

Chapter 6 Multi–Messenger Astronomy: Compact Binary Coalescence

Summary: Compact Binary Coalescence

Authors: Poonam Chandra (on behalf of the SAC)

The coalescences of compact binaries announce themselves via multiple messengers. In September 2016, the merger of two stellar mass black holes led to the first direct detection of gravitational waves. Since then several such events have been found, and gravitational waves have been the only signatures of these mergers. However, if at least one of the compact object of the binary system is a neutron star, the coalescence of such a system is expected to produce a plethora of signatures, including but not limited to gravitational waves, a collimated short gamma-ray burst, and a quasi-isotropic kilonova. The merger of two neutron stars on 17 August 2017 revealed all these phenomena in gravitational waves as well as across the electromagnetic spectrum. This event thus marked the unambiguous initiation of multi-messenger gravitational wave astronomy.

It is speculated that in some cases, the mergers involving neutron stars may temporarily lead to a massive, rapidly spinning magnetar or a supra-massive neutron star before the final collapse. This temporarily stable magnetar may power synchrotron emission via energizing the kilonova ejecta by depositing part of its rotational energy. However, there is also a possibility to create interesting precursor transients before the mergers, serving as early gravitational wave warning systems and unraveling new surprises. Simulations have shown that a reasonable amount of dipole misalignment in the magnetic fields of the two neutron stars may lead to coherent pre-cursor radio emission or X-ray flares. There are also a few favorable scenarios where compact binary coalescence may provide favorable conditions for fast radio bursts (FRB) production before, during or after the merger.

Sometimes the intrinsic signals produced in the coalescence may undergo propagation effects, especially if the magnetic field of the medium is high. Hence it is clear that coalescence of compact binaries leads to a landscape of varied astrophysical phenomena. Radio observations will play a critical role in unraveling this diversity. With its unique combination of wide FOV and high sensitivity, DSA-2000 will play an especially important role. The large FOV of DSA -000 will be very useful for covering the large localization regions of gravitational wave events when searching for electromagnetic emission. In fact, if a coalescence involves a neutron-star and black hole, radio signals may be the only electromagnetic signals. If a magnetar has formed, then reenergized kilonova ejecta is expected to produce a delayed synchrotron signal at radio wavelengths; however the timescales at which one expects these signals is not known. As DSA-2000 will carry out a multi-epoch survey of the northern sky, the chances of detecting these signatures are quite high. The search for FRB-like events before, during, and after the merger is also highly likely due to the large instantaneous field of view of DSA-2000. In addition, radio measurements are the ideal way to constrain the inter-galactic medium magnetic field and thus quantify the damping of gravitational waves. The next few chapters elaborate on these astrophysical phenomena resulting from the coalescence of compact binaries and how DSA-2000 will prove instrumental in improving our understanding of them.

6.1 Compact binary coalescences in the era of multi-messenger astronomy

Authors: Alessandra Corsi

Introduction

The discovery of GW170817, the merger of two neutron stars (NSs) observed via both its gravitational wave (GW) siren and its glow at all wavelengths of light, has marked spectacularly the start of multi-messenger GW astronomy. The discovery of a radio afterglow from GW170817 played a unique role in (i) uncovering the first ever off-axis afterglow of a gamma-ray burst (GRB); (ii) probing the existence and structure (energy and speed profile) of the relativistic jet launched in the merger; (iii) reducing the degeneracy between observing angle and distance that affects the GW measurements and the impact that these can have on cosmological studies. Here we describe the role that DSA-2000 can play in the context of multi-messenger studies of compact binary coalescences over both the near- (next 5 years) and longer-term (next 10-15 years) future.

State of the Field

Over the next 5 years, the LIGO, Virgo, and KAGRA GW detectors should allow us to go from 1 to ~ 10 GW170817-like events (LIGO Scientific Collaboration and Virgo Collaboration 2017; Abbott et al. 2017e), by enabling the localization of a growing number of NS-NS and black hole (BH)-NS mergers to sky areas $\lesssim 100 \text{ deg}^2$. Finding the radio counterparts of these events is key to probing their diversity in terms of ejecta energy and velocity profile, density of the material surrounding the merger site, and viewing angles (e.g., Nakar and Piran 2011; Hallinan et al. 2017c; Mooley et al. 2018b; Lazzati et al. 2018; Petrov et al. 2022; Balasubramanian et al. 2022 and references therein). In particular, unveiling NS-NS/BH-NS mergers that may not be optically bright, at distances matching the improved reach of GW detectors, requires radio arrays with an optimal combination of survey speed, sensitivity, and resolution. The DSA-2000 is one such array.

