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Cosmic Baby and the Mystery of Fast Radio Bursts

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Abstract

With the discovery of "Pulsar" a new probe of short duration radio pulses arises to the astronomers. Searching the "tomography" of the galaxy using the short-pulses offered a new method to measure the fairly accurate distance to the new sources of pulse radiation i.e. Pulsars. Another pulse radiative object i.e. fast radio burst (FRB) remains a mysterious object till today. Analysis of observed data indicates that FRBs have multi-source origin, variation in location of the burst generation (i.e. radial distance from their central compact objects, the Magnetar's surface) depending on model to model. Two most important puzzle creating facts of FRBs are: (a) microstructure appearance in FRBs on time-scale of ≤ 10 μs; (b) No FRBs observed at low latitudes.
Recoding of observed parameters from Cosmic Baby, i.e. Swift J1818.0 – 1607, shows that it has a steep spectra at first and then flat spectra later which indicates possibly be a transient object between normal pulsars and magnetars. This unusual characteristic of radio spectrum provides a clue to rethink about the magnetar origin of FRBS. i.e. Cosmic Baby can be a probe of resolving the mangetar originated FRB problem.
The author thus encourages the radio wave burst community for continuous observation through advanced radio telescopes ALMA, VLA, CHIME, UTMOST with a hope that detection of unseen FRBs at low latitudes unveil the secrets of the Universe.

Keywords: Pulsar; Magnetar; Radio-pulses; FRBs

Abbreviations: FRB: Fast Radio Burst; ASKAP: Australian Square Kilometer Array Pathfinder; CHIME: Canadian Hydrogen Intensity mapping Experiment, FAST: Five hundred meter Aperture Spherical radio Telescope; GRBs: Gamma Ray Bursts; SLSNe: Super-Luminous Supernovae.

Introduction

Before the Dawn of the 2020s

In 1967 Summer time, radio astronomer Hewish A, et al. [1] and his graduate student Jocelyn Bell (who is persuing her Ph.D.) were observing the scintillation (twinkling) of stars, particularly quasars through the specially designed radio-telescope in Cambridge University, UK [1]. They observed an unusual signal at a wavelength of 3.7 m — a sharp burst of radio energy at a regular interval of about one second. After thorough analysis they found these signals were not like signals from our known sources such as stars, solarwinds, and galaxies. According to Bell who noted the observational data, she realized that this unusual reading (called it "Scruff") was regular at an interval of every 1.3373011 second synchronizing with sidereal (star end) time but not Earth time. They suggested that the signal was "Extraterrestrial"- might be a message sent by the intelligent beings from another world?

In continuing her research observation for another source Bell also fund another pulsing signal, which was slightly different from that of the earlier observation one, having a pulse of 1.2 second inverval coming form other side of the sky. These two differences which as extremely unlutely, made them puzzle with a thought the the source was intelligent beings.

Looking into theoretical perdiction put forwarded by Robert Oppenheimer and Fritz Zwicky in the 1930's that when a massive star died, it would collpase — leaving a remnant of an incredibly dense, spinning body named Neutron Star (name was as it is made of 'neutrons') they finally concluded that

- the detection was the first evidence of neutron star;
- the pulsating signal source became known as a "PULSAR" because spinning pulsar's radio emission was perceived in pulses.

The discovery of pulsars stimulated the astronomers to see the Universe in a different look. Advancement in observation technology and theoretical works gave an impetus to search the secrets of the universe.

At the Dawn of the 2020s

The detection of neutron stars in the form of pulsars offers an opportunity to the astronomers to search supernovae explosions, expansion of supernovae shells via the coherent short duration of radio pulses [2-4]. Several decades later, i.e. by the year 2000 searching the "tomography" of the galaxy using pulse radiation astronomers were capable to measure the fairly accurate values of the distances to the new sources of pulse radiation i.e. pulsars.

On 24th July 2001, the Parkes 64 m Radio Telescope (in Australia) detected a bright, dispersed radio pulse. But this detected signal remained unnoticed for several years till 2007. As the detection of the first pulsar gave an opportunity to search the other pulsars through their bright, single pulse, the studies of single pulse therefore allow the astronomers for further knowledge of pulsars. As a continuation of this single pulse search Lorimer D, et al. [5] and his group were searching the archival records of bright dispersed radio pulses, detected by Parkes Radio Telescope (in Australia) on the 24th July 2001, and suddenly noticed the detected signals (which were unnoticed), re-analyzed the observed parameters and found that

- a similarity in appearance, i.e. the unnoticed signal have an appearance similar to the individual pulsar's pulse [5].
- These signals possess a large dispersive delay.
- The large dispersive delay means these signals are originated from a far outside our own galaxy, the Milky Way.
- The original luminosities of the detected signals were many more orders of magnitude.

