits both the decay of inner magnetic fields and the cooling of the neutron star, i.e., the magnetar (because the effect is the same for magnetars and neutron starsal magnetic fields, i.e., a mixed magnetic field). Our primary goal is to examine the ellipticity and stability of the deformed neutron star, magnetar Swift 1818.0-1607. Heras [55] discovered that in a realistic instance, the initial magnetic fields in the interior of young neutron stars lay in the range 1014-1016 G in a comparative investigation of pulsars and magnetars. Because ambipolar is present, Our primary goal is to examine the ellipticity and stability of the deformed neutron star, magnetar Swift 1818.0-1607. Heras [55] discovered that in a realistic instance, the initial magnetic fields in the interior of young neutron stars lay in the range 1014-1016 G in a comparative investigation of pulsars and magnetars. Because ambipolar is active, it prevents both the decay of interior magnetic fields and the cooling of the neutron star, i.e., the magnetar (because the effect is the same and applies to both magnetars and neutron stars), causing the magnetar core temperature to remain higher than several times 10<sup>8</sup> K for thousands of years. (at least 10<sup>3</sup> years). This ellipticity of newly born magnetar may not vary much. Because ambipolar is active, it prevents both the decay of interior magnetic fields and the cooling of the neutron star, i.e., the magnetar (because the effect is the same and applies to both magnetars and neutron stars), causing the magnetar core temperature to remain higher than several times 10<sup>8</sup> K for thousands of years. (at least 10<sup>3</sup> years). This ellipticity of newly born magnetar may not vary significantly during the following thousand years. Because the Swift J1818.0-1607's characteristic age is just 300 years, i.e., the baby phase compared to thousands of years, it will very certainly exhibit triaxiality, i.e., triaxial behavior, at least up to the age of 1000 years. Because ambipolar is active, it prevents both the decay of interior magnetic fields and the cooling of the neutron star, i.e., the magnetar (because the effect is the same and applies to both magnetars and neutron stars), causing the magnetar core temperature to remain higher than several times 10<sup>8</sup> K for thousands of years. (at least 10<sup>3</sup> years). This ellipticity of newly born magnetar may not vary significantly during the following thousand years. Because the Swift J1818.0-1607's characteristic age is just 300 years,

i.e., the baby phase compared to thousands of years, it will very certainly exhibit triaxiality, i.e., triaxial behavior, at least up to the age of 1000 years.

~~toroidal and the poloidal magnetic fields i.e. a mixed magnetic field. Our main purpose is to check the ellipticity of the deformed neutron star i.e. magnetar Swift 1818.0-1607 and its stability. In a comparative analysis pulsars and magnetars Heras [55] found the initial magnetic fields in the interior of nascent neutron stars lie in the range  $10^{14}$ – $10^{16}$  G in realistic case. As ambipolar is active that prevents both the decay of interior magnetic fields and cooling of the neutron star i.e. magnetar (as the effect is same and applicable for magnetars as well as neutron stars also) such that magnetar core temperature stays higher than several times  $10^8$  K for a period of few thousands of years (at least  $10^3$  years). This ellipticity of new born magnetar might not be changed too much during the period of thousand years. As the characteristic age of the Swift J1818.0-1607 is only 300 years i.e. the baby phase still compare to thousands years it will definitely exhibit triaxiality i.e. triaxial behavior at least up to its age 1000years.~~

This magnetar's estimated ellipticity is within the range for triaxiality, and it will remain at that value for several thousands of years if it exhibits triaxiality. As a result, we believe Swift J1818.0-1607 is a triaxial magnetar, or simply a triaxial star.

~~The estimated ellipticity of this magnetar lies within the range for triaxiality and its ellipticity will remain on that value for exhibiting triaxial nature for several thousands years. We thus propose that the Swift J1818.0-1607 is a triaxial magnetar or simply a triaxial star.~~

## **6. Conclusion**

If the ratio T/W surpasses a certain threshold, a freshly formed revolving neutron star can spontaneously violate its axial symmetry. Magnetars are an uncommon kind of somewhat slow-rotating neutron stars with extremely strong magnetic fields. A magnetic field with a component parallel to the rotation axis breaches circular conservation and introduces spontaneous symmetry breaking as a non-dissipative mechanism. The Swift J1818.0-1607 is a 300-year-old baby magnetar with an extremely powerful internal core magnetic field of  $8.9424 \times 10^{17}$  G. It has the shortest spin or rotating period of the 31 magnetars discovered, measuring 1.36 seconds. Its magnetic fields are not perpendicular to the rotational axes. The Swift J1818.0-1607's aforesaid features indicate that it is a good triaxial magnetar (compact object) for testing or studying the discovery of a triaxial star and its odd properties. Although its internal core magnetic field is too powerful, it has at least one slow decay mode via ambipolar diffusion that becomes active soon

after its birth. (birth). Because this process can prevent the magnetar core from cooling below a few times  $10^8$  K (i.e.,  $10^9$  K) for thousands of years, continuous observation of Swift J1818.0 - 1607 will allow us to better understand the evolution of magnetar magnetic fields. A magnetic field with a component parallel to the rotation axis breaches circular conservation and introduces spontaneous symmetry breaking as a non-dissipative mechanism. The Swift J1818.0-1607 is a 300-year-old baby magnetar with an extremely powerful internal core magnetic field of  $8.9424 \times 10^{17}$  G. It has the shortest spin or rotating period of the 31 magnetars discovered, measuring 1.36 seconds. Its magnetic fields are not perpendicular to the rotational axes. The Swift J1818.0-1607's aforesaid features indicate that it is a good triaxial magnetar (compact object) for testing or studying the discovery of a triaxial star and its odd properties. Although its internal core magnetic field is too powerful, it does have a gradual decay mode via ambipolar. It has the shortest spin or rotating period of the 31 magnetars discovered, measuring 1.36 seconds. Its magnetic fields are not perpendicular to the rotational axes. The Swift J1818.0-1607's aforesaid features indicate that it is a good triaxial magnetar (compact object) for testing or studying the discovery of a triaxial star and its odd properties. Although its internal core magnetic field is too powerful, it has at least one slow decay mode via ambipolar diffusion that becomes active soon after its birth. (birth). Because this mechanism can keep the magnetar core from dropping below a few times  $10^8$  K (i.e.,  $10^9$  K) for thousands of years, ongoing study of Swift J1818.0 - 1607 will provide us with a chance. Although its internal core magnetic field is too powerful, it has at least one slow decay mode via ambipolar diffusion that becomes active soon after its birth. (birth). Because this process can prevent the magnetar core from cooling below a few times  $10^8$  K (i.e.,  $10^9$  K) for thousands of years, continuous observation of Swift J1818.0 - 1607 will allow us to better understand the evolution of magnetar magnetic fields.

~~Newly born rotating neutron star can break their axial symmetry spontaneously if the ratio  $T/|W|$  exceeds some threshold value. Magnetars are classified as a rare class of relatively slow rotating neutron stars that possess very strong magnetic fields. As a non-dissipative mechanism a magnetic field with a component parallel to the rotation axis breaks circular conservation and introduces symmetry breaking spontaneously. The swift J1818.0-1607 is a baby magnetar of characteristic age of  $\sim 300$  years, having very strong internal core magnetic field  $\sim 8.9424 \times 10^{17}$  G. It is the fastest among the detected 31 magnetars having spin or rotational period  $\sim 1.36$  s. Its magnetic fields are not aligned with the rotational axes. The above properties of the swift J1818.0-1607 indicate that it is an ideal triaxial magnetar (compact object) where detection of a triaxial star and its bizarre properties can be tested / studied. Its internal core magnetic field, though too much strong, yet have ( at least) a slow decay mode through ambipolar diffusion which becomes active soon after formation (birth). As this process can prevent the cooling of the magnetar core below a temperature of few times of  $10^8$  K (i.e.  $< 10^9$  K) for thousands of years, continuous observation of Swift J1818.0 - 1607 will thus offer us an opportunity for understanding our knowledge of the evolution of magnetic fields of magnetars.~~

The frequency of the produced continuous gravitational waves would be quite low because the spinning period of this magnetar is 1.36 s, which is within the range of 1-10 s [56, 57]. This author asks the Gravitational Wave Community to regularly observe this triaxial infant magnetar (i.e., Swift J1818.0-1607) while observing compact objects via electromagnetic equivalents.

As the rotational period of this magnetar is 1.36s i.e. within the range 1—10s, the frequency of the emitted continuous gravitational waves would be very low [56,57] this author encourages the Gravitational Wave Community to observe this triaxial baby magnetar (i.e. the swift J1818.0-1607) continuously during their observation of compact objects through electromagnetic counterparts.

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**Data Availability Statement :**Data sharing not applicable as no datasets were analysed.

**Ethical conduct :**Not applicable

**Reference :**

1. Chandrasekhar,S. :Ellipsoidal Figures of Equilibrium. Yale University Press, New Haven (1969)
2. Bonazzola S, Friebe J,Gourgoulhon E. 1998 Spontaneous symmetry breaking of rapidly rotating stars in general relativity.Astron.&Astrophys. 1998;331;280 .doi: 10.48550/arxiv.gr-qc/9710121.
3. Friedman J L,Stergioulas J.Rotating Relativistic Stars , Cambridge University Press, Cambridge, UK (2013),
4. Straumann, N. General Relativity ,Springer, Netherlands(2013)
5. Uryū K, Tsokaros A, Baiotti L, Galeazzi F, Sugiyama N, Taniguchi K,Yoshida S.Do Triaxial supramassive compact stars exist ?Phys. Rev.D. 2016; 94; 101302.doi:10.1103/PhysRevD.94.101302.
6. Lai D, Shapiro S L. Gravitational Radiation from Rapidly rotating Nascent Neutron stars. Astrophys. J. 1995;442; 259. Doi:101086/175438.
7. Piro A L, Ott C D. Supernova Fallback onto Magnetars and Propeller-powered Supernovae.Astrophys. J. 2011;736 ; 108. Doi:10.1088/0004-637X/761/1/108.
8. Piro A L, Thrane E. Gravitational Waves from fallback accretion onto neutron stars.Astrophys. J.2012;761; 63. Doi:10.1088/0004-637X/761/1/63.
9. Harry G M.(LIGO Scientific Collaboration),:Alignment sensing and control in advanced LIGO". Class. Quan. Grav.2010;27; 084006.

**Comment [Bs2]:** If the author can add some more references, it will give clear image of the contents

10. LambiF S, Benkaiem D, Joyce M. On the generation of triaxiality in the collapse of cold spherical self-gravitating systems. *MNRAS*. 2015 ;449; 4458.  
doi.org/10.1093/mnras/stv581
11. Rather I A, Rahaman U, Dexheimer V, Usmani A A, Patra S K. Magnetic deformation in Neutron Stars. in *Proc. DAE Symp in Nucl. Phys.* 2021;65; 478
12. Haskell B, Samuelsson L, Glampedakis K, Andersson N. Modelling magnetically deformed neutron stars. *MNRAS*. 2008;385; 531. Doi:10.1111/j.1365-2966.2008.12861.x.

(11)

13. Gehrels N. et al. The Swift Gamma-Ray Burst Mission. *Astrophys. J.* 2004;611; 1005.  
Doi:10.1086/422091
14. Evans PA, Gropp J D, Kennea J A. et al. Swift-BAT trigger 960986: Swift detection of a new SGR Swift J1818.0-1607. 2020; GCN circular #27373
15. Esposito P, Rea N, Borghese A, Coti-Zelati F. et al. A Very Young Radio-loud Magnetar. *Astrophys. J. Lett.* 2020;896; L30. Doi:10.3847/2041-8213/ab9742
16. Enoto T, Sakamoto T, Younes G. et al. NICER detection of 1.36 sec periodicity from a new magnetar, Swift J1818.0-1607. 2020; (Astronomer's Telegram # 13551)
17. Champion D, Desvignes G, Jankowski F. Spin-evolution of the new magnetar J1818.0-1607. 2020; (A. Tel # 13559)
18. Blumer H, Safi-Harb S. CHANDRA Observations Of the Newly discovered Magnetar SWIFT J1818.0-1607. *Astrophys. J. Lett.* 2020 ;904; L19
19. Duncan R C, Thompson C. Formation of Very Strongly Magnetized Neutron Stars. *Astrophys. J.* 1992 ;392 ; L9 . doi:10.1086/186413
20. Paczynski B. GB 790305 as a very strongly magnetized neutron star. *Acta Astron.* 1992 ;42; 145.
21. Thompson C, Duncan R C. soft gamma repeaters as very strongly magnetized neutron stars. *MNRAS*. 1995 ;275; 255. Doi:10.1093/mnras/275.2.255
22. Ruderman A. Pulsars: Structure and Dynamics. *Ann. Rev. Astron. Astrophys.* 1972 ;10 ; 427. Doi:10.1146/annurev.aa.10.090172.002235
23. Dev K, Gleiser M. Anisotropic Stars: Exact Solutions. *Gen. Rel. Grav.* 2002; 34; 1793.
24. Cutler C. Gravitational waves from neutron stars with large toroidal B fields. *Phys. Rev. D* 2002 ; 66 ; 084025. Doi:10.1103/PhysRevD.66.084025
25. Lai D, Shapiro S. Cold Equation of State in a Strong Magnetic Field: Effects of Inverse beta-Decay. *Astrophys. J.* 1991 ;383 ; 745. Doi:10.1086/170831
26. Melatos A. The Equation of State of Neutron Star Matter in Strong Magnetic Fields. *Astrophys. J.* 1991 ;519 ; L77. Doi:10.1086/309010
27. Goldreich P. Neutron Star Crusts and Alignment of Magnetic Axes in Pulsars. *Astrophys. J.* 1970 ;160 ; L11. Doi:10.1086/180513
28. de Campli W M. *Astrophys. J.* 1980 ;242 ; 306 .

29. Thompson C, Duncan R C. Neutron Star Dynamos and the Origins of Pulsar Magnetism. *Astrophys. J.* 1993 ;408 ; 194 . Doi:10.1086/172580
30. Moriya T J, Tauris T M. Constraining the ellipticity of strongly magnetized neutron stars powering superluminous supernova. *MNRAS.* 2016 ;460 ; L55. Doi:10.1093/mnras/slw072
31. Cutler C, Jones D I. Gravitational wave damping of neutron star wobble. *Phys. Rev. D* 2001 ; 63; 024002. Doi:10.1103/PhysRevD.63.024002

(12)

32. Del Zanna L, Bucciantini N. Covariant and 3 + 1 equations for dynamo-chiral general relativistic magnetohydrodynamics. *MNRAS.* 2018 ;479; 657. Doi:10.1093/mnras/sty1633
33. Cioffi R, Kastaun W, Kalinani J V, Giacomazzo B. First 100 ms of a long-lived magnetized neutron star formed in a binary neutron star merger. *Phys. Rev. D.* 2019; 100; 023005. Doi:10.1103/PhysRevD.100.023005
34. Franceschetti K, Del Zanna L. General Relativistic Mean-Field Dynamo Model for Proto-Neutron Stars. *Universe* 2020 ;6 ; 83. Doi:10.3390/universe6060083
35. Dall'Osso S, Granot J, Piran T. Magnetic field decay in neutron stars: from soft gamma repeaters to 'weak-field magnetars'. *MNRAS.* 2012 ; 422; 2878. Doi:10.1111/j.1365-2966.2012.20612.x
36. Thompson C, Duncan R C. The Soft Gamma Repeaters as Very Strongly Magnetized Neutron Stars. II. Quiescent Neutrino, X-Ray, and Alfvén Wave Emission. *Astrophys. J.* 1996 ;473 ; 322. Doi:10.1086/178147
37. Goldreich P, Reisenegger A. Magnetic Field Decay in Isolated Neutron Stars. *Astrophys. J.* 1992 ;395; 250. Doi:10.1086/171646
38. Pons J A, Link B, Miralles J A, Geppert U. Evidence for Heating of Neutron Stars by Magnetic-Field Decay. *Phys. Rev. Lett.* 2007 ;98; 071101. Doi:10.1103/PhysRevLett.98.071101
39. Pons J A, Geppert U. Magnetic field dissipation in neutron star crusts: from magnetars to isolated neutron stars. *Astron. Astrophys.* 2007 ;470 ; 303. Doi:10.1051/0004-6361:20077456
40. Dall'Osso S, Shore S N, Stella L. Early evolution of newly born magnetars with a strong toroidal field. *MNRAS.* 2009 ;398 ; 1869. Doi:10.1111/j.1365-2966.2008.14054.x
41. Zhou E, Tsokaros A, Rezzolla L, Xu R, Uryu K. Uniformly rotating, axisymmetric, and triaxial quark stars in general relativity. *Phys. Rev. D* 2018 ; 97; 023013. Doi:10.1103/PhysRevD.97.023013
42. Kouveliotou C, Stohmayer T, Hurley K, van Paradijs J, Finger M H, Dieters S, Wood P, Thompson C, Duncan R C. Discovery of a Magnetar Associated with the Soft Gamma Repeater SGR 1900+14. *Astrophys. J. Lett.* 1999 ;510 ; L115. Doi:10.1086/311813