The community is also developing concepts for improved sensitivity and next generation ground-based GW observatories (such as, LIGO A#, Voyager, the Einstein Telescope, and Cosmic Explorer; e.g., Branchesi et al. 2023; Evans et al. 2023) that would become operational in the next decade (starting from the 2030-2035s). These improved GW detector networks could probe, for the very first time, compact binary mergers associated with short gamma-ray bursts (GRBs) up to the peak of star formation (Ronchini et al. 2022; Gupta et al. 2023). At these higher redshifts, radio arrays like DSA-2000 may be our only way to uncover (on-axis) radio afterglows in relatively large localization areas, unless the US retains capabilities such as those of the *Swift* satellite (arcmin localization of short GRBs). In this respect, the DSA-2000 would be complementary to other next generation radio facilities such as the ngVLA (Murphy 2018), that could probe to very deep limits (and at higher frequencies) the more nearby events that would be localized by next generation GW detectors to regions $\lesssim 1 - 10 \text{ deg}^2$ (Gupta et al. 2023).

DSA-2000's impact

Over the next 5 years, the ability of DSA-2000 to reach sensitivities of $\approx 1.2 \mu\text{Jy}$ (1σ) over areas of $\approx 10 \text{ deg}^2$ in 1 hr will enable follow up of GW triggers localized to within 100 deg^2 . Over the next 10-15 years, the key advantage of the DSA-2000 will be the ability to probe the nearly on-axis radio afterglows from NS-NS and BH-NS mergers that will be unveiled by next generation GW detectors at the higher redshifts where localizations would still $\sim 100 \text{ deg}^2$ (hence requiring the DSA-2000 survey speed).

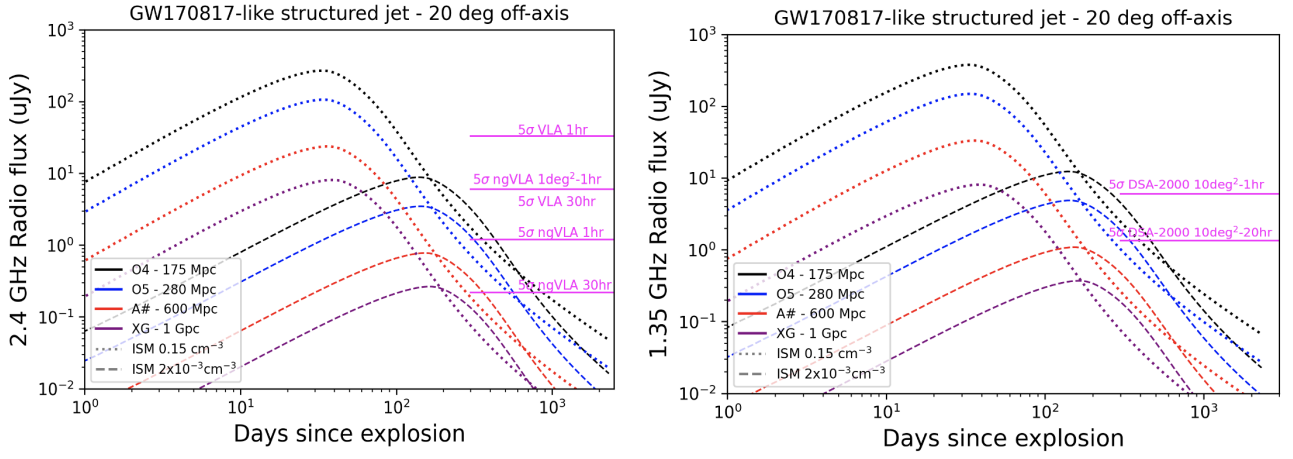


Figure 6.1: Off-axis radio afterglows from jets with structure similar to that of GW170817 (models use the afterglowpy code by [2020ApJ...896..166](#)). During the next 5 years (O4/O5 runs of the LIGO-Virgo-KAGRA detectors), typical GW localization areas of NS-NS mergers will remain large ($\sim 100 \text{ deg}^2$) so the challenge is to uncover their radio afterglows even in the absence of an optical counterpart enabling arcsec-localization (as systems may be optically dark either intrinsically due to the lack of a blue kilonova component, or due to the larger distance reach of GW detectors, or a combination of these two factors). For large localization areas (right panel) the DSA-2000 will offer a clear advantage over the best current and next generation radio arrays (VLA and ngVLA; left). As GW detectors improve their sensitivity and localization capabilities (next generation GW detectors, XG in the figure), their localizations of events within 1 Gpc will shrink to order $1\text{-}10 \text{ deg}^2$ which would be accessible to the ngVLA. However, DSA-2000 would play a critical role for probing the higher-redshift, nearly on-axis NS-NS/BH-NS events associated with GRBs up to peak of star formation ($z \approx 2$). The last can be detected by XG detectors but would have larger localization areas (see Figures 2, 3 and 5 in Ronchini et al. [2022](#); see also Table I in Gupta et al. [2023](#)).

System requirements / desired additions to baseline design (see table below)

The current design of the DSA-2000 works well for this science case. A key requirement is the ability to respond to ToOs within 1-3 days.

Table 6.1: Project requirements compared to DSA-2000 baseline reference design

	DSA-2000 baseline reference design	match to project
need for additional modes	N/A	✓

6.2 Searching for the Elusive Magnetar Remnant Radio Signal from Binary Neutron Star Mergers

Authors: Genevieve Schroeder (Northwestern University)

Summary

The DSA-2000 all sky survey will very likely detect the radio afterglows of some short gamma-ray bursts (SGRBs). These detections can help inform radio follow-up, as well as help provide constraints on the circumburst densities of these events. Additionally, the survey will observe the fields of many previously detected SGRBs, which may have formed magnetar remnants that can energize surrounding ejecta and produce radio emission $\sim$ years after the burst. Therefore, the DSA-2000 survey will also help probe the existence of these magnetar remnants.

State of the Field

The merger of two neutron stars (NSs) is known to produce gravitational wave (GW) emission, a short gamma-ray burst (SGRB), and kilonova, and may also be responsible for the production of a massive, rapidly spinning, highly magnetized NS, known as a magnetar. If this magnetar remnant is at least temporarily stable against collapse, it will deposit a fraction of its rotational energy (ejecta energy E_{ej} up to $\sim 10^{53}$ erg) into the surrounding kilonova ejecta (mass M_{ej}), powering a synchrotron radio signal from the interaction of the ejecta with the circumburst medium, which may be detected $\sim$ years after the burst (Nakar and Piran 2011). We can use radio observations to search for these magnetar signatures, and place constraints on the fraction of SGRBs that produce stable magnetar remnants as well as the maximum mass of a non-rotating NS.

Several attempts to detect this type of emission have been performed in the past by observing the fields of SGRBs in the radio at late times (i.e. Metzger and Bower 2014; Horesh et al. 2016; Fong et al. 2016; Klose et al. 2019; Liu, Gao, and Zhang 2020), with no definitive detections to date. Recently, a new survey combined all of the previous observations, along with 9 new observations of SGRBs, to place limits on the E_{ej} of these mergers. With these limits, the fraction of SGRBs that produce stable magnetars was constrained to $< 50 - 80\%$, and the maximum mass of a non-rotating NS was constrained to $< 2.24M_{\odot}$ (Schroeder et al. 2020). These constraints are limited by the small sample size (< 30 SGRBs followed-up at late times), but deep all sky surveys will allow for more robust constraints.

The expected brightness of the magnetar emission is estimated using SGRB afterglow parameters, such as the circumburst density (n_0). Radio detections of the SGRB afterglow are some of the best tools to accurately constrain these parameters (see Fong et al. 2015). However, few radio afterglows of SGRBs have been discovered to date (see Schroeder et al. 2023). Utilizing all sky radio surveys, such as the DSA-2000 survey, will allow for more informed radio followup by providing template images to compare new radio observations against, as well as likely serendipitously detecting SGRB radio afterglows (see Fig. 6.2).

DSA-2000's impact

The DSA-2000's all sky survey will be a valuable resource for both the discovery and follow up of SGRB radio afterglows, as well as potentially the radio signal from a magnetar remnant. With it's ~ 4 month cadence and deep $\sim 2\mu\text{Jy}$ RMS, it is well matched to the detectability timescale and flux of a short GRB radio afterglow (see Fig. 6.2). Additionally, the survey will cover the locations of many previously detected SGRBs. Therefore, we can utilize the DSA-2000 all sky survey to perform systematic searches

for late time radio emission from NS mergers to probe the existence of a magnetar remnant (see Fig. 6.3).

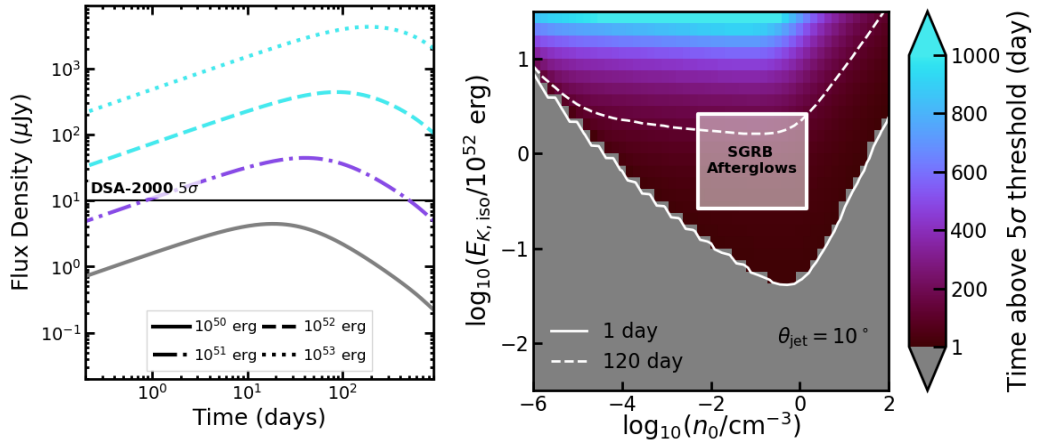


Figure 6.2: *Left:* Example light curves for an SGRB radio afterglow at 1.3 GHz, with varying isotropic kinetic energies ($E_{K,iso}$, $z = 0.64$, all other parameters fiducial, no opening angle is assumed). Light curves are colored by how long the afterglow remains above the DSA-2000 single epoch 5σ threshold (i.e. $10\mu\text{Jy}$). *Right:* The $E_{K,iso}$ vs circumburst density (n_0) parameter space for SGRB radio afterglows (all other parameters fiducial, we assume an opening angle of 10°). The grid is colored the same way the left plot is. The solid white line denotes where the afterglow is detectable for at least 1 day (i.e. with fortuitous DSA-2000 coverage, the afterglow may be detected). The dashed white line denotes where the afterglow is detectable for 120 days (i.e. no matter what time the field is observed by the DSA-2000, the afterglow should be detected). The white box represents the median 68% parameters for SGRBs (Fong et al. 2015).

System requirements / desired additions to baseline design

The current design of the DSA-2000 works well for this science case. Importantly, having quick access to data products and even prior knowledge to when a field would be observed would be very beneficial. If one could query the DSA-2000 to see when a certain field would be observed next, it could help inform radio follow up. E.g. if an SGRB is detected and the DSA-2000 will observe that field in the next $\sim$ week, we may choose to hold back triggering ToO programs until the DSA-2000 observations have been taken and analyzed, to see if a radio afterglow was detected.

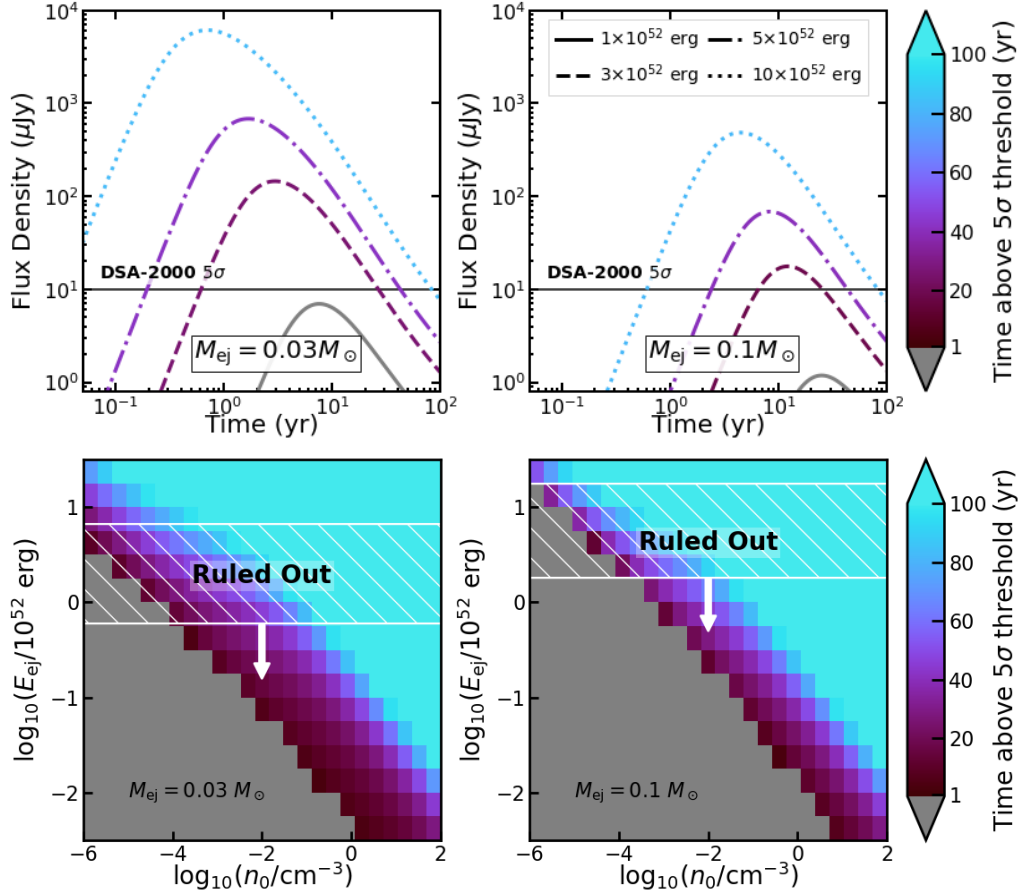


Figure 6.3: *Top:* Example light curves for magnetar emission models at 1.3 GHz, with varying ejecta energies (E_{ej} , $z = 0.3$, all other parameters fiducial) for kilonova ejecta masses of $M_{\text{ej}} = 0.03 M_{\odot}$ (left) and $M_{\text{ej}} = 0.1 M_{\odot}$ (right). Light curves are colored by how long the afterglow remains above the DSA-2000 single epoch 5σ threshold (i.e. $10 \mu\text{Jy}$). *Bottom:* The E_{ej} vs circumburst density (n_0) parameter space (all other parameters fiducial) for magnetar emission models for $M_{\text{ej}} = 0.03 M_{\odot}$ (left) and $M_{\text{ej}} = 0.1 M_{\odot}$ (right). The grid is colored the same way the top plots are. The hatched region denotes the range of E_{ej} ruled out by Schroeder et al. 2020.

6.3 Fast radio precursors transients to merging neutron stars

Authors: Elias Most

Summary

Gravitational wave events of merging neutron stars might be accompanied by Fast-Radio-Burst-like transients. These could be the result of processes in the common magnetosphere, present in the late stages of the inspiral phase. Recent numerical simulations have been able to show that this could happen for field strengths well below the magnetar level. Driven by the interaction of strong electromagnetic flares, emitted from the premerger system, millisecond-long bursts of radiation with frequencies 2-20GHz for magnetic fields of $10^{10} - 10^{11}$ G at the stellar surface could be detectable. Overall luminosities would fall in the range of $10^{41} - 10^{42}$ erg/s, with potential millisecond periodicity of 2-5 episodes.

State of the Field

Over the past few years, the LIGO-VIRGO-KAGRA collaboration has detected gravitational wave (GW) from merging binary neutron star (Abbott et al. 2017c; Abbott et al. 2020), and black hole – neutron star (Abbott et al. 2021) systems. Due to the presence of neutron-rich matter, these events can power electromagnetic counterparts optical & infrared (Cowperthwaite et al. 2017; Chornock et al. 2017; Villar et al. 2017; Nicholl et al. 2017; Troja et al. 2018; Tanvir et al. 2017; Drout et al. 2017), gamma- (Abbott et al. 2017b; Savchenko et al. 2017) and X-ray (Troja et al. 2017; Margutti et al. 2017a; Margutti et al. 2018; Hajela et al. 2019), as well as radio (Hallinan et al. 2017a; Alexander et al. 2017; Ghirlanda et al. 2019; Mooley et al. 2018a; Mooley et al. 2018c) bands, making these systems exciting targets for multi-messenger astronomy. However, not all of these systems are expected to feature such counterparts, especially in the case of black hole –neutron star system (Anand et al. 2021; Coughlin et al. 2020b; Coughlin et al. 2020a), see also (Raaijmakers et al. 2021). However, for the currently inferred coalescing neutron star – black hole population, it seems unlikely that enough remnant matter is left after the merger to power afterglow transients (Biscoveanu, Landry, and Vitale 2022).