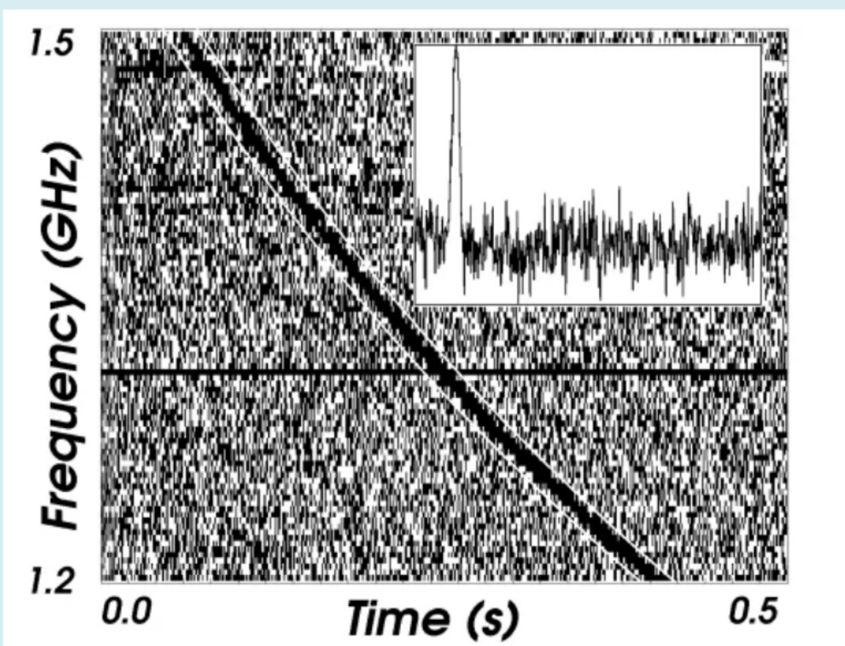

Figure 1: The Lorimer Burst in the radio profile of the first Fast Radio Burst. The smearing of the signal across frequencies hints at its extragalactic origin. The inset box shows the time sequence of the signal strength at one frequency, corrected for the dispersion. (adopted from Lorimer, et al. [5] and courtesy the Planetary Society).

This unnoticed signal is now known as Fast Radio Burst i.e. FRB010724 (also known as Lorimer's Burst. See Figure 1).

What is causing mysterious bursts of radio waves from the deep space? This question puzzles the astronomers for finding the answer. As a possible solution astronomers thought as "an ejection from a magnetar" that would have caused its rotation to slow. Because it's strong twisted magnetic field lines can influence the flow of electrically charged materials from its magnetosphere.

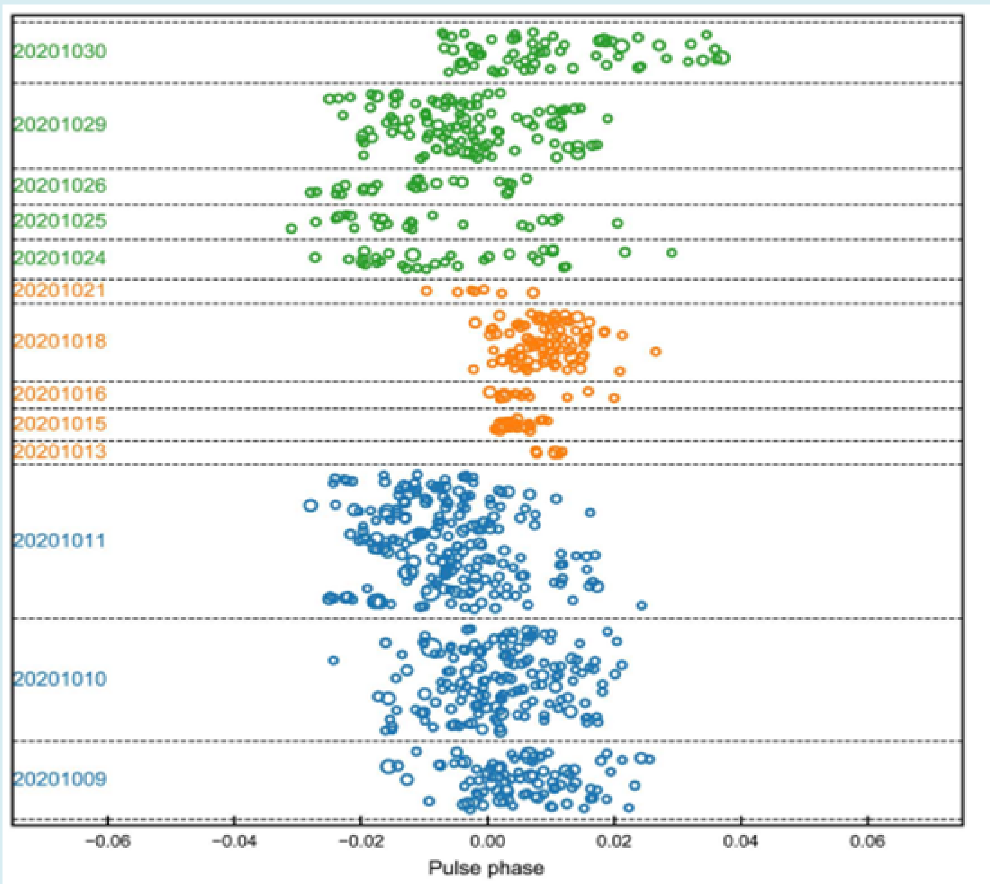

Figure 2: A plot of spin phases of the radio pulses (emitted from SGR 1935 + 2154) detected by the FAST telescope during October 2020. Signal to Noise (S/N) of these pulses is represented by the size of the marker. Three emission phases are separated by three different colors indicating the pulse phase distribution is different (adopted from Zhu W, et al. [6]).

