3.20 Search for transients in coincidence with Fast Radio Bursts

3.20.1 Abstract

Since the publication in summer 2013 of four Fast Radio Bursts (FRBs) identified in Parkes Telescope data [527] there has been considerable scientific interest in these millisecond-scale radio transients which, based on their observed dispersion measures, appear to occur at cosmological distance scales. Currently, while numerous papers have suggested plausible sources for these radio transients, their origin is unclear. While not all plausible mechanisms for emission of FRBs are likely to result in simultaneous gravitational wave (GW) emission at detectable frequencies, there are several mechanisms which may result in coincident signals. The High Time Resolution Universe (HTRU) Collaboration has negotiated an MoU (see M1400007) with the LSC and Virgo in order to share trigger times, location and other information on currently unpublished Fast Radio Bursts. We have performed searches using GEO and Virgo data for several FRBs already under this agreement. This search plan describes plans to continue analysis of FRBs during O1 as per the MoU already signed with HTRU.

- Lorimer etal(2007)らが Parkes 電波望遠鏡のアーカイブデータを解析すると、継続時間がミリ秒で、dispersion measure の測定から宇宙論的な距離からのイベントらしい電波トランジェント(Fast radio transient)が検出されたことを皮切りに、この手の FRB は Parkes で数個検出され、2013 年に観測論文が出版された。いくつかのイベントは LIGO S6 が行われていた時期だったので、秘密裏にフォローアップ観測も行われたが、付随する重力波は検出されなかった。しかしこのことは LIGO 内部でも秘密裏に行われたために不満も多く、MoU の結び方（実際、MoU の枠外の活動だった）が検討された。
- HTRU と LIGO-Virgo の間でまだ出版されていない FRB イベントについてのトリガーサーチに関する MoU が結ばれた。
- その MoU に従ってフォローアップ観測を行う。

3.20.2 Scientific Justification

FRB についてはその波源がまるでわかっていないので、バーストサーチを行う。願わくばそのメカニ済みに関して何かヒントを得たい。

- **もし FRB が星のコア崩壊型のものだったり、地球の peryton であったら重力波検出は期待できない。**

peryton

- **Cosmic strings**

Cosmic strings - Cosmic strings, formed during symmetry breaking in the early universe, are topological defects thought to be capable of emitting large amounts of energy from their cusps or kinks [529] and have been suggested as a possible emission mechanism for FRBs [530, 531]. A cosmic string cusp may emit gravitational waves with a $f^{-4/3}$ frequency dependence up to a cutoff frequency [532], potentially at frequencies and amplitudes detectable by ground-based interferometers [405, 27].

This class of sources is particularly promising for purposes of an FRB related search since the distance scales on which GW signals may be observable for cosmic strings are consistent with the cosmological scales suggested by current FRB observations.

- **CBC**

Binary neutron star coalescence - There are several models for radio emission in coincidence with a compact binary coalescence GW signal. This may be pulsar-like radio emission, either from the reactivation of the dormant pulsar emission in one of the neutron stars through interactions prior to merger [533] or by a hypermassive neutron star, which may sometimes result as an intermediate result of a merger before collapsing to a black hole, emitting at radio frequencies through a pulsar mechansism [534]. A third possible mechanism is the radiation at radio frequencies as a result of magnetospheric interactions [535].

Given an appropriate density in the surrounding environment, the gravitational waves emitted by a compact binary coalescence may induce electromagnetic radiation through magnetohydrodynamic interactions. While this interaction would directly produce radiation at the same relatively low frequencies as the GWs themselves, upconversion through inverse compton radiation may result in emission at radio frequencies [536]. This particular magnetohydrodynamic mechanism does not necessarily require neutron star coalescence as the mechanism for production of the GWs, but this class of source is likely to be able to produce GWs of suitable amplitude and may be surrounded by an environment suitable to this mechanism [537].

- **Single neutron stars**

Single neutