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Cosmic Baby and the Detection of a Neo-Natal Triaxial Star: A Possibility

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Abstract: ***Triaxial star remains undetectable till date. Detection of gravitational waves gives an impetus to the astronomers to detect the compact object in a different look in the light of gravitational wave radiation. Recently, Zhang et al (2022) re-analyzed the earlier observed parameters of GRB 130310A and found the age of the magnetar associated with this GRB is only two weeks. Taking into account the facts for a new born magnetar having a magnetic tilt angle (Xu & Huang, 2015): a) the long-lasting /stable survive remnant of binary neutron star merger is millisecond magnetar which injects power to the short gamma ray bursts (SGRBs) and kilonovae, b) the apparent magnetic field decreases with the decrease of the tilt angle, c) the evolution scenario of the energy loss rate is consistent with the overall light curves of gamma ray bursts exhibiting a plateau structure in their afterglow phase, d) the origin of some gamma ray bursts having a plateau shape in their afterglow phase is the newly born millisecond magnetar, I estimate the interior magnetic field strength and ellipticity of this millisecond magnetar in GRB 130310A and found interior magnetic field 3.95 x 10 ^{17} G and the corresponding ellipticity $\epsilon \sim 4 \times 10^{-3}$ which is within the limit of ellipticity $\epsilon \sim 0.004 - 0.007$ for being a real triaxial star.For quantitative analysis 73 milisecond magnetars are considered. It is found majority of magnetars are of 2weeks aged possess ellipticities of $\sim 10^{-3} - 10^{-4}$ and out of these only 6 magnetars (3 in each LGRBs and SGRBs) satisfy the norm of triaxiality whose physical existence is possible. As it possesses the required values of ellipticity and magnetic field strength this author, thus, proposes the associated magnetar of GRB 130310A was a "Neo-natal Triaxial Star". Weak gravitational wave radiation may be produced by the new born magnetar due to its deformation structure. He encourages the Gravitational Wave Community to search this neonatal triaxial star (i.e, magnetar of GRB 130310A) during their observation of compact objects.***

Keywords: Gravitational Wave, Neutron Star, Magnetar, Triaxial Star

1. Introduction

The discovery of gamma-ray-bursts (GRBs), in fact, was unexpected, serendipitous. Initially it was thought the sun, the moon as well as the earth may be their origin. Klebesadel et al [1] first showed that these bursts were from outside our solar system representing a hitherto unobserved phenomenon in which enormous amount of energy was involved ranging of 20 Kev to 2 Mev. More than 3000 bursts have been observed till date. Observations hint that a burst may last for 30 ms to a several thousand seconds. Not only that, these bursts consist mainly of several pulse structures with a rapid rise and a slower decay phase [2] i.e., the initial phase of the emission of the bursts is predominantly of gamma ray.

Randomly occurred this GRBs throughout the universe are classified into two groups- short gamma ray burst (SGRB) and long gamma ray burst (LGRB) [3]. In short GRBs the duration of T_{90} (i.e., the time it takes burst to emit between 5% and 95% of its isotropic emission) is < 2 s and for long GRBs T_{90}> 2 s [4]. The origin of LGRBs is associated with the gravitational collapse of massive stars whereas the short GRBs are with the compact binary coalescence (which is confirmed by Abbott et al [5]). The main common feature in GRB phenomenology lies in their afterglow light curves i.e., a plateau emission in the early stage observed in almost a large fraction of x-ray afterglows. Our present understanding of a canonical x-ray after- glow model includes four different emission phases [6]:

a) A steep in early decay i.e., initial steep decay phase which is accepted as the tail of the prompt emission [7].
b) A shallow decay or plateau shape phase which is considered as a continuous energy injection into the external shock [8, 9].
c) A late or normal decay phase
d) Achromatic jet breaks steeper-than-normal decay phase
e) Flare

Note that sometimes, the phases of achromatic jet breaks and flare don't always appear together and also the flares are often superimposed on to the plateau phase [10].

A magnetar is a special type of isolated neutron star with internal strong magnetic fields. Observations show that this internal magnetic fields play an important role in shaping the structure and dynamics of compact objects. Again, possession of greatest compactness of astrophysical objects makes them the most effective source of gravitational waves. Observations also show that a nascent magnetar experiences fast evolution in the first minute of its life. The typical spin periods of magnetars are about few seconds i.e., (2–12) s [11].

Theoretically, a new born millisecond magnetars are rapidly rotating neutrons stars with extremely strong magnetic fields [12, 13, 14] and thought, these are produced from the merger of binary neutron stars or core collapses of massive stars, associated with gamma ray bursts (GRBs). Special characteristics of these magnetars are, in general, deemed to produce a strong x-ray emission (in the form of flare or plateau) in their GRB afterglows and also gravitational wave radiation effect on x-ray plateau due to a large ellipticity and high spin [15, 16, 17]. Other causes of generation of strong gravitational waves radiation are- asymmetric deformations due to magnetic flare –induced oscillation [18, 19], rotation

induced radio oscillation [20] and accretion instability-induced non-axisymmetric shape [21].

The structural asymmetry of the accreting magnet appears due to magnetically channeling by accreting materials towards the magnetar polar cap (so called accretion columns). This accretion column-induced deformation produces weak gravitational waves which are in the detectable range of the Advanced LIGO and VIRGO detectors [22]. Thus, a new born millisecond magnetar accretes the fall material after its formation resulting which this new-born magnetars possess an extremely strong magnetic field ~ 10^{14} – 10^{15} G and its millisecond period, therefore most probably, makes very different from normal magnetars (i.e., neutron stars) [23, 24].

Another primary power source of Magnetars isthe decay of their enormous magnetic fields, responsible for their transient emission behavior [24,25]. The influence of a new born magnetar associated with the transient emission is highly dependent on the spin down behavior of the magnetar (i.e., neutron star). The spin down is usually determined by (i) the magnetic dipole rotation, and sometimes also by (ii) the gravitational wave radiation provided the ellipticity of the magnetar is high enough. Again, the early evolution of the new born magnetar and consequently, the transient emission both would be influenced by the fall back accretion [26, 27] although the time scale of the majority of the material falling on is very short.

The direct observation of AXPs and SGRs through the detection of flaring events from these sources confirms (i) the existence of magnetars in our galaxy, and (ii) magnetars (i.e., neutron stars) possess a strong dipole magnetic field ~ 10^{14} – 10^{15} G although they are millions of years old [28, 29]. A star can be deformed by its strong magnetic field [30, 31] and its ellipticity is roughly proportional to the magnetic energy. Therefore, It is expected that new born magnetars, with their intense magnetic field, possess significant ellipticities [32].

In this paper I consider the available observed parameters for 14 newborn magnetars that are associated with various long GRBs and estimate the characteristic ages and ellipticities of these magnetars and then investigate the internal magnetic field and ellipticity of the new born magnetar associated with the GRB 130310A. Comparison of these calculated data shows that the estimated values satisfy the conditions for being a triaxial star and this magnetar is the youngest. It is, thus, proposed that the associated magnetar of GRB 130310A was a “Neo-Natal Triaxial Star”.

The paper is organized as follows: the discovery of a weeks old magnetar is described in Sec.2. Sec.3 deals with the magnetar as origin of GRBs. In Sec.4 gamma ray bursts, afterglow scenarios and magnetic tilt angled relations are discussed. New born magnetar as origin of short GRBs is described in Sec.5. A description of formation of millisecond magnetar in binary neutron star merger, its support from numerical and observational evidence are made in Sec.6. Central engines for GRBs, ellipticity and internal magnetic field of the magnetar associated with the GRB130310A is made in Sec.7. A view of magnetically induced effects on newly born magnetars associated with the GRB 130310A and in other various 73 GRBs are described in Sec.8 while Sec.9expresses the possible triaxial nature of the magnetar of GRB130310A. Finally, conclusion is made in Sec.10.

2. Discovery of a weeks old Magnetar in GRB 130310A

On 10th March 2013 (i.e., denoting this time as T_0) at 20: 09: 41.503 UTC several high energy missions including Fermi/ GEM, Fermi LAT [33], Konus Wind [34], and Suzaku WAM [35] detected a high flare event GRB 130310A. It is newly born magnetar in nature and situated in the host galaxy g0927191 – 170053 at RA = $+09^h27^m$ 19.70^s and DEC = -17° 00′ 53.0″ with a luminosity distance 70Mpc. This gamma ray burst consisted of two main emission episodes: a precursor and a main. The magnitude of this hyper flare was thousand times brighter than typical magnetar giant flare. The observed and estimated parameters of this GRB 130310A were:

Observed Parameters at the time of discovery
Burst (precursor + main) lasting a total ~ 4.2 s
Precursor lasting ~ 0.8 s
Thermal spectrum (characteristic) with KT = $45.06^{+13.57}_{-5.69}$ KeV
Spin Period ~ 80 ms
Age of the magnetar (i.e., GRB 130310A) ~ only few weeks i.e. 2 weeks old
Magnetic field at birth ≈ 10^{14} – 10^{15} G
Red Shift (z) = 0.0001 – 10

Estimated values at the time of discovery (Zhang et al 2022 [87])
This neo-natal magnetar possesses magnetic field as high as ~ 10^{16} G and normalized to $10^{15.5}$ G (or 3.2 x 10^{15} G)
Characteristic age ≈ 3 weeks
Minimal age = 11 days
Maximal age = 56 days

The magnetar is likely born from an off-axis merger event of two neutron stars. If it is originated from the merger of two neutron stars, this also consistent with the host galaxy g0927191-170053 which is an elliptical galaxy.

3. Magnetars and origin of Gamma ray bursts (GRBs)

Histories of gamma ray bursts (GRBs) and magnetars indicate that they are both intertwined. It isalso known that cosmological gamma ray bursts (GRBs) arise from distinct progenitors i.e., short GRBs, mostly from neutron star mergers, and long GRBs from a rare type of core collapse supernova (CCSN) called collapsars. Magnetars (i.e., highly magnetized neutron stars) also generate energetic, short duration gamma ray transients, so called magnetar giant flares (MGFs). All these three have been observed in our Milky Way galaxy and its satellite galaxies.

Regarding magnetar formation several proposed mechanisms are

a) Normal core collapse supernovae (CCSNe) [36],
b) Engine driven core collapse (CCSNe), such as type I super-luminous supernovae (SLSN-I), long gamma ray bursts [37, 38],
c) Accretion induced collapse (AIC) of white dwarfs [39],
d) Merger of two neutron stars (NS – NS) [40].

All the different transient events, generate from engine driven supernovae, accretion induced collapse (AIC) and NS – NS merger, are expected (hypothesized) to create a convective dynamo that amplifies the magnetic field of the newly born neutron star to magnetar strength, i.e., millisecond magnetar. Note that the outcome of NS – NS merger is a stable, more massive neutron star [39] and the magnetic field of this stable neutron star can be amplified though a dynamo driven by internal turbulence. Significance is that host galaxies of these magnetars would have similar characteristics to the host of short gamma ray bursts [41].

Investigating the consistency of the GRBs with the origin of magnetar's giant flares Burns et al. [42] found the significant results which are:

a) Analysis of the circumstantial evidence of a sample of short GRB, detected by Swift observatory from the afterglow events, provide a clear indication of their origin towards a neutron star merger [43],
b) Direct confirmation that some GRBs arise from binary neutron star mergers, the similar one with GW170817 and GRB 170817A [44],
c) Soft gamma ray repeaters (named phenomenologically for weak, recurrent short bursts) was identified for the first time before their origin was known. For example, the flares on the 05th March 1979 i.e., GRB 790305B, and the subsequent similar events GRB980827 and GRB041227 are originated from magnetars located in the Milky Way and referred to as magnetar giant flares [45, 46].
d) Their considered GRBs matches expectations for an MGF origin,
e) MGFs can have multipulses.
f) Some magnetars produce multiple MGFs.

Overall, their studies allow to constrain GRBs thathave a magnetar MGF origin i.e. origin from magnetar.

4. GRBs, Afterglow phase and Magnetic tilt angle

Gamma ray burst (GRB) observations suggested that new born magnetar should be with millisecond rotational periods in order to support GRB progenitor i.e. the rotational energy must be as high as ~10^{52} ergs in comparison to the energy released in GRB explosions. This implies that the dipole magnetic fields of new born magnetars are required to be > 10^{15}G [47, 48]. The reason is that on the time scale of GRB duration a significant amount of rotational energy definitely be released. But in order to explain the scenario of relatively long- lasting shallow decay in the afterglow phase, this magnetar should have a dipole magnetic field strength ~<10^{15} G [49 – 51].

According to Shapiro and Teukolsky [15] a new born magnetar can lose its energy through dipole radiation at a rate

$$\dot{E} = -(2/3\, c^3)|\dot{m}|^2 \quad (1)$$

where 'c' is the speed of light in vacuum and 'm' dipole moment of the magnetar. If we assume that Ω = the angular frequency at which the magnetar rotates, and α = the angle of orientation of the magnetic dipole moment w.r.t its rotation axis then magnetic moment 'm' can be expressed as a function of time [52] as

$$m = \tfrac{1}{2} B_p R^3 (e_{\parallel} \cos\alpha + e_{\perp}\sin\alpha \cos\Omega t + e_{\perp}\sin\alpha \sin\Omega t) \quad (2)$$

where B_p = surface magnetic field strength at pole, R = radius of the magnetar, $e_{\parallel}$ = unit vector parallel to Ω, $e_{\perp}$= fixed mutually orthogonal unit vectors perpendicular to $e_{\parallel}$.

Observational evidences favoring the existence of the magnetic inclination 'α' in newborn magnetar (i.e. neutron star) is very less because of poor observability of new born magnetars (i.e. neutron star) which are surrounded by opaque material. But theoretical investigations on the emission geometry for a number of pulsars showed that

a) $\alpha \leq 30^o$ for five pulsars,
b) $\alpha = 19^o$ in the case of 1600 years old pulsars J1119 – 6127 whose dipole magnetic field strength is 4.2 x 10^{13}G
c) Investigations on the stability of the field consisting of toroidal, poloidal and mixed of toroidal-poloidal fields i.e. "twisted torus" suggest that
d) $\alpha = 0^o$forboth the purely toroidal and the combined toroidal-poloidal i.e. "twisted torus" show the same stabilizing effect on the rotation quantitatively [53].
e) $\alpha = 90^o$forpurely toroidal field which reveals a much less stabilizing effect of rotation.
f) $\alpha \leq 45^o$for sufficiently fast rotating newborn neutron star with P ≤ 6 msthat retains their magnetic field strength ~ 10^{15} G as magnetar [54].

In the case of GRB 130310A, after a time span of 2 weeks, its dipolar magnetic field strength is ~ 10^{14} – 10^{15} G and period ~ 80 ms implies that the magnetar associated with this GRB had a significantly higher internal magnetic field [55, 56] which could be as high as ~ 10^{17}G or even more [57]. So, in the early new born phase such strong magnetic field would lead to a significant deformation. This means that the said magnetar with its fast rotation period ≪ 80ms was a strong source of gravitational wave emission. On the other hand, observed afterglow light curve of it suggested the possibility of rapid decrease in the magnetic tilt angle, resulting which shallow phase appeared. Precisely, the rapid decrease in the tilt angle, according to Xu and Huang [15], means the perpendicular component of the magnetic dipolar field at the surface of the magnetar also decreases rapidly which causes in one side- an apparent magnetic field can be high in the beginning (i.e., the prompt GRB phase), while on the other side- will be much lower on the later time (i.e., the afterglow phase). According to Xu and Huang [15, 58], such type of GRBs with a plateau stage in the afterglow light curve can be possible only when it is originated from a newly born magnetar.

5. Newborn Magnetar as origin of GRB x-ray afterglow

In searching the origin of GRBs' x-ray afterglow exhibiting plateau features, the essential part is the signature of a long-lasting energy supply from the central engine: either black hole accretion system or new born millisecond magnetar. Now,

Case 1: If the central engine is a black hole, then the amount of injected energy, comes from the fall accretion, may be too large to satisfy the explanation a plateau at late phase > 10^5 s [59].

Case 2: If the central is a new born millisecond magnetar, then it can well explain the two types of plateaus in x-ray afterglow light curves i.e.,

a) External plateau-originated from external shock due to an accelerated magnetar wind,
b) Internal plateau- which is produced by an internal energy dissipation in the magnetar wind i.e. magnetic reconnection.

So, it is clearly understood that the new born magnetar plays an important role , in particular, of injecting power to the GRBs x-ray afterglow by losing its rotational energy (i.e., spin down) via electromagnetic radiation and gravitational waves.

6. Formation of Millisecond Magnetar in binary Neutron Star Merger

Theoretically, there are four possible ways of formation of millisecond magnetars as discussed in Sec.3. Out of these four, the important one is binary/ double neutron star (NS) merger which is considered in this investigation. In the marging of two neutron stars, the common prediction is that they form a heavy neutron star that collapses into a blackhole within the time period of milliseconds or less. Study of GRBs [60, 61] suggests that it is also possible to form a long-lasting or stable, rapidly spinning magnetar, instead of collapsing into a blackhole. This millisecond magnetars can serve as the central engine of some gamma ray bursts [62]. For example, observation of the shallow decay phase in the early x-ray light curves of GRBs is ascribed to the dipole radiation of a new born magnetar. The electromagnetic signals of this (NS – NS) merger (i.e., from the remnant) include short gamma ray bursts (SGRBs), kilonova or radio afterglow and possible x-ray emission. As the black hole, in the fall back disk accretion scenario, could also be the cause of x-ray bump and re-brightening GRBs [63], so confirmed identification of the formation of millisecond magnetar from binary neutron star merger is also possible through numerical simulations and observations.

A stable magnetar could be formed from the coalescence of double neutron stars. Thus, the stable millisecond magnetar provides the signal of its formation in radio and optical / ultra-violet bands when the central rapidly rotating magnetar deposits its rotational energy in the form of a relativistic leptonized wind. This means that *the optical transient in the form of short gamma ray bursts (SGRBs), kilonovae (also known as macronova) could be the first and confirmed evidence of the formation of post- merger millisecond magnetar* [64 – 66].

Wang et al [67] proposed another method to search the signature of the post- merger millisecond magnetar formation in the x-ray and gamma ray band. They used the optical / x-ray transients with a gravitational wave (GW), which is not associated with SGRBs. They considered the appearance of Synchrotron Self Compton (SSC) emission as a result of reverse shock when powered by new born millisecond magnetar in the post merger event. The electron in the reverse shock are ultra-relativistic resulting which the Inverse Compton (IC) emission would have an influential effect on the period of the magnetar spin down such that this IC emission will be completely attenuated if the amount of the ejecta mass is $\gtrsim 3 \times 10^{-3} M_{\odot}$. According to them the birth of post merger millisecond magnetar can be detected by gamma ray observation via energy band of 1 and 100 GeV upto the distance ~ 1 Gpc (i.e., red shift z = 0.2) which is within the detectable range for *Fermi* Large Area Telescope (*Fermi* LAT) [68] and Cherenkov Telescope Array (CAT) [69].

6.1 Numerical Simulation Studies

Case 1: In a fully general relativistic numerical study Giacomazza and Perna [39] considered a binary system composed of two equal mass neutron stars of gravitational mass M ~ 1.2 $M_{\odot}$with equation of state (EoS) at high densities and found formation of differentially rotating, ultra-spinning magnetar (as end product) whose magnetic field was amplified by about two orders of magnitude. Gravitational Waves and SGRBs were detected simultaneously.

Case 2: In another simulation study Giacomazzo et al. [40] performed their experiment using fully relativistic magneto-hydrodynamic code "*WHISKY"* and observed formation of millisecond magnetar, leading to large amplification of the magnetic field because of the development of turbulence and instabilities in the interior fluids. They found the amplified magnetic field ~ 10^{16} G was produced in the product (i.e. magnetar) in binary neutron star merger. This large magnetic field corresponds to a magnetic energy in the plasma of ~ 10^{51} ergs that was a rapid production in the moments after the merger onset. Such a powerful electro-magnetic transient i.e. the conversion of a small fraction of the magnetic energy into escaped photon undergoes a violent reconnection in the merger remnant (i.e. new born magnetar) atmosphere that could power electromagnetic explosions in the form of high energy transients associated with SGRBs or even the SGRB itself. This means that if a stable magnetar is formed after merger, only then a long-lasting gravitational wave (GW) emission is possible.

Thus, above two numerical simulations showed the confirmed formation of millisecond magnetar as a product of binary neutron star merger.

6.2 Observational evidences of millisecond magnetar formation

Evidence 1:

Although the dichotomy of GRB consists of long gamma ray burst and short gamma ray burst, a new subclass arises known as short GRB with extended emission (SEE). It appears towards the long period end of the distribution and long GRBs towards the short period end. This isotropic emission's have T_{90}> 2s like the Long GRBs (LGRBs) while their spectral properties are similar to those of SGRBs. The general picture of GRB phenomenology is that a large fraction of x-ray afterglows show a plateau emission in the early phase, followed by a steepening of the light curve in line such that a central engine provides a prolonged energy supply to the plateau. This central engine may be a new born, spinning down neutron star i.e., new born magnetar or fall back matter accreted blackholes, Recently, Li et al [70] suggested a mixed population, (i.e., ~ 20% of the plateaus being consistent with the maximum energy of a neutron star and the rest ~ 80% with a blackhole remnant), of central engine for some GRBs.

Using the best fit values of magnetic field (B) and period (P) for long GRBs plus SEEs in the log – log B – P planes i.e.

$$\text{Log } B = 0.84 + (0.83\ ^{+0.16}_{-0.18}) \log P \quad (3)$$

Stratta et al [71] studied sample of 40 LGRBs and 11 SGRBs and found

a) The environment of proto-magnetar is highly anisotropic;
b) Once a proto-magnetar is formed, then it will preceded by an outflow which will be highly collimated;
c) A magnetar, if born at the center of a collapse, is the main source of collimation type emission energy during both the prompt phase and the afterglow phase.

Their investigation strongly support the origin of the x-ray plateaus are due to the magnetar central engine.

Evidence 2:

*Swift x-ray Telescope (*XRT) observations of GRBs showed existence of plateaus in many GRBs prior the power law decay phase in their early x-ray afterglow. Appearance of these plateaus are, in general, 10 – 1000 s after the GRB trigger with a typical slope (α_1) ~ 0.5. The standard model for GRB after glow two types of plateau namely- (i) "external plateau" which is characterized by a normal decay i.e. observed temporal normal decay slope (α_2) ≤ 1.75 after the plateau, while the other one is called "internal plateau" having a steep decay (α_2)> 1.75 after the plateau. As per our present understanding, the origin of "external plateau" is due to energies injected into the external shock [72] while the internal plateau arises because of continuous supply of magnetic energy through internal dissipation from the central engine. It is argued that the plateau phase would be the evidence for long-lasting activity of magnetar central engines. For understanding this emission efficiency of such magnetars in the x-ray Yi et al [73] made an investigation by analyzing 24 x-ray afterglow light curves those are exhibiting plateaus with steep decays.

They used the known relation of the break time of the inter plateau which is assumed to be the spin down time of a magnetar ($T_{spindown}$) i.e.,

$$T_{spindown} = 3c^3 I / B^2 R^6 \Omega_o^2 = 3 c^3 I P_o^2 / 4\pi^2 B^2 R^6 \quad (4)$$

where $\Omega_o = 2\pi / P_o$ = the initial angular frequency, I = moment of inertia, R = stellar (i.e., magnetar, neutron star) radius, C = speed of light

$$B = (3 c^3 I^2 / 2 R^6 L_{sd} T_{sd}^2)^{½} \quad (5)$$

= the dipole magnetic field of the magnetar,

$$L_{sd} = I \Omega_o^2 / 2 T_{sd} \quad (6)$$

= the spin down luminosity of the magnetar

and $$P_o = \{ 2 \pi^2 I / L_{sd} T_{sd} \}^{1/2} \quad (7)$$

= the initial period

Applying the above equations in the power law relation i.e., $L_x - L_{sd}$ correlation between magnetars and GRBs Yi etal. [73] found the expression of luminosity of x-ray and the corresponding conversion efficiency (η) of rotationl energy into non-pulsed x-ray emission as

$$\eta = L_x / L_{sd} = 10^{-13.56 \pm 1.90} (L_{sd} / \text{erg. s}^{-1})^{0.28 \pm 0.05} \quad (8)$$

It is clearly seen from the above relation that the efficiency η is dependent on the spin down luminosity L_{sd}. But the conversion efficiency of the rotational energy of a magnetar into x-ray emission and its interpretation of x-ray plateaus is not yet known. So, Yi et al. [73] calculated the spin down luminosity, initial period (P_o) and dipole magnetic field strength (B) of the magnetar using eqn. (5), (6), (7) and found

a) the estimated initial spin period ranges 1 – 10 ms which is consistent with the values expected in magnetar model;
b) the dipole magnetic field strength with the range 10^{14} – 10^{15} G which is also consistent with the values of magnetic field of soft gamma ray repeaters (SGRs) and anomalous x-ray pulsars (AXPs) ;
c) comparing with the statistical results [74, 75] for both long and short GRBs their estimated values match with the initial spin period mainly in the range 1 – 10 ms and the dipole magnetic field strength in the range (5 x 10^{14} – 5 x 10^{15}) G for the long GRB magnetars. This implies that central spinning down magnetars could be the power source for the origin of internal plateaus in |GRB x-ray afterglow.

As the magnetar plateau emission efficiency in x-rays matches close to 100% with the central engines of some long GRBs, their conclusive remark is- " the central engines of some long GRBs are millisecond magnetars".

In addition, millisecond magnetars, originating from some binary neutron star mergers, could be a central engine to power the short GRBs.

Evidence 3:

In general, a gamma ray bursts (GRBs) have a shallow decay phase i.e., the plateau phase (no spectral evolution) suggests that the afterglow phase is powered by one of the possible continuous energy sources like (a) long-lived remnant which is originated from gravitational collapse [76] or (b) from a compact object binary merger [77]. It is also expected that the remnant would be in the form of a rapidly rotating, highly magnetized neutron star i.e., a millisecond

magnetar. If this happens, then the nascent neutron star i.e., newly born magnetar would be able to provide continuous energy to the system through stabilizing itself via electromagnetic and gravitational wave emission [17, 78]. As a result, the afterglow luminosity decreases gradually w.r.t. the deceleration of the star over the spin down time scale (τ_{sd}). On the other hand, the efficiency of both electromagnetic and gravitational wave radiations emitted by a new born magnetar (i.e., neutron star) depends on its orientation and triaxiality [79] i.e., inclination or tilt angle (α) between the rotation (Ω) and magnetic (B) axes [80] as well as the strength of internal magnetic field. It is believed that new born magnetar (i.e., neutron star), originated from supernova explosion or collapse of massive stars, possess fast rotation and strong magnetic field. This fast rotation and strong magnetic field affect the shape of the magnetar i.e., newly born magnetar in the form of ellipticity. In the case of new born magnetar (i.e. neutron star) with fast rotation and highly deformed (i.e. high ellipticity) the early time precession of such a magnetar (i.e. neutron star) may the spin down luminosity to some extent on the time scale less than τ_{sd}.

In a study to search the role of the magnetar central engine on GRBs Suvorov and Kokkatas [81] considered the *Swift* XRT data of a long burst GRB 080602 and a short burst GRB 090510. They first estimated the rotational kinetic energy of a new born magnetar (i.e. neutron star) as energy reservoir using the relation

$$E_{rotation} = \tfrac{1}{2} I \Omega^2 \sim 2 \times 10^{51} M_{1.4} R_6^2 P_{-3}^{-2} \text{ ergs.} \quad (9)$$

where $I \sim (2/5) M R^2$ = the moment of inertia for the stellar mass M, radius R and spin period $P = 2\pi/\Omega$.

If it is assumed that the new born magnetar (i.e. neutron star) is an oblique rotator having millisecond period and strong magnetic field ($\sim 10^{15}$ G), then the electromagnetic spin dwon luminosity can be expressed as

$$L_{ElectroMag} = \{B_p^2 R^6 \Omega^4 / 6 c^3\} \lambda(\alpha) \quad (10)$$

where B_p = strength of dipole magnetic field and λ = the orientation of the magnetar which depends on the inclination angle 'α' and the magnetospheric physics. For example, in vacuum the $\lambda(\alpha) = \sin^2\alpha$ which indicates a real perfectly isolated system (i. e, magnetar).

The evolutionary phase of the inclination angle 'α' due precession at a time 't' less than the spin down time τ_{sd} can be expressed as [82]

$$\alpha^{\bullet} \approx k \Omega_p CSc\, \alpha \sin(\Omega_p \times t) \quad (11)$$

subscript 'p' indicates for precession,
where $\Omega_p = 2\pi / P_p$ = the Precession velocity,
$= \epsilon \Omega$ for oblateness due 'ϵ' (i.e. ellipticity),
k = an order unity factor defining the triaxial magnetar (i.e. neutron star) [83].

For Long GRB 080602 case
The observed parameters of GRB 080602 are:

a) The prompt bursts duration T_{90} = 74.7 s at red shift z = 1.82 in the 15 – 350 kev band.
b) The delay between the prompt emission and the afterglow = several tens of seconds i.e. $\geq$ 10s
c) Observed steep decay in the flux until 't' ~ 150s after the onset of extended emission, i.e. after the *swift* Burst Alert Telescope (BAT) trigger.

With the best fit values for the precession model of a canonical neutron star (i.e. magnetar) with mass M = 1.4 $M_\odot$ and radius R = 12 Km, and efficiency parameter $\eta \leq 1$

$B_p / \sqrt{\eta}_{0.5} = 1.02 \times 10^{15}$ G

$$P_o / \sqrt{\eta}_{0.5} = 1.25 \text{ ms} \quad (12)$$

$k = 0.29$, $\delta = -0.46$, $\alpha_o = -0.47$ and $\epsilon / \sqrt{\eta}_{0.5} = 1.45 \times 10^{-4}$

Suvorov and Kokkatus [81] applied on long GRB 080602 as an orthogonal rotator for the first 150 s and found the values

$B_p / \sqrt{\eta}_{0.5} = 7.91 \times 10^{14}$G and $P_o / \sqrt{\eta}_{0.5} = 1.21$ ms (13)

Implying that the significant consequences as the effect of precession:

a) During the first ~< hours of millisecond magnetar's life a natural fluctuation in the radiation luminosity appears due to the magnetic inclination angle α "wobbles".
b) This "wobbling" clearly shows it's presence as damped oscillations in the x-ray fluctuations as seen in the GRB afterglow scenario when powered by energy injection from new born millisecond magnetars.
c) These observed oscillations were consistent with the realistic observed short time variability in GRBs 080602 and 090510.
d) The values of the precession induced expected ellipticities from the newly born millisecond magnetars they obtained, are well matched with that values expected from magnetic deformation [84].

For short GRB 090510 case
The observed parameters of short GRB 090510 were:

1) Prompt emission duration $T_{90} = 0.3 \pm 0.1$ s in the 15 – 350 kev band at redshift z = 0.9.

In this short GRB, using the best fit parameters for precession model

$B_p / \sqrt{\eta}_{0.1} = 5.63 \times 10^{15}$ G, $P_o / \sqrt{\eta}_{0.1} = 2.94$ ms, $\epsilon / \sqrt{\eta}_{0.1} = 9.65 \times 10^{-4}$,
$k = 0.25$, $\delta = -0.51$, $\alpha_o = -0.47$, $M = 2.0 M_\odot$, R = 12 km
they found

$B_p / \sqrt{\eta}_{0.1} = 3.22 \times 10^{15}$ G,

$$P_o / \sqrt{\eta}_{0.1} = 2.48 \text{ ms}, \quad (14)$$

which implies that

a) No impulsive fireball phase appeared,
b) The obtained parameters fit $\approx$ 75 % over the entire data set for precession model,
c) The internal magnetic field strength B_{int} ~< 3 B_p and the magnetic induced ellipticities match same order with that obtained by Mastrano et al [84],
d) The measured ellipticity "ϵ" is unsurprisingly large indicating that the remnant, may be highly deformed and possibly originating from a merger event.

Thus, Suvorov and Kokkatas [81] concluded that their investigation provides

a) Evidences for early time precession in a newly born magnetar, and
b) The origin of which either supernova (for long GRBs) or merger event (for short GRBs).

c) **Conclusively** favors the millisecond magnetars at least in some cases for explaining the extended emission,
d) Evidence of precession in the early phase of a newly born millisecond magnetar which would lead modulation in the X-ray luminosity indicating **triaxiality of the system.**

Evidence 4:

Kilonova observation associated with Short GRB 200522A

It is accepted that magnetars are isolated neutron stars having very strong magnetic fields. But their unique location of formation is debated i.e. the formation of new born magnetar and of its spotted location are not yet observed. Theoretically, various locations have been mentioned as discussed in Sec.3. Recently, Fong et al [85, 86] discovered a radio afterglow and near infrared counterpart of the *Swift* short GRB, now known as GRB 200522A event. It is located at ≈1Kpc from the center of the host galaxy at z = 0.5536. According to Fong [85] - "When two neutron stars merge, the common predicted output is that they form a heavy neutron star that collapses into a blackhole within milliseconds or less. Our study shows that it's possible that, for this particular short gamma ray burst, the heavy object survived. Instead of collapsing into a blackhole, *it became a magnetar*. A rapidly spinning neutron star that has large magnetic fields, dumping energy into its surrounding environment and creating the very bright glow that we see"

This means that a stable magnetar was formed as remnant of NS – NS merger.

Analyzing the observed data of short GRB 200522A Fong et al [86] found the following significant results:

a) GRB 200522A showed itself as a diverse form of observed behavior of short GRB.
b) Kilonovae associated with this short GRBs detected. This detected kilonovae, which is different from others detected kilonovae so far, demonstrates itself as a diversity of kilonovae emission resulting from binary neutron star merger.
c) The x-ray, radio luminosity of GRB 200522A is comparable to that of cosmological SGRBs afterglow.
d) The near infrared (NIR) counterpart (i.e., ≈ 10^{42} erg.s^{-1}) is sub-luminous compare to detected SGRB afterglow but one order of magnitude brighter than so far known kilonovae or kilonova candidate.
e) The near infrared (NIR) excess emission could be a kilonovae that boosted by energy deposition or supply from a stable magnetar remnant or a radioactively powered kilonova.
f) GRB 200522A is originated in the bright region of its host galaxy, with a projected offset of ≈ 1 Kpc from the center (which is closer than 90% of SGRB).
g) The detected near infrared (NIR) counterpart of GRB 200522A may have a diverse counterpart observed in gravitational wave detected binary neutron star merger.
h) For confirmation of the progenitor of GRB200522A, i.e. stable magnetar, observation of late-time synchrotron radio emission is required for a period of 0.3 – 6 years.

7. Ellipticity and Internal Magnetic Field of GRB 130310A

Recently, Zhang et al [87] reanalyzed the observed data of gamma ray burst GRB130310A and its subsequent x-ray plateaus and found the power diverse transient (i.e., expense of magnetic energy) in the form of giant flares and identified it as an hyper flare originated from a magnetar which have age only a few weeks old, located in a nearby galaxy. This magnetar is likely born from an off-axis neutron star binary merger event. Comparing the hypothetical millisecond magnetar parameters with that of the observed galactic magnetar they concluded it was a broader channel of magnetar-powered-gamma ray transient. The concerned magnetar was a millisecond magnetar with period ~ 80 ms.

Assuming the above findings are correct, I have estimated internal magnetic field and ellipticity of this magnetar associated with the GRB 130310A.

Millisecond Magnetar Engines for GRBs

The energy reservoir of a new born magnetar consists primarily of its rotational kinetic energy [81] i.e. from equ. (9)

$E_{rot} = ½ I \Omega^2 \sim 2 \times 10^{52} M_{1.4} R_6^{\,2} P_{-3}^{-2}$ erg

Where, $I \sim 2 M R^2 / 5$ is the moment of inertia for stellar mass M, radius R, and spin period $P = 2\pi / \Omega$.

In the magnetar central engine model for GRBs, the x-ray afterglow following the prompt emission is powered by the injection of energy into the forward shock i.e. the conversion of mechanical energy into radiation energy with luminosity (L)

$$\dot{E}_{rot} = - I \Omega \dot{\Omega} = \eta L \quad (15)$$

where $\eta \leq 1$ is an efficiency parameter.

In the case when the efficiency both electromagnetic and gravitational radiation emitted by a newborn magnetar (i.e. neutron star) is active it (i.e. efficiency) depends on the details of *magnetar's orientation and triaxiality* [88] i.e., mainly on the inclination angle (α) made between the rotation (Ω) and the magnetic (B) axes [80].

The spin down luminosity associated to a neutron star (i.e. magnetar) with polar field strength (B_{pole}) is:

$L_{Electro\ Magnetic} = \{B_{pole}^2 R^6 \Omega^4 / 6 c^3\} \lambda(\alpha)$ (16)

where λ depends on neutron star (i.e. magnetar) orientation through inclination angle (α) and the magnetospheric physics. In general, for an orthogonal rotator model in vacuum with $\alpha = \pi/2$, then luminosity (L) takes the form [81]

$$L\perp = \{B_p^2 R^6 \Omega_0^4 / 6 c^3\} (1 + t / \tau_{spindown}) \quad (17)$$

where $\tau_{spindown} \sim 2.3 \times 10^3$ s x $(M_{1.4} B_{p.15}^{-2} P_{0,-3}^{\,2} R_6^{-4})$ being the characteristic spin down time for birth period $P_0 = 2\pi/\Omega_0$.

This means that GRB afterglow follows a roughly constant plateau phase ($t << \tau_{spindown}$).

The characteristic age of the magnetar is estimated by Zhou et al [89] with the formula

$$T_c \approx P / 2\dot{P} = (2.39 \text{ days}) \times (B_s / 10^{15.5} \text{ G})^{-2} (P / 80\text{ms}) \quad (18)$$

which is about three weeks for nominal parameter. Here B_s is assigned magnetic field strength with 50% uncertainty. $10^{15.5}$ G is the normalized value w.r.t. the magnetic field of a young magnetar which can be high as ~ 10^{16} G [87, 15].

The period of the magnetar associated with GRB 130310A is P ~80 ms which is directly connected to the magnetar (i.e., magnetar) rotation. I now consider the magntic dipole radiation, then the spin down rate $\dot{P}$can be estimatedas [15]

$$\dot{P} = 1.94 \times 10^{-8} \text{ s s}^{-1} (P / 80 \text{ ms})^{-1} (M / 2\ M_{\odot})^{-1} (B_s / 10^{15.5} \text{ G}) (R_s / 10^6 \text{ cm})^6 \quad (19)$$

where M, R_s, B_s are the mass, surface radius and surface magnetic field of the magnetar, respectively. The normalization of M and B_s are:

M by 2 $M_{\odot}$ considering that the magnetar is likely born form a binary neutron star merger, and

B_s by $10^{15.5}$ G, using the observed magnetic field strength of a young magnetar that can be as high as ~ 10^{16} G (or 3.2 x 10^{15} G) [90].

The spin down luminosity ($L_{spindown}$) can be estimated using the formula [87]

$$L_{spindown} \cong 2.35 \times 10^{42} \text{ erg.s}^{-1} (P / 80 \text{ ms})^{-4} (B_s / 10^{15.5} \text{ G})^2 (R_s / 10^6 \text{ cm})^6 \quad (20)$$

Here, Zhang et al [87] found a significant result i.e., the observed peak luminosity of GRB 130310A is higher than the estimated value using eqn (7). This clearly suggest that the hyper flare is not powered by the spin down of the magnetar rather by significant magnetic energy dissipation in the early phase of the life of a magnetar.

8. Magnetically induced effects on Newborn Magnetarin GRB 130310A

The early life of magnetar is far more poorly understood although various phenomena- based models suggest that newborn magnetars have rapid rotation. In previous papers [91,92,93] I have discussed in details the estimation of internal magnetic fields, ellipticity and triaxiality, core cooling of a magnetar (i.e. neutron star). In this paper I make use the formulae and significant results for calculating the strength of internal magnetic field ($B_{internal}$), ellipticity of a newborn magnetar associated with the GRB 130310A for checking its triaxiallity.

Assuming that a rapidly rotating millisecond magnetar (i.e. neutron star) would remain after the explosion of the GRB [94]and the magnetar dipole radiation from the magnetar could generate a flux-dominated outflow to power the x-ray plateau. Observational evidences and theoretical models suggest magnetar with initial period P_0 ~ 1 ms and dipole magnetic field strength B_{dipole} ~ 10^{14} – 10^{15} G usually have the ellipticity (ϵ) ~ 10^{-3} [95] and minimum rotation period ~ (0.3 – 0.5) ms [95, 96].

The best fitting relation between the initial spin period P_0 and the ellipticity ϵ, dipole magnetic field strength B_{dipole} [97]

$$\log \epsilon = 3.79^{+0.52}_{-0.43} + (2.19^{+0.17}_{-0.15}) \log P_0 \quad (21)$$

$$\text{and } \log \epsilon = -22.50^{+2.15}_{-2.22} + (1.29^{+0.15}_{-0.14}) \log B_{dipole} \quad (22)$$

Suggest that

a) Magnetars having a stronger and / or a slower spin period correspond to the large ellipticity;
b) A longer rotation period corresponds to possession of a stronger magnetic field;
c) The neutron star deformation is co-related to its surface dipolar field to some extent.

But argument is raised favoring the strong internal magnetic field i.e., it is argued [98, 99,100] that instead of the dipole magnetic field magnetar (i.e. neutron star) deformation may be induced by a strong internal magnetic field ($B_{internal}$) in the magnetar core through the relation

$$\approx 10^{-8} (B_{internal} / 10^{12} \text{ G}) \quad (23)$$

The above relation hints at the possession of a very strong internal magnetic field (i.e., $B_{internal}$ ~ (10^{16} – 10^{17}) G is needed in order to the ellipticity ϵ ~ 10^{-3} – 10^{-4} as well as the required strength of the internal core magnetic field that should be at least 1– 2 order of magnitude greater than that of the surface magnetic field (i.e., B_{dipole} ~ 10^{15} G). In table I we show the estimated internal magnetic field, ellipticity of the magnetar of GRB 130310A for different values of surface magnetic fields.

Table I: Estimated surface dipole magnetic field, internal magnetic field and the corresponding ellipticity of the magnetar of GRB 130310A.

B_{dipole}	$B_{internal}$	ϵ
10^{14} G	1.2522 x 10^{17} G	1.3 x 10^{-3}
10^{15} G	3.955 x 10^{17}	4.0 x 10^{-3}

8.1. Magnetically induced effects on 73 new born Magnetars in GRBs

Gamma ray bursts, unpredictable and non-repetitive violent flashes of gamma rays, comes randomly from random directions in the sky and have lasting period from ~0.1 s to ~ 1000s [101]. Analysis of observed fluxes and distances suggest that GRBs emit radiation isotropically with the estimated isotropic equivalent luminosity L_{iso} ~ 10^{40} – 10^{47} W i.e., the total isotropic energy output of these GRB events is $E_{iso} \approx 10^{49}$ – 10^{55} ergs. Magnetars are the main power source of these GRBs. Due to randomness it is very difficult to estimate the internal magnetic field strength and their actual age of the GRB associated magnetars. Assuming the spike and the pulsating tail of a giant flare as the main burst Zhang et al [87] estimated the total isotropic energy of the main burst of GRB is

E_{iso} = 2.37 x 10^{49} ergs.

As it is assumed that the released magnetic energy during GRB 130310A event is approximately isotropic energy of the main burst, it will affect in estimating the magnetic field and age of the magnetar. Therefore, following the energy

budget formula, proposed by Thompson and Duncan [24], one can estimate the magnetic field (B) of the magnetar as

$$E_{iso} \sim (B^2 / 4\pi) (\Delta R)^3 \quad (24)$$

ΔR = the typical spatial scale of the magnetar's magnetic field
= 10 Km , taking neutron star's radius.

Now, for the magnetic field (B) , two cases arise:

In the case of high magnetic field magnetars- its dipole magnetic field may be smaller than its total magnetic field (for example, normal magnetar has B = 10^{15} G [102]; for magnetar SGR 1806 – 20 has the highest characteristic magnetic field $B_{charact}$ = 2 x 10^{15} G for explaining the giant flare). But survey of GRB/SN transient [102] hints that these are produced by the millisecond neutron stars having dipole field strength (B_d) ~ 10^{12} – 10^{16} G and initial spin period (P_o) ≈0.7- 10 ms [102]. Putting ΔR = 10 Km and E_{iso} ~ 2.37 x 10^{49} erg in eqn (24) the magnetic field B comes to value i.e. B = 2 x 10^{16} G (i.e., > 10^{15}). This means for normal magnetar, high magnetic field magnetars, the derived parameters from the estimated value of B would provide a higher value than its actual value.

Similar happenings in the case of low magnetic field magnetars (i.e. as low as that of normal pulsars having magnetic field strength ~ 10^{12} G [103, 104].

As the interior magnetic field of compact objects like neutron star can not be measured directly, the natural expectation is the surface magnetic field strength which is as high as the multipole field strength (or total field). Therefore, if we consider the surface magnetic dipole field is as high a B = 2 x 10^{16} G, then using B the derived parameters such as period derivative ($\dot{P}$), characteristic age (τ_c), characteristic magnetic field of pulsars (B_{charac}) will offer us an expected value (not exact value) of these parameters as [105] as:

$$B_{charac} = 3.2 \times 10^{19} (P \dot{P})^{1/2} \text{ G} \quad (25)$$
$$\tau_c = P / 2\dot{P} \quad (26)$$

If one use $B_{charac} \approx$ B = 2 x 10^{16} G then the expected period derivative ($\dot{P}$) and the expected characteristic age (τ_c) are 5 x 10^{-6} s s^{-1} and 2.3 hrs, respectively.

In another way, Zhang et al [87] suggested to normalize the surface magnetic dipole field strength to $10^{15.5}$G (as the magnetic field of a young can be as high as ~ 10^{16} G) and the mass $M_\odot$ to $2M_\odot$ (as the magnetar is likely to born from binary neutron star merger) for obtaining more exact values of the derived parameters (than that of using B) i.e. the characteristic age of the magnetar expressed in eqn (19) as

$$\tau_c = (23.9 \text{ days}) \times (B_{dipole} / 10^{15.5} \text{ G})^{-2} \times (P/80\text{ms}) \quad (27)$$
$$= (23.9 \text{ days}) \times (B_{dipole} / 3.2 \times 10^{15} \text{G})^{-2} \times (P/80\text{ms}) \quad (28)$$

In this study I consider 73 new born magnetars which are associated with the long GRBs, short GRBs, and fall back accreted GRBs and estimate various parameters as shown in table II.

Table II: Millisecond magnetars with their estimated internal magnetic fields, corresponding ellipticities and characteristic ages. (Parameters takes from ref. Stratta et al [71], Zou et al [106], Gibson et al [107], Xie et al [108])

Magnetars in GRBs	TotalIsotropic energy E_{iso} x 10^{51} erg	B_{pole} x 10^{14} G	Initial Period P_o in ms	Internal magnetic field $B_{internal}$ x 10^{17} G	Ellipticity ϵ	Characteristic age	Valifdity of Triaxiallity with $\epsilon \sim 10^{-3}$ - 10^{-4}
Long GRBs							
060605	0.04	32.4	6.5	2.03168	2.03 x 10^{-3}	12.24 day	yes
060714	0.05	50.5	7.5	2.72461	2.72 x 10^{-3}	01 day	yes
060814	0.06	44.0	11.1	3.08	3.1 x 10^{-3}	02 day	yes
060906	**0.009**	**61.0**	**15**	**4.23485**	**4.23 x 10^{-3}**	**1.2 day**	**yes**
061222A	0.2	17.7	31.76	1.1421	1.14 x 10^{-3}	3.7 day	yes
070208	0.001	182	37	0.11488	1.15 x 10^{-2}	02 day	No
070306	0.005	15.0	8.1	1.543178	1.54 x 10^{-3}	11 day	yes
070318	0.04	28	23.7	3.60646	3.6 x 10^{-3}	09 day	Yes
080310	0.02	45	11.9	3.23972	3.24 x 10^{-3}	02 day	yes
080430	0.04	42.0	15.7	3.59502	3.6 x 10^{-3}	03 day	yes
081029	0.04	25	7.6	1.92976	1.93 x 10^{-3}	04 day	yes
081221	0.2	97	6.8	3.59557	3.6 x 10^{-3}	2.2 day	yes
090418A	0.01	31	4.1	1.5783	1.58 x 10^{-3}	1.3 day	yes
091029	0.04	26	7.1	1.90214	0.22 x 10^{-3}	3.2 days	yes
100219A	0.1	9	2.7	0.164316	1.64 x 10^{-4}	10 day	yes
100615A	……	1.1	0.57	0.011085	1.108 x10^{-5}	170 days	No
101024A	……	17	2.30	0.276832	8.754 x 10^{-5}	2.4 day	No
110102A	……	3.6	1.12	0.1058	1.06 x 10^{-4}	26 days	yes
110213A	0.02	45.1	7.0	2.4875	2.5 x 10^{-3}	1.0 day	yes
110422A	0.2	62	8.0	3.11794	3.12 x 10^{-3}	0.6 day	yes
111008A	0.1	16.4	3.1	0.99823	9.93 x 10^{-4}	3.5 day	yes
111228A	…..	2.8	1.38	0.027519	2.75 x 10^{-5}	01 m 24 days	No
120118B	0.004	51	9.1	3.0160	3.0 x 10^{-3}	1.0 day	yes
120324A	……..	3.1	1.02	0.248948	2.45 x 10^{-4}	33 day	yes
120327A	0.3	38	4.6	1.85095	1.85 x 10^{-3}	01 day	yes
120404A	0.08	66	8.2	3.2569	3.25 x 10^{-3}	0.6 day	yes

120521C	0.06	33	8.5	2.3447	2.34×10^{-3}	1.6 day	yes
120811C	0.1	38	5.1	1.9489	1.95×10^{-3}	1.1 day	yes
120907A	**0.04**	**104**	**10.4**	**4.60427**	**4.6×10^{-3}**	**0.3 day**	**yes**
120922A	0.05	37	10.7	2.7856	2.78×10^{-3}	2.4 day	yes
121128A	0.3	68	5.3	2.657788	2.66×10^{-3}	0.35 day	yes
131105A	0.04.	57	11	3.50559	3.5×10^{-3}	01m 08 days	yes
131117A	0.1	47	13	3.46057	3.46×10^{-3}	1.8 day	yes
140206A	1.0	9.3	1.59	0.53835	5.383×10^{-4}	5.6 day	yes
140506A	0.4	15	5.2	1.23644	1.23×10^{-3}	07 day	yes
140512A	0.2	28	5.9	1.79942	1.80×10^{-3}	2.3 days	yes
141017A	……	5.5	1.65	0.42174	4.22×10^{-4}	17 days	yes
160630A	……..	6.3	1.53	0.434654	4.4×10^{-4}	12 days	yes
170113A	…….	2.1	0.64	0.1623	1.6×10^{-4}	01m 14 day	yes
170607A	…….	0.9	1.02	1.3413	1.4×10^{-3}	01y 00m 20d	yes
180626A	**……..**	**5.2**	**1.71**	**4.1747**	**4.20×10^{-3}**	**20 days**	**yes**
180706A	…….	7.2	2.81	0.6297199	6.3×10^{-4}	17 days	yes
060714	1.36	0.21	0.60	0.1571496	1.6×10^{-5}	42 days	No
061121	28.2	2.3	0.58	0.1626984	6.2×10^{-5}	34 days	No
Short GRBs							
051221A	0.002	104	44	9.47045	9.5×10^{-3}	3.25 days	yes
060614A	3.3×10^{-6}	156	111	18.4226	1.9×10^{-2}	01 day	No
060912A	0.01	435	35	17.274	1.7×10^{-2}	0.05 day	No
061201	0.02	206	22	9.4248	9.4×10^{-3}	0.16 day	yes
070714B	0.01	369	35	15.9101	1.6×10^{-2}	0.08 day	No
070809	0.002	58	20	4.76823	4.8×10^{-3}	3.29 days	yes
070810A	**0.01**	**178**	**17**	**7.0127**	**7.0×10^{-3}**	**5.0 days**	**yes**
090428	**0.01**	**212**	**10**	**6.446**	**6.5×10^{-3}**	**0.07 day**	**yes**
090510	**0.02**	**116**	**8.0**	**4.2648**	**4.3×10^{-3}**	**0.20 day**	**yes**
100724A	0.01	235	34	12.5145	1.3×10^{-2}	0.20 day	No
Fall back Accreted LGRBs							
050502B	……..	4.7	4.0	0.60702	6.0×10^{-4}	55.40 days	yes
060124	……	1.65	0.70	0.15046	1.5×10^{-4}	78.66 days	yes
060526	…….	6.6	9.97	1.1356	1.5×10^{-3}	70 days	yes
060904B	……..	7.4	9.94	1.2007	1.2×10^{-3}	56 days	yes
060929	…….	5.51	10.0	1.0392	1.0×10^{-3}	101 days	yes
061121	……	11.5	2.82	0.7972	7.97×10^{-4}	07 days	yes
070520B	…….	10.1	9.79	1.3921	1.4×10^{-3}	30 day	yes
070704	……..	4.3	9.99	0.91758	9.2×10^{-4}	165 days	yes
090621A	……..	4.58	9.99	0.94698	9.5×10^{-4}	146 days	yes
100619A	……..	71.9	1.53	1.46838	1.5×10^{-3}	0.1 days	yes
110709B	……..	1.3	0.69	0.13259	1.3×10^{-4}	125 days	yes
110801A	…….	20.5	8.47	1.84478	1.8×10^{-3}	06 days	yes
110820A	…….	4.8	9.99	9.69463	9.7×10^{-4}	133 days	yes
121123A	……..	15.7	9.77	1.7339	1.8×10^{-3}	12 days	yes
121217A	……	2.9	2.78	3.97511	4.0×10^{-3}	101 days	yes
140817A	…….	8.5	9.46	1.2554	1.3×10^{-3}	40 days	yes
141031A	……	2.6	9.43	0.69320	7.0×10^{-4}	427 days	yes
141130A	……..	9.4	5.35	0.99281	9.9×10^{-4}	19 days	yes
160425A	……..	3.49	9.99	0.82665	8.3×10^{-3}	251 days	yes

It is note-worthy that the correlation ϵ - B_p (i.e., eqn. (22)) suggests that the ellipticities $\epsilon \sim (10^{-3}$- $10^{-4})$ indicate the deformation of this much amount favors the triaxial nature of neutron stars under the very strong internal magnetic field $B_{int} \sim (10^{16} – 10^{17})$ G [30] such that this internal magnetic field (i.e., toroidal magnetic field, as the contribution of poloidal field is negligible [110]) may induce magnetar (i.e. neutron star) deformation to produce large ellipticity $\epsilon \approx 0.016 (B_{int} / 10^{17})^2$.

Several theoretical studies of the maximal ellipticity for multiple equation of state (EoS) for both Newtonian and relativistic stars suggest that a broad range of ellipticities ϵ of neutron star are possible [30, 111, 112]. For a "typical' neutron star the maximum ellipticity $(10^{-6} – 10^{-7})$ seems reasonable [109] This maximum ellipticity can reach $\sim 10^{-1}$ for more exotic states (such as superconducting quark matter) presence in the interior of neutron stars [113].

In a study of searching the continuous gravitational waves from fast pulsars Ashok et al [114] found ellipticity varies 2.7×10^{-4} to 1.5×10^{-8} and half of the considered pulsars have ellipticities $\lesssim 3 \times 10^{-7}$ (that could be sustained by neutron star crust) and the tightest ellipticity (for PSR J0154) bound to 1.7×10^{-8}, which constrains to the well known neutron star crust supported tightest ellipticity $\approx 1.5 \times 10^{-8}$. In another study, searching of quasi-monochromatic gravitational wave signal emitted from the young, energetic X-ray pulsar (for example, PSR J0537 – 6910) shows the

fiducial equatorial ellipticity which constrains for any young pulsar to $\sim< 3 \times 10^{-5}$ [115]

A non-axisymmetric deformation, arises due to magnetic distortion, is sustainable in neutron stars that offer them as potential source of continuous gravitational wave for ground-based detectors. For example, galactic millisecond magnetars, associated with the short and long GRBs, can be used as valuable tools for calibration of ground- based detectors because of its ellipticity is magnetic – distortion - induced, i.e. the value of ϵ may be measured or estimated with certainty from the observational parameters available during the detection of gravitational wave signal. For example, millisecond magnetars are considered as rapidly spinning, strongly magnetized, supra-massive neutron stars. Recent statistical analysis of observed properties of *Swift* short GRBs shows the value of $\epsilon \sim 0.005$ for millisecond magnetars associated in SGRBs. This means that in order to achieve the amount of $\epsilon \sim 0.005$ a millisecond magnetar must have a very high magnetic field strength $\sim 10^{16} – 10^{17}$ G. This implies that the internal (i.e., toroidal) magnetic field of the magnetar may be more than 1 – 2 orders of magnitude stronger than its dipole field strength value 10^{15}G. Investigations regarding the modeling of x-ray plateau of short GRBs, loss of rotational energy dominated by gravitational waves, and mass distribution of galactic double neutron star system indicates that

a) The large value of $\epsilon \sim 0.01$makes it physically difficult to attain, where as
b) The value $\epsilon \sim 0.004 – 0.007$ is marginally constraint with the possible range of ϵ implying that the presence of a triaxial star is physically possible.

This means that for most of long GRBs associated magnetars this ellipticity ϵ is constraint to the value $\sim 10^{-3}$ i.e., for the ellipticities larger than 10^{-3}, the magnetars would lose the significant amount of their rotational energy via gravitational wave emission. For the magnetars in short GRBs the ellipticity of the millisecond magnetars in the range of 0.004 – 0.007 and the dipole magnetic field strength of typically 10^{15} G have a significant physical reality for gravitational wave radiation. In this context, it is suggested that millisecond magnetars only with the ellipticity around $\epsilon \sim 5 \times 10^{-3}$ and dipole magnetic field strength (B_p) $\sim 10^{15}$ G can well explain the distribution phenomena of GRB x-ray plateau and its duration [108].

Neutron stars, in particular rotating neutron stars such as pulsars, magnetars are considered basically as triaxial star having a range of ellipticities $\epsilon = 10^{-1} - 10^{-7}$ and gravitational wave initial frequencies- i.e., frequencies at the beginning of observations ($f_{gw,\ obs}$ = 100 – 3000 Hz) [115]. In this present study, I therefore, limit the calculation of ellipticities in the range 0.004 – 0.007 in order to check the triaxial phase of the millisecond magnetars associated with the Long GRBs, Short GRBs and fall back accreted GRBs. I consider 73 magnetars out of which 54 magnetars are in LGRBs, 10 magnetars are in SGRBs and 19 magnetars are in fall back accreted GRBs. Magnetars of 2 weeks old are in numbered 34 in LGRBs and 4 in fall back accreted GRBs while all the 10 magnetars in SGRBs are of 2 weeks aged. 2 – 4 weeks old magnetars are present by 2number in each LGRBs and fall back accreted GRBs.

Majority of the millisecond magnetars in LGRBs are triaxially deformed within the ellipticity in the range ($0.22 \times 10^{-3} – 9.90 \times 10^{-4}$). In the case of SGRBs ellipticities varies in the range ($1.3 \times 10^{-2} – 9.5 \times 10^{-3}$) with the corresponding interior magnetic field variation (4 – 18) x 10^{17}G while in the fall back accretion case the range of ellipticity and corresponding interior mangetic fields are ($1.0 \times 10^{-3} – 9.9 \times 10^{-4}$) and (0.15 – 9.69) x 10^{17} G, respectively. The significant result found is that 3 magnetars in LGRBs and 3 magnetars in SGRBs have their ellipticities within the range (0.004 – 0.007) with their ages of two weeks and the corresponding internal magnetic fields are (1.9 – 4.6) x 10^{17} G. This means that the neo-natal magnetars 180626A (with ellipticity $\epsilon = 4.20 \times 10^{-3}$, internal magnetic field $B_{int} = 4.1747 \times 10^{17}$ G), magnetar 120907A ($\epsilon = 4.6 \times 10^{-3}$, $B_{int} = 4.6 \times 10^{17}$G), magnetar 060906 ($\epsilon = 4.23 \times 10^{-3}$, $B_{int} = 4.23 \times 10^{17}$ G) in the LGRBs and magnetar 070810A ($\epsilon = 7.0 \times 10^{-3}$, $B_{int} = 7.0 \times 10^{17}$ G), mangetar 090428 ($\epsilon = 6.5 \times 10^{-3}$, $B_{int} = 6.44 \times 10^{17}$ G) and magnetar 090510 ($\epsilon = 4.3 \times 10^{-3}$, 4.26×10^{17}G) in SGRBs have the possibility of being physically existing triaxial stars. In the case of magnetar in GRB 130310A possesses ellipticity $\epsilon = 4 \times 10^{-3}$ with internal magnetic field $B_{int} = 3.95 \times 10^{17}$ G which is within the ellipticity limit range $\epsilon \sim 0.004 – 0.007$ implying that its existence as a triaxial star is physically possible. Thus, it can be inferred from this quantitative analysis that the millisecond magnetar in GRB 130310A was a neo-natal triaxial star.

9. Triaxiality of the Magnetar of GRB 130310A

At the time of discovery on 10th March 2013 the x-ray afterglow plateau of GRB 130310A created a puzzle to the astronomers. Presently, the certainty is that the associated magnetar with this GRB has characteristic age ~ 3 weeks. The follow up observations suggest the following up dated properties:

To date values
Age of the magnetar ~ 9.5 years old
Total energy ~ 2.37×10^{49} ergs.
Afterglow flux ~ 1.02×10^{-12} / 3.04×10^{-6} m Ty
Rotational period ~ 80 ms

It is to be noted that the decay of core magnetic field of the magnetar is to be considered at the high temperature. The temperature of the newborn magnetar core material will be > 10^{9} K [116]. Studies of magnetic field decay in the magnetar core (i.e., neutron star core) [25, 117] hint three separate processes- ohmic dissipation, ambipolar diffusion and Hall drift are involved that affect the evolution and dissipation of the magnetar's interior magnetic fields. As the magnetar core magnetic field is $\leq 10^{18}$ G (which is > 10^{16} G) it is suggested [118, 119] that the ambipolar diffusion in the magnetar's core is expected to be the dominant mode of the interior field decay as far as the early phase of evolution (i.e, ages much less than ~ 10^{4} years) of a magnetar is concerned. The significance of ambipolar diffusion is that it becomes active soon after the formation of a magnetar and can prevent the cooling of the magnetar core below a temperature ~ 10^{9} K for a period of thousands of years (at least 10^{3} years) [31].

Using equations (21), (22) and (23) and with the above parameters as input we calculate internal core magnetic fields and ellipticity of the magnetar of GRB 130310A and found for internal magnetic fields (1.25, 3.95) x 10^{17} G ellipticities are (1.25, 4.0) x 10^{-3}, respectively. In this context, Rizaldy and Sulaksono [116] shows that the balance between the gravity and magnetic field is significantly different for various directions in the case of small mass rather than massive magnetars. Not only that, the gravity pull of the magnetic field on the z-axis is significantly more than for the other axes and as a result, an oblate shape is much less in the case of massive neutron star than in comparison to that of less massive stars. This means the internal toroidal magnetic field is more effective than the poloidal field in magnetar. Even, the deformation associated to the poloidal field (for $B_{polar} \approx 10^{14}$ G and 10^{15} G) and the corresponding correction in ellipticity (which is ~ 10^{-4} – 10^{-2}, respectively) are negligible [120].

Although the recent view [30, 98, 121, 122] of magnetic deformation of magnetars (i.e., neutron stars) arise due to the effect of both the toroidal and the poloidal magnetic fields i.e., a mixed magnetic field, I consider the effect of the toroidal magnetic field only. The main purpose in this study is to check the ellipticity of the new born magnetar and its stability.

In a comparative study of pulsars and magnetars, Heras [123] found the initial magnetic field, in relativistic cases, in the interior of nascent magnetar lies in the range 10^{14} – 10^{16} G. As the ambipolar diffusion is active to prevent both the decay of interior magnetic fields and cooling of the magnetars (i.e., neutron stars as the effect is same and applicable for magnetars as well as neutron stars) such that magnetar core temperature stays higher than several times 10^8 K for a period of a few thousand years (at least 10^3 years). The characteristic age of the newly born magnetar of GRB130310A is only 2 – 3 weeks i.e. neo-natal phase compared to thousands of years.

Recently, Parui [92,93] proposed that the cosmic baby i.e., Swift J1818.0-1607 wouldbe a triaxial star. In table IIII tabulate the estimated internal magnetic field and ellipticity of the newly born magnetar of GRB 130310A with the parameters of cosmic baby and three other magnetars which are less than 1000 years old and their ellipticities are in triaxial nature.

Table III: Various parameters of five Magnetars exhibiting their triaxial phase (parameters taken from Parui [93, 94])

Name of Magnetars	Spin Period (P)	Surface dipolar magnetic field (G)	Age	Intenal core magnetic field ($B_{internal}$)	Ellipticity (ϵ)	Condition fulfilled for exhibiting Triaxial phase	Inferrence
Magnetar of GRB 130310A	80 ms	10^{14} - 10^{15}	2 weeks	3.95 x 10^{17}	4.0 x 10^{-3}	Satisfied	Possibly be a Triaxial Star
Cosmic Baby Swift J1818.0 - 1607	1.36 s	2.7 x 10^{14}	240 years	8.5 x 10^{17}	4.48 x 10^{-3}	Satisfied	Possibly be a Triaxial Star
SGR1806-20	7.547s	20 x 10^{14}	240 years	54.39 x 10^{17}	5.439 x 10^{-2}	Satisfied	Exhibiting the Triaxial phase
1E1547.0-5408	2.0721 s	3.2 x 10^{14}	690 years	11.4 x 10^{17}	1.14 x 10^{-2}	----------	Near the end of the phase
PSRJ1846-0258	0.3265 s	0.49 x 10^{14}	730 years	1.77 x 10^{17}	1.77 x 10^{-3}	----------	Near the end of the phase

The estimated internal core magnetic field and ellipticity of the magnetar of GRB130310A are ranging (1 – 2) x 10^{17} G and (1 – 4) 10^{-3}, respectively, which are less than that of the cosmic baby, i.e. Swift J1818.0 – 1607. For GRB 130310A the age of the magnetar is 2 weeks only i.e., very very less than the cosmic baby's age, whereas the spin period (i.e., 80 ms) is superfast than the spin period of cosmic baby (i.e. 1.36 s). It is seen from the table III that associated newly born magnetar of GRB 130310A satisfies the conditions for becoming a triaxiality star i.e., internal core magnetic field, ellipticity and minimum rotation period should be ~ 10^{16}–10^{17}, ~ 10^{-3} – 10^{-4}, and ~ 0.3 – 0.5 ms, respectively. In this case, it has also been fulfilled that the core magnetic field should be 1 – 2 order more than the surface magnetic field. As the associated magnetar is only 2 – 3 weeks old, it is expected that it would exhibit its triaxiality property almost for a period of 1000 years. We thus propose that the new born magnetar associated with the GRB 130310A was a "Triaxial magnetar" or precisely, a "Neo-Natal Triaxial Star".

10. Conclusion

Millisecond magnetars produced in the center of dying massive stars or in the binary merger of neutron stars are one of the prominent models to power gamma ray bursts (GRBs). Unlike radio pulsars, canonical neutron stars, magnetars do not have enough rotational energy to power their emission. So, the energy reservoir must be magnetic.

The existence of magnetars in our galaxy and direct observations of AXPs and SGRs flaring events from these sources suggest that they are neutron stars with dipole fields ~ 10^{15}G. Magnetar like flare events confirmed the central engine of these events to be magnetars with strong dipole magnetic field of~ 10^{14} – 10^{15}. Majority of the observational evidences support for the possible presence of a newly born magnetar as the central engine for both long and short GRBs. This means the possibility that all GRBs are powered by magnetars. But the central engine remains hidden from direct electro-magnetic observation.

A magnetar, straight after birth, is a fluid body and as the star cools its crust only freezes later. Thus, the star's internal magnetic field $B_{internal}$ provides a certain "rigidity" to the

fluid that manifested in the fact that it can induce some distortion (i.e., ellipticity ϵ) to the star [32]. To explore the effects of the surface dipolar magnetic field, rotation on the progenitor and the new born magnetar I estimate the interior core magnetic field strength and the ellipticity of the newly born magnetar associated with the GRB 130310A. The correlation of ϵ - $P_0$and ϵ - B_P suggest that the magnetar with a stronger magnetic field and / or a slower spin period corresponds to the larger ellipticity. Again, for most of large GRB models the ellipticity is constrained to ~ 10^{-3}, which means that the magnetar would lose significant rotation energy via gravitational wave emission if the ellipticity of the magnetar is larger than 10^{-3}. Again, statistical properties of short GRBs indicated that only the ellipticity and dipole field strength of magnetars valued ~ 5 x 10^{-3} and B_{dipole} ~ 10^{15} G can re-produce the distribution of GRB x-ray plateau and duration [124]. In the case of millisecond magnetar (of 2 weeks old) in GRB 130310A it possesses, as calculated, ellipticity $\epsilon = 4.0 \times 10^{-3}$, internal magnetic field strength B_{int} = 3.955 x 10^{17} G which are within the limits of ϵ (i.e., 0.004 – 0.007), B_{int}(i.e., ~ 10^{17}G) for exhibiting as aphysically existing triaxial star it is therefore suggested that this magnetar associated with the GRB 130310A was a "neo-natal triaxial star".

The ellipticity of the magnetar depends on the deformation mechanism and gravitational wave may be the ultimate probe into the central engine. Weak gravitational wave radiation may be produced by the new born magnetar due to its deformed structure although the GW radiation from a new born magnetar has still not been detected by Advance LIGO and VIRGO detector [125]. As the rotational period of the newly born magnetar associated with the GRB 130310A is ~ 80 ms and the frequency of the emitted continuous gravitational waves would be low [126, 127] this author encourages the Gravitational Wave Community to observe this neo-natal Triaxial Star continuously during their observation of compact objects as well as magnetar of this GRB by electromagnetic counterparts through Advanced LIGO and VIRGO.

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Data Availability
Data sharing is not applicable as no data sets were analyzed.

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