NASA sent two x-ray telescopes , i.e. NICER (Neutron star Interior Composition Explorer) and NUSTAR (Nuclear Spectroscopic Telescope Array), in space in particular to zoom in on dead, old stars to observe their erratic behavior such as release of bright bursts of radio waves. The origin of all the known FRBs was in faraway galaxies. A break-through appears on 28th April 2020 when astronomers detected a mysterious, fleeting flashes of radio waves (known as FRBs) from a highly magnetized neutron star (or magnetar), SGR 1935 + 2154, situated very near our own galaxy (Figure 2).

As per estimation it was known that this magnetar will repeat its burst next time in Oct 2022. This time what the astronomers saw:

A neutron rotates by virtue of a "hot spot" on its surface which looks like one of the poles of the star's magnetic field. Duration of this hot spot was once ever 3.2 seconds i.e. the hot spot of neutron star spins in and out of view once ever 3.2 seconds only and this brightness appears as pulse detected by the detector in NICER.

As the temperature of the hot-spot is very high, so the x-ray emission from this hot spot is hot than the other x-rays coming from charged particles writhing in the neutron star's strong magnetic fields (Figure 3). As a result, within hours in the detector of NUSTAR astronomers watched a neutron star glitch - i.e. suddenly neutron star started spinning faster (so called First glitch). 4 hours later astronomers watched the second glitch [7].

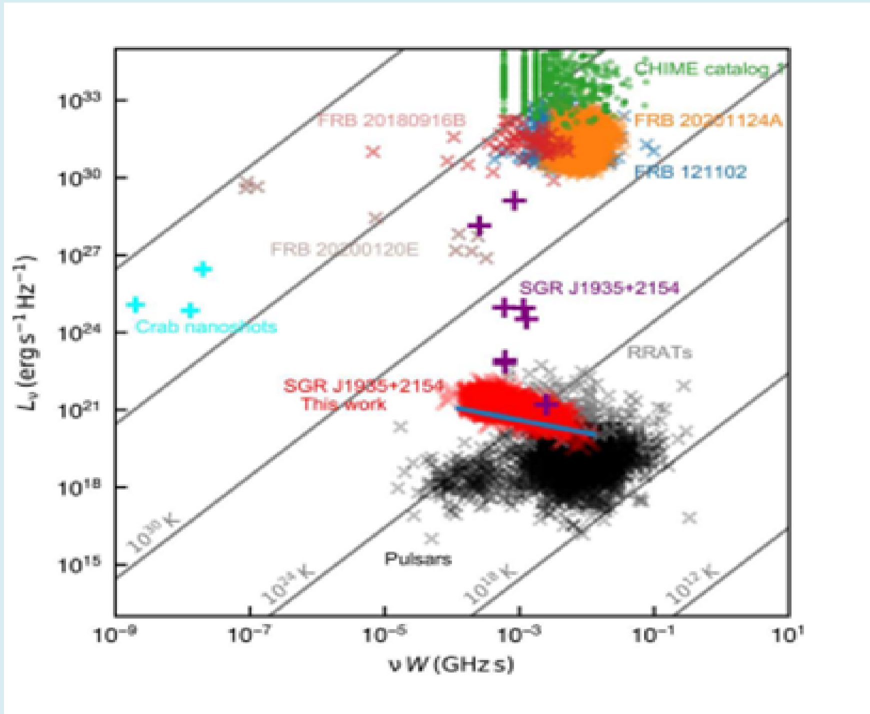

Figure 3: Comparison of various radio emissions from SGR 1935 + 2154 with emission from other sources. Y-axis represents radio luminosity while x-axis for the product of frequency (ν) and width (w) of radio emission (burst / pulse). Note that thick red crosses denote the single pulse of SGR 1935 + 2154; blue lines position of the detection threshold for FAST observation; purple plus for radio bursts from SGR1935 + 2154 (adopted from Zhu W, et al. [6]).

Analysis of the glitch parameters hints that during the glitches, the characteristic of the spectra showed that the x-ray were largely coming from the “hot-spots” while leading up to and driving the radio burst, in the interval between two glitches, the emission was from the particles that were magnetically trapped in the magnetosphere. In other words, the radio pulsar phase of the magnetar SGR 1935 + 2154 provides first time the possible clues to magnetar FRB mechanism.

Till today, a large number of FRBs are identified and analysis of their observed parameters showed that most of the FRBs appear as a single burst i.e. one off, few appear as repeated i.e. two sources. However, main unsolved issue remains today is:

What is the exact origin of the FRBs? This means that the origins of the FRBs are still unknown and the present source –class is based only on observation basis.

What is Fast Radio Burst

Primarily, the fast radio bursts are mysterious millisecond duration transients in the domain of radio-sky implying that a fast radio burst (FRB) is a transient radio-pulse of length ranging from a fraction of a millisecond; whereas an ultra-fast radio burst (u-FRB) possesses pulse length of 3 seconds [8].

In brief, the bursts are bright, unresolved (i.e. like a point source) broadband, millisecond flashes which implies that these bursts are looking like a single spike of energy that are coming from all the direction of the sky without any change in its strength over time.

Origin / Source of the Fast Radio Bursts

In the above we see that the FRB signals are coming from all directions over the sky and most of the FRBs are extragalactic. Polarization measurements of these FRBs hints that the origin of these bursts may be from a rapidly rotating neutron star, or a black hole or an extraterrestrial intelligences, including binary compact objects mergers and also magnetars arising from the normal core collapse supernovae [9,10].

In Table 1 various FRBs with their possible origins are shown. From this table it is clear that origin of FRBs are multi-sources. But recent observation emphasizes magnetars as one of the most promising source of FRBs because they are neutron stars with extremely high magnetic fields ≥ 1014 G and above as well as exhibiting various x-ray phenomenon like sporadic sub-second bursts, long-term duration of flux enhancement and variable rotation period derivative [11-13]. However, recent detection of a FRB [14,15], originated from the Galactic Magnetar SGR 1935 + 2154 confirms the idea i.e. the association between some FRBs and Magnetars [14-18].

Name of FRBs	Observed Parameters	Location of Bursts	Source Characteristics /Origin of Bursts.	Reference
FRB010724	3^{o}Jy dispersed bursts	3^{o} from the Small Magellanic Cloud	Source was a singular event like supernova or merger of relativistic objects (Extra-Galactic origin)	Masui K, et al. [19]
FRB 110523	Archival data of Green Bank Telescope collected in 2011. Signal's dispersion delay	First FRB having linear polarization	(Extra-Galactic origin)	Totani T [20]
FRB121102	Signal's dispersion delay (Plasma Dispersion)	Direction Auriga in northern hemisphere	Origin in a young rotating neutron star, Pulsar or Magnetar or Roche lobe overflow in a neutron star white dwarf (NS-WD) binary. (Extra-galactic origin)	Overbye D [21], Jodrell Bank [22]
FRB 140514	Dispersion Measure (DM) = 562.7 pc./cm. Circularly polarized	_	(Extra-galactic origin)	RAS [23]
FRB150418	Apparent radio afterglow of flash	_	The afterglow was originated from an Active Galactic Nucleus (AGN) that is powered by a supermassive Black hole with dual jets blusts	HSCFA [24]
FRB180916	_	_	Originated from a medium sized spiral galaxy SDss J01580.28 + 654253.0 about 500 million light year distance	Boyle PC [25]
FRB180924	_	_	Source is a galaxy (nearly as large as Milky Way galaxy) active side is likely a place for magnetar , an older and less active galaxy. (Magnetar origin)	Bannister KW, et al. [26], Clery D [27]
FRB190520	Dispersion Measure	_	Dense, magnetized and turbulent environment	O'Callaghan J 2019 [28]

FRB190523	Non repeating burst	Located to a few arc second region containing a single massive galaxy at a redshift 0.66	Extra-galactic origin	Ravi V, et al. [29], Mack E [30]
FRB20190502B	Multiple bursts		Source having Magnetic Field Reversal	Cosmo [31]
FRB200120E	Repeated bursts		A grand design spiral galaxy M81 about 12 million light year away	Starr M [32], Kirsten E, et al. [33], Bharadwaj M, et al. [34]
FRB200317A	Archival data		One of the faintest FRB source	Snaping Y, et al. [35]
FRB200428	Bright radio burst, DM of 332.8 pc/cc. -----Had a fluence of > 1.5 MJy ms.		Galactic Magnetar SGR 1935+2165 about 30,000 light year away. Claimed that source is inside Milky Way galaxy, Link sharply support that FRBs emanate from magnetars (Magnetar origin within our Milky Way Galaxy)	Scholz P, et al. [36], Zhang SN, et al. [37,38], ESA [39]
FRB200610			Rare Hob-like group of galaxies	Strickland [40]
FRB201124	Extremely bright pulse		May originate from a magnetar/ Be star binary. (Magnetar origin)	Wang FY, et al. [41], Ferreira B [42]
FRB210401	Very high burst activity		This bursts a repeating i.e.repetition of FRB20201124A.	Kumar P, et al. [43]
FRB 220414	A bright burst with signal to noise ratio i.e. S/N ~ 15 for ~ 2.2 ms duration		(Extragalactic origin)	Yu Z, et al. [44]
FRB221206			Possibly detection of a magnetar originated gamma ray burst at or near the same time and location as FRB was detected (Magnetar Origin)	Younes G, et al. [45]
FRB240114A	Three repeated bursts		Associated with a galaxy cluster at 425 MPc away	Shin K, et al. [46], O'Connor B, et al. [47]

Table 1: Various FRBs with their observed parameters , location of the bursts and possible sources.

Physical Mechanism of FRBs

Observational data, obtained from various observatories such as Parkes Radio Telescope (in Australia), ARECIBO (in USA), Green Bank Telescope (in West Virginia, USA), Australian Square Kilometer Array Pathfinder (ASKAP), the Canadian Hydrogen Intensity mapping Experiment CHIME [16], the Five hundred meter Aperture Spherical radio Telescope (FAST) (in Guizhou, China) provide some important typical facts of FRBs :

- Duration → FRB duration or width (w) is few milliseconds implying the characteristic length scale of the engines that power the FRBs is length ≤ 3 x 107 cm x (w / ms). This hints towards the most compact objects i.e. a magnetar (i.e. neutron star) or a stellar mass black hole [48].
- Repetition → For more than 20 FRBs which are repeated implying that it can be speculated that the majority of the FRBs are repeaters [49,50] although apparently non-repeating FRBs [51,52].
- Periodicity → In the case of repeating source, FRBs with a period of ~ millisecond to seconds indicate that they are originated from neutron stars. But flux variation with time with a mean flux density ~ 190 μJy suggest that such FRBs are associated with a bright steady source i.e. this type of special sources are possible when it is a young magnetar wind nebula or near a supermassive

black hole [53,54].

- Multi-wavelength Counterparts→ During the follow-up observation of FRBs no “afterglow” like emission is seen which is consistent with the theoretical prediction [55]. But observation in the case of FRB 200428 associated with Galactic magnetar SGR 1935 + 2154 detected a hard x-ray / soft γ-ray burst [56-58]. This was, therefore (i) only certain / confirmed counterpart against that of non-detection cases [58,59], and (ii) it unambiguously established the fact that magnetars as the source of at least some FRBs [56,57].
- Spatial Distribution → The observed facts showed that the directional distribution of FRBs and the cosmological origin of FRBs both are consistent with being isotropic in nature [60].
- Luminosity / Energy Function → For both the cases (whether repeating or non-repeating) the global luminosity / energy function of FRBs are consistent following a power law function [61,62].
- Event rate density → Covering the whole sky observation it was found that the observed FRB event rate is roughly ~ several thousands per day implying that the event rate density of FRBs reaching about 3.5 x 104 GPc – 3 yr – 1 which is approximately > 1042 erg.s- 1 [62,63].
- Host Galaxy → As mentioned earlier that FRBs are multi-source associated. This means that the types of host galaxy and the local environment of most FRBs are not consistent in comparison to those FRBs associated with long GRBs and super-luminous supernovae [64,65]. Observational data analysis also suggests that the data are consistent when the magnetar engine scenario model of FRBs are involved with both the normal magnetar as well as the magnetars born of either gamma ray bursts (GRBs) or super-luminous supernovae (SLSNe).

Role of Magnetar’s Magnetosphere towards the FRB – Magnetar Connection: Astronomical compact objects, such as neutron stars, pulsars, magnetars, white dwarfs possess magnetospheres where plasma density exists under extreme conditions. Under such high density, the quantum degeneracy becomes important in such systems implying that the electron thermal speed may reach a value close to the speed of light in a vacuum [66]. In fact, a dense stellar plasma consists of predominantly electrons, positrons and ions which are under the influence of star’s magnetic field where perturbation creates shocks solitary profiles for magneto-acoustic Waves [67,68]. Not only that, mass and energy transport in helio-spheric environment, plasma turbulence, magnetic reconnection, particle acceleration, etc. are also play key role in understanding the phenomena like FRB, GRB, X-ray emission, etc [69,70].

Magnetars have twisted magnetosphere compared to that of normal pulsars, neutron stars i.e. the magnetic fields of normal pulsars may be in the form of mainly dipole with no twist and that can be considered as the ground state of the magnetic field configuration whereas magnetic fields of magnetars may be a twisted dipole, plus some local twisted magnetic field [71,72]. Significance is that this twisted magnetic field has free energy compared to that of with a dipole field. In other words, the release of this magnetic free energy may be responsible for the burst as well as multi-wave emission of the magnetars [73-75].

Radio emission from the magnetars provides a link between magnetars and normal pulsars. till date 31 magnetars have been detected. Out of these only 6 magnetars i.e. i) XTE J1810 – 197 [73] (first radio emitting magnetar and first transient magnetar) [74], ii) 1E 1547.0 – 5408 [75], iii) PSR J1622 – 4959 [76], iv) SGR 1745 – 2900 [77], v) SGR 1935 + 2154 [6], vi) Swift J1818.0 – 1607 (now known as Cosmic Baby) [78]. Analysis of the observed parameters received from the first radio emitting magnetar XTE J1810 – 197 [73], and others hints that

- Radio emissions from magnetar have a flat spectra;
- These emissions are highly variable such as flux, pulse profile, timing, etc.;
- They are transient i.e. disappear during the out burst decay while revive during the next out burst.

These characteristics are not similar in the case of Cosmic Baby i.e. magnetar Swift J1818.0 – 1607 [78]. Recoding of the observed parameters shows that cosmic baby has a steep spectra at first and then flat spectra later indicating possibly be a transient object between normal pulsars and magnetars where as a bright and narrow single pulse and flat polarization angle is similar to other magnetars and that of FRBs [79,80].

Radiation Emission: Based on most of the above mentioned observed properties of FRBs various models, such as reconnection generated FRB in the neutron star magnetosphere model [81], coherent curvature radiation near the neutron star surface model [82], shock model [83], and magnetosphere model [84] have been proposed. But it is very difficult to differentiate these models because flavors of each model are able to explain to-date most observation facts. However, two important models among these are shock model proposed by Metzger BD, et al. [83] and magnetosphere model by Lu W, et al. [84] (Figure 4).

In these two models, like the other two models also, an energetic neutron star or magnetar progenitors are situated around the center but the location of emission are placed at different.

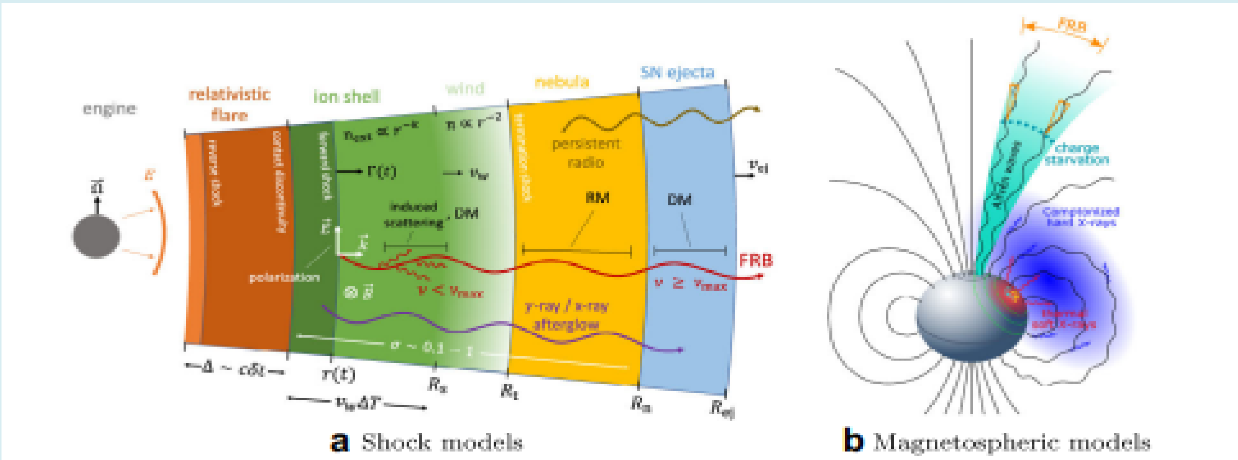

Figure 4: Schematic diagrams of two different FRB emission models : (a) a Shock model from Metzger BD, et al. [83] where the FRB is produced at large radii from the compact central engine (e.g., a magnetar or black hole)., and (b) Magnetosphere model from Lu W, et al. [84] where the FRB is produced in the neutron star magnetosphere. (Figures adopted from Zhang B [60]) radial distances from the surface of the star, i.e. different site of emission. In the earlier two models the side of emission is at a radial distance of ≤ 10 4 km, where as in other two models the FRBs are generated through synchrotron MASER emission at a radial distance ≥ 105 km [83].

Another constraint arises from recent observations regarding the microstructure appears in FRB pulses on time scales < ~ 10μs. In this case the radial distance (R) from the central compact object is R ~ 10 5 km with Lorentz factor (Γ) ~ 10, radiative efficiency (ζ) ≤1 showed the minimum time scale for emission is Δt ~ 10 μs [5,60]. This implies that for variation on time scale of emission shorter than 10 μs (i.e. < 10μs) it is very difficult to explain the generation of FRBs at large radii from the central compact object as per proposed model of FRBs

Another strongest constraint on progenitors arises in the case of observed repetition of some FRBs [5] which is still remain an open question.

It is expected that in the future the detection of a direct association of an FRB event may possibly provide a clue to solve the above mentioned problems [5].

Modeling of FRB with Magnetar as Central Engine: As discussed above in all models the actual source and its location is not yet known. Various models of FRB source engine, like Kashiyama and Margalit B, et al. [54], Murase K, et al. [85], Waxman E [86], have developed based on the observed parameters, yet magnetars play a crucial role among them. Because young, rapidly rotating magnetars, as central engines, involves in a diverse set of transient astrophysical phenomena such as gamma ray bursts (GRBs), superluminous supernovae (SLSNe), fast radio bursts (FRBs) and binary neutron star merger (BNS).

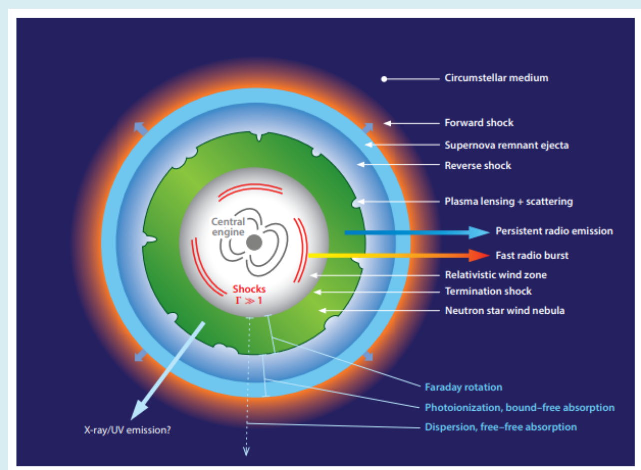

Figure 5: Schematic diagram of an FRB source engine with a young, highly magnetized neutron star,i.e. magnetar developed by Margalit B, et al. [54]. (Figure adopted from ref. Cordes JM, et al. [87] and Metzger B, et al. [83]).

Figure 5 shows the model of an FRB central source engine associated with a young, spinning magnetar. Possible features of FRBs generated in this model proposed by Margalit B, et al. [54] are shown by labeling with arrows. The magnetar, as central engine, is located at the center and an expanding cloud of supernova ejecta material creates an envelope where spin down and / or magnetically driven wind shocks ultimate produce a hot nebula (green). Different emission lines, like UV and x-ray radiation from this nebula, then photo-ionizes the ejecta. This ionized, created by the forward and reverse shock ultimately creates the circum-stellar medium (CSM). On the other side FRB or synchrotron radio emission generated within or inside the nebula suffers dispersion and free-free absorption travelling to the observer through the ejecta. This FRB also faces scattering and Faraday rotation while passing through the magnetized nebula. Recent FRB model is shown below in Figure 6.