43. Jawor J A, Tauris T M. Modelling spin evolution of magnetars. *MNRAS*. 2022 ;509; 634  
Doi:10.1093/mnras/stab2677
44. White C J, Burrows A, Coleman M S B, Vartanyan S. *Astrophys. J.* 2022 ;396 ; 111.
45. Yakovlev D G, Gnedin O Y, Gusakov M E, Kaminkar A D, Lavenfish K P, Potekhin A Y. Neutron star cooling. *Nucl. Phys. A*2005 ;752; 590.  
Doi:10.1016/j.nuclphysa.2005.02.061
46. Chamel N, Haensel P. *Physics of Neutron Star Crusts Living Rev. Relativity* 2005 ; 11 ; 10 .doi:10.12942/lrr-2008-10

(13)

47. Bucciantini N, Pili A G, Del Zanna L. Modelling the structure of Magnetic Fields in Neutron Star: from the interior to the magnetosphere, .in *Proceedings of the 10th International Conference on Numerical Modeling of Space Plasma Flows*, ( 2015)
48. Lindbolm L, Pwen B J, Morsink S M. Gravitational Radiation Instability in Hot Young Neutron Stars. *Phys. Rev. Lett.* 1998 ;80 ; 4843. Doi:10.1103/PhysRevLett.80.4843
49. Doneva DD, Kokkatas K D, Prigouras P. Gravitational wave afterglow in binary neutron star mergers. *Phys. Rev. D*2015; 92 ; 104040.  
Doi:10.1103/PhysRevD.92.104040
50. Koranda S, Stergioulas N, Friedman J L. Upper Limits Set by Causality on the Rotation and Mass of Uniformly Rotating Relativistic Stars. *Astrophys. J.*1997 ;488; 799.  
Doi:10.1086/304714
51. Xie L, Wei D M, Wang Y, Jin Z P. Constraining the Ellipticity of the Newborn Magnetar with the Observational Data of Long Gamma-Ray Bursts. *Astrophys. J.*2022 ;934; 125 .  
doi:10.3847/1538-4357/ac7c13
52. Majid W A, Pearlman A A, Prince T A, Naudet C A, Bansal K. Flattening of Swift J1818.0 – 1607's spectral index via dual radio frequency observation with the Deep Space Network “. 2022 ; A. Tel # 13898.
53. Rizaldy R, Sulaksono A. Magnetized deformation of neutron stars. in *Proc. 3<sup>rd</sup> Padjajaran Int. Phys. Conf. Symp., J. of Phys. Conf. Series* 2018; 1080; 012031
54. Morasi S, Ciolfi R, Schneider R, Stella L. Stochastic background of gravitational waves emitted by magnetars. *MNRAS*. 2011 ;411 ; 2549. doi:10.1111/j.1365-2966.2010.17861.x
55. Heras R. Pulsars are born as Magnetars. *ASP Conf. Ser.*2012 ;466 ; 253
56. Sieniawska M, Bejger M. Continuous Gravitational Waves from Neutron Stars: Current Status and Prospects. *Universe* 2019 ; 2019; 217. Doi:10.3390/universe5110217
57. Ibrahim A Y, Borghese A, Rea N, Cotzelati F. Deep X-Ray and Radio Observations of the First Outburst of the Young Magnetar Swift J1818.0–1607. *Astrophys. J.* 2023 ;943; 20.  
Doi:10.3847/1538-4357/aca528

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