However, these electromagnetic counterparts, such as the kilonova afterglow (Metzger 2017), may not be the only ones that can be sourced by the merger. Different from transients sourced after the merger, there may also be the possibility to create counterparts before the merger. Since neutron stars feature strong magnetic fields in the inspiral, their interaction prior to merger might release substantial amounts of energy, potential capable of powering precursor transients (Hansen and Lyutikov 2001; Lai 2012; Piro 2012; Lyutikov 2019). These transients may be relevant for proposed early gravitational wave warning systems aiding their pursuit (James et al. 2019; Sachdev et al. 2020; Yu et al. 2021; Wang et al. 2020c). All-sky capability may help associate detected radio bursts to rapid localizations of neutron star gravitational wave events (Gourdji et al. 2020).

Although most progress in this field has been limited to analytical work (Hansen and Lyutikov 2001; Wang et al. 2016a; Lyutikov 2019; Sridhar et al. 2021; McWilliams and Levin 2011; D’Orazio and Levin 2013; Mingarelli, Levin, and Lazio 2015; D’Orazio et al. 2016), over the past decade numerical simulations of the common magnetosphere have been carried out (e.g., (Paschalidis, Etienne, and Shapiro 2013; Palenzuela et al. 2013a; Palenzuela et al. 2013b; Ponce et al. 2015; Carrasco and Shibata 2020; Carrasco, Shibata, and Reula 2021; East et al. 2021)). These have focused on continuous emission signatures, largely associated with the motion of the orbiting stars. Recently, three-dimensional relativistic force-free electrodynamics have uncovered a novel flaring mechanism in magnetospheres of binary neutron star systems (Most and Philippov 2020), see Fig. 6.4 . These flares are emitted quasi-periodically, and do not strongly depend on the magnetic field configuration

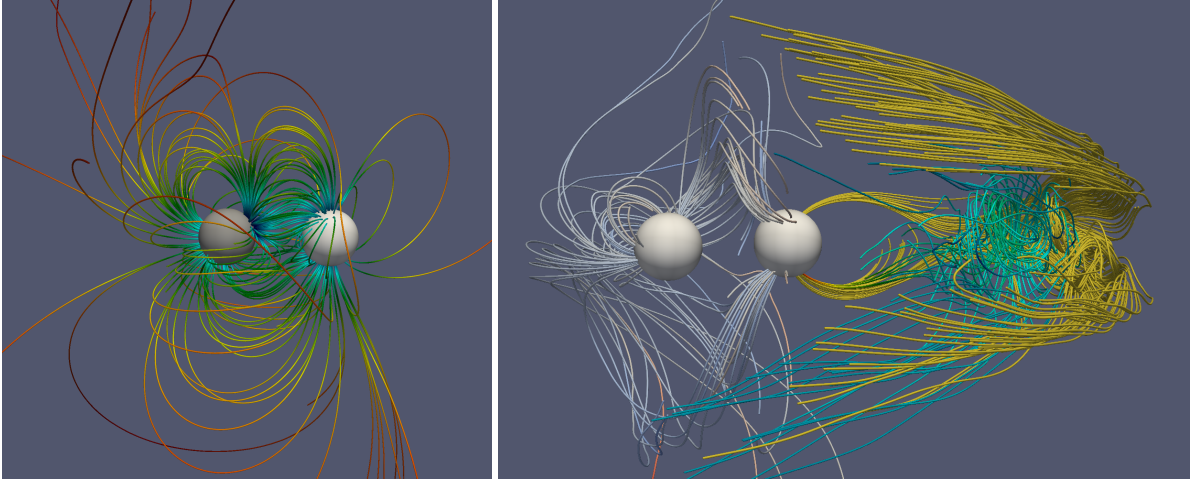


Figure 6.4: (Left) interaction of the common magnetosphere in a neutron star binary (Most and Philippov 2020). Shown are colored magnetic field lines, as well as the stellar surfaces. (Right) Flaring event leading to a fast radio transient. Shown is the flare (cyan), the orbital current sheet (yellow), and other field lines (gray). The interaction of the flare with the orbital current sheet could ultimately lead to the production of Fast-Radio-Burst-like transients.

(Most and Philippov 2022b), as long as sufficient misalignment of the two dipoles is possible. In the case of black hole – neutron stars, similar behavior has been observed (Most and Philippov 2023). Part of the magnetic energy is also released in reconnection processes, leading to potential X-ray flares (Beloborodov 2017) and coherent radio emission (see (Most and Philippov 2020) for details). However, the main emission mechanism has been found to lie in the radio band (Most and Philippov 2022c). More precisely, the interaction of the flare with the orbital current sheet can trigger forced reconnection leading to plasmoid formation and merger. The resulting fast waves can travel below the plasma frequency (and only decouple later), which otherwise would be high in these systems (Carrasco, Shibata, and Reula 2021). This emission mechanism is similar to the one proposed by Lyubarsky for linearly polarized Fast-Radio-Bursts (Lyubarsky 2020).