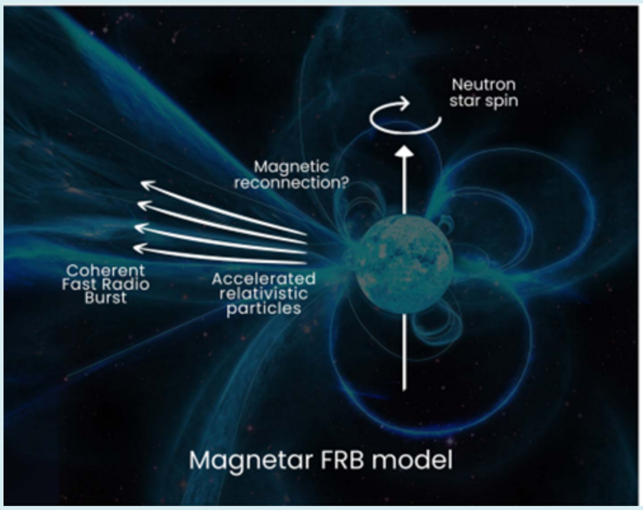

Figure 6: Recent Magnetar FRB Emission model shows the generation of FRB with the indication of reconfiguration of the intense magnetic fields around a magnetar and release of relativistic particles that generate coherent radio emission in the magnetosphere, possibly in the form of FRBs. (Adopted from Cordes JM, et al. [87]).

FRBs and the Unsolved Problems that Answer we Need with Future Observations

It is now known that FRBs are millisecond flashes of radio waves coming from distant astronomical sources. First FRB (now known as Lorimer burst) was discovered in 2007 [5]. More than 15 years have passed few hundreds of FRBs have been detected. Among them some are repeaters while most of them are non-repeater. Origin of FRBs are multi-sources with un-cleared actual origin sites. Association of FRBs with gamma ray bursts (GRB) does not fully known but with magnetars some FRBs are linked certainly.

However, some important unsolved on FRBs are listed below:

- Why FRBs are multisource origin?
- Location of generation of the FRBs from the central compact object's surface — For shock models this radial distance is ≥ 105 km while that of for magnetar's magnetosphere model ≤ 104 km. Why this difference?
- FRBs and Lesson from SGR 1935 + 2154 - Recently detected Galactic Magnetar SGR 1935 + 2154 having radio burst of a MJy–ms offers the astronomers to think in a new way for exploring the FRBs – Magnetar connection. Follow-up observations of nearby, bright FRBs of fluence ≥ 10Jy – ms through the advanced, sensitive telescope like FAST, GBT, SKA shows the detection of the lower fluence after-shocks whereas radio burst (FRB similar spectra for FRB202001) of SGR 1935 + 2154, observed through CHIME, shows double peaked and perhaps upward drifting in frequency. What is the reason behind it?
- Emission Physics — What is the shortest time scale structure in FRB-bursts? How do the polarimetric properties change with frequency?
- Progenitor configuration — Variation in their activity for all repeating FRBs follows a periodic manner (?) i.e. "Does different repeat activity window represent the different binary configuration [88]?
- AGN vs Young Magnetar for FRBs — Study Zhang B [89] showed that neutron star population bounds to Active Galactic Nuclei (AGN) i.e. NS – AGN configuration provides a specific picture to study the low duty cycle bursts. On the other hand, a galaxy center offers an alternative environment (such as having an old galactic-centered mangetar J1745 – 2900) for large Rotation Measure (i.e. RM ~ 105 rad m – 2) with time variable. This means FRBs should exhibit periodicity at the neutron star (NS) orbital period and its associated burst polarization (with the magnetic field) must interact with the AGN's jet flow [90,91]. This implies that for bright FRBs if a young magnetar is required then question arises regarding the necessity of an external triggering or external magnetic fieldthe baryon content in the Universe Yang KB, et al. [92] found no observed FRBs are located at low galactic latitudes and also at low galactic longitudes. The reason why this is so remains unclear to date. This may require further deep observations of FRBs. etc.

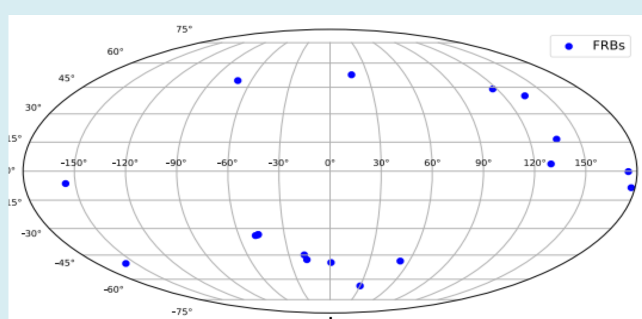

Figure 7: shows location of the detected FRB so far with an indication of no FRBs at low galactic latitudes and low galactic longitudes as obtained by Yang et al [92].

Conclusion

The basic understanding of magnetars is that they (i.e. magnetars) are young, strongly magnetized neutron stars. The energy output from these magnetars may be dominated by magnetic energy release. Pulsars are also rotating magnetized neutron stars. The basic magnetospheric physics of pulsars shows that pulsars have multi-wave emission ranging from radio to GeV. In the case of magnetars, they have longer periods and larger period derivatives than that of normal pulsars. In general, magnetars are young (age 104 – 105 yrs) and strongly magnetized (magnetic field strength ≥ 1014 G) neutron stars compared to that of normal pulsars.