Based on these simulations, we expect these flares to lead to Fast-Radio-Burst-like transients with frequencies of 2-20GHz for magnetic fields of $10^{10} - 10^{11}$ G at the stellar surface. Overall luminosities would fall in the range of $10^{41} - 10^{42}$ erg/s, with potential millisecond periodicity of 2-5 episodes. (Most and Philippov 2022c).

6.4 On radio detection of gravitational waves and gravitational wave sources

Authors: Bing Zhang (UNLV)

Summary

This contribution includes two parts: 1. possible frequency-dependent damping of long-wavelength gravitational waves (GWs) potentially detectable with pulsar timing arrays (PTAs); and 2. several possible, yet-detected, FRB-like signals associated with various types of GW sources from compact binary coalescences (CBCs), including signals before, during, and after the events.

State of the Field

1. PTA and low-frequency GWs

The PTA community is on the verge of detecting low-frequency GW background.

Possible damping of GWs has been discussed over the years but no known effect can significantly damp GW fields. In Lieu, Lackeos, and Zhang 2022, we showed that there is likely a damping effect of very long wavelength GWs if the magnetic field strength in the intergalactic medium (IGM) is strong enough. The basic arguments include the following ingredients: (1) GWs accelerate charged electrons and protons in the ionized IGM, allowing them radiate electromagnetic waves; (2) Different thermal velocities of electrons and protons allow that the radiations of electrons and protons do not exactly cancel out; (3) Some modes (X-mode for $\mathbf{k} \perp \mathbf{B}$ or R-mode for $\mathbf{k} \parallel \mathbf{B}$) of the very low electromagnetic waves can propagate if the wave frequency is below the Larmor frequency. As a result, the GWs will undergo partial damping at low frequencies if the IGM magnetic field is strong enough. As a result, one expects a turnover in the low-frequency end of the GW background spectrum with the turnover-frequency depending on the strength of the IGM magnetic field. In the future, if the nHz GW background as detected by various PTAs shows a turnover in the low-frequency regime as compared with the model prediction, it would give a measurement of the average IGM magnetic field strength.

2. Possible FRB-like signals associated with CBCs

Even though the origin of cosmological fast radio bursts (FRBs) is still not fully identified, it is now well accepted that the dominant population of FRBs likely originates from repeating sources such as magnetars. Nonetheless, compact binary coalescences (CBCs, including NS-NS, NS-BH, and BH-BH mergers) provide the physical environments to produce FRBs or FRB-like events, which may have or have not been detected. In the following, I list several possible mechanisms I have proposed in recent years. Due to the limited space, this section is not meant to be a comprehensive review of all possible FRB-like signals proposed in the literature. The topics will be discussed in three subsections: charged CBC (cCBC) effect during the merger, magnetospheric interactions long before the merger, and the blitzar mechanism after the merger.

2.1. During the merger: cCBC signals

If at least one of the members of a CBC system is charged, then besides the rapid increase of GW power towards the coalescence (the GW chirp), the electromagnetic (EM) power of the system also quickly increases towards the coalescence (Zhang 2016; Zhang 2019), which we may define it as an “EM chirp”. The absolute power of EM radiation is proportional to $\hat{q}^2$, where $\hat{q}$ is the charge of the member normalized to the characteristic charge defined by its mass. The power increases rapidly as the separation a decreases, i.e. $L \propto a^{-4}$ for electric dipole radiation and $L \propto a^{-15}$ for magnetic dipole radiation. For comparison, the GW luminosity increases following $L_{\text{GW}} \propto a^{-5}$. One can see that a cCBC naturally gives rise to a brief EM radiation pulse. If a fraction of the released EM energy goes to the radio band in the form of coherent radiation, it may generate

FRB-like events. Such events are expected to occur simultaneously with respect to the GW chirp after the plasma dispersion correction.

The question is how much charge a compact object can carry. Neutron stars are spinning magnets so by definition they carry charges. For reference, Crab-like pulsars carry $\hat{q} \sim 10^{-7}$. NSs with stronger B fields or faster spins carry larger $\hat{q}$ values. The case of black holes is less clear. The collapse of a spinning NS makes a Kerr-Newman (spinning charged) BH, but the charges may be lost through balding later, even though the timescale of losing the charges is not well studied.