FRBs are millisecond duration but extremely high brightness radio signals. The detection of x-ray burst FRB 200428 originated from the Galactic magnetar SGR 1935 + 2154 suggests that at least some FRBs are produced by magnetar. i.e. it established a confirmed connection between magnetars and FRBs. But the location of FRB generation from the magnetar is still debated. As at least some FRBs are produced by magnetars means the observational evidence pointing towards a magnetospheric origin of FRB emission.

On the other hand, argument against this magnetospheric origin of bright FRBs suggests that radio wave associated with an FRB may lose most of their energy before leaving the magnetosphere because of scattering large amplitude electromagnetic waves in the presence of a strong magnetic field. But investigation showed that FRB radiation, when travelling through the open field line region of a magnetar's magnetosphere, does not suffer much loss implying the disfavor of this idea but support the model of generation of FRBs in the magnetosphere of the magnetar [93].

Detection of cosmic baby i.e. Swift J1818.0 – 1607, with its unusual characteristic of radio-spectrum provides a clue to rethink about the magnetar origin of FRBs. Statistical study of large FRB samples shows an interesting finding that the waiting-time distributions of very active repeating FRBs exhibit a universal double-peaked features with left peaks lower than the right ones [94]. If we assume that these two peaks are independent and initial comparable then question arises — how the observed asymmetric shape can be described by the propagational effect in the magnetar's magnetosphere. The Northern cross FRB Project dealing with millisecond radio transients observed at cosmological distance has strengthened the proposed idea of FRB – Magnetar connection appeared from the discovery of an FRB – like event from the Galactic magnetar SGR J 1935 + 2154 still the nature of the progenitors, origin of FRBs remain unanswered [95].

In the above we see various unsolved problems are linked with the FRBs' mystery. High cadence observations through the advance radio telescopes Atacama Large millisecond / sub-millimeter Array (ALMA), VLA, CHIME, UTMOST provide us a reasonable success towards the investigation of FRBs (Figure 8). In this Figure 8 the timeline representation (blue) indicates the

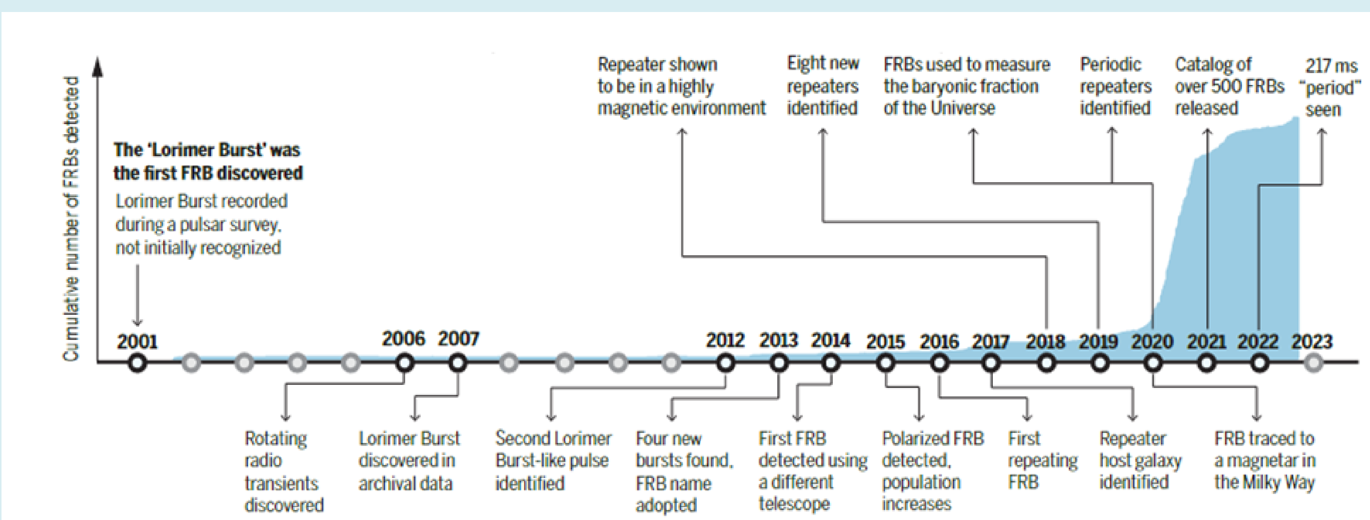

Figure 8: Schematic diagram of "timeline" of some important breakthroughs in the observation of FRBs. Blue colour graph indicates the cumulative number of FRBs detected (Figure 8 adopted from Bailes M [88], source: HeRTA : FRBSTATS online catalog) cumulative number of FRBs detection (observed) with a beginning from the first FRB detection to till date and will continue until the astronomers receive the clues to solve the mystery of the FRBs.

Radio-bursts are obviously important probes of magnetized plasma of all kinds, in particular magnetosphere of magnetars, neutron stars and other compact objects at extragalactic distances for remote sensing of the extreme environments around the burst sources. This author, thus, encourages the astronomers for continuous observation through advanced radio telescopes in order to find a possible clue to unravel the secrets of the Universe.

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Declaration

Competitive Interest

The author declares no competitive interest.

Ethical Interest

Not applicable.

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