Since $\hat{q}$ is typically small, the cCBC signals are quite faint. NS-NS mergers and NS-BH mergers with NS tidal disruption are expected to produce bright EM counterparts (short GRBs and kilonovae) and dirty environments, so the associated cCBC signals are difficult to observe. BH-BH mergers likely produce very faint cCBC signals. The best chance of detecting cCBC signals is from plunging NS-BH systems (Zhang 2019), because the cCBC signal should exist (the NS is charged) and be clean (without the contamination of the tidally disrupted material surrounding the merger remnant). For a Crab-like NS in the system, the maximum total luminosity is $\sim 10^{42} \text{ erg s}^{-1}$. Since only a fraction of emission may go to the radio band, the luminosity of these events may fall into the range of low-luminosity FRBs. The detection or non-detection of such signals in association with plunging NS-BH merger events will place constraints on the charge of the NS member in the merging binary.

2.2. Before the merger: magnetospheric interactions for NS-NS mergers

Most EM precursor models for NS-NS mergers invoke processes right before the merger. It is worth noting (Zhang 2020) that repeated, FRB-like events might happen long before the merger, because for typical parameters, the magnetospheres of the two NSs have started to interact decades or even centuries before the merger. Since the two NSs have different rotation periods and likely different inclination angles with respect to the orbital plane, magnetic reconnections may happen occasionally. If these reconnections produce narrowly beamed jets and coherent radio emission, these systems can produce repeated FRB-like events with the expense of the magnetic energy (and eventually the spin energy) of the two NSs. According to this picture, some nearby FRB repeaters could be GW sources detectable by future space-borne GW detectors such as DECIGO, LISA, Taiji and TianQin.

2.3 After the merger: blitzar events due to the collapse of supramassive NSs

If the neutron star equation of state is stiff enough, NS-NS mergers may leave behind supramassive neutron stars that can survive for an extended period of time. Later the supramassive neutron star will collapse to a black hole to power an FRB (Zhang 2014). The FRB mechanism is the so-called blitzar mechanism (Falcke and Rezzolla 2014), which invokes the ejection of the magnetosphere of a supramassive neutron star by a newly formed black hole. A potential association between the NS-NS merger event GW 190425 and the one-off FRB 20190425A that occurred 2.5 hours after the GW event has been proposed (Moroianu et al. 2023; Panther et al. 2023). If such an association is physical, one would expect more GW-FRB association pairs in the future.

If the merger leaves behind a long-lived magnetar, which requires even stiffer neutron star equation of state, the source may emit repeated bursts similar to known magnetars. In such a case, a NS-NS merger remnant may become a repeating FRB source.

DSA-2000's impact

DSA-2000's large field of view and high sensitivity make it an ideal equipment to carry out studies in the above-mentioned areas.

In the case of PTA and GW detection, DSA-2000 will detect more millisecond pulsars that will be suitable

for GW detection. The detection of the GW background and the measurement of the GW spectrum reply on the already-accumulated data from the PTAs. The benefit of using DSA-2000-detected new pulsars would be therefore in long term. Because the expected spectral turn-over would appear in the very long-wavelength regime (again the break frequency depends on the IGM magnetic field, Lieu, Lackeos, and Zhang 2022) and because long observing time will probe the regime of long wavelength, the precise measurement of the GW spectrum in the long-wavelength regime requires very long observing time. The impact of the DSA-2000 observations on this subject is expected to show up decades later.

The search for GW-associated FRB-like events before, during, and after the CBCs is more straightforward. This requires the instantaneous field of view of DSA-2000 to be as large as possible, so that the chance of catching FRB-like events during or shortly after CBC events is as high as possible. High sensitivity also helps because some predicted events (e.g. cCBCs from plunging NS-BH mergers) are expected to be very faint. For GW190425/GRB 20190425A-like associations (Moroianu et al. 2023; Panther et al. 2023; Zhang 2014), target-of-opportunity (ToO) observations are encouraged for BNS mergers hours after the mergers. For repeating FRB-like emissions, e.g. magnetospheric interactions decades/centuries before a BNS merger (Zhang 2020) or magnetar emission years after a BNS merger, no special requirement is needed. One just needs to search for possible associations between established FRB repeaters and known GW sources, including the GW sources detected by space-borne GW detectors for the pre-merger models and the BNS merger remnants identified from the ground-based GW/EM observations for the post-merger models.

System requirements / desired additions to baseline design (see table below)

ToO observations are desirable

Table 6.2: Project requirements compared to DSA-2000 baseline reference design

	DSA-2000 baseline reference design	match to project
Cadence	1 every 4 months	ToO observations are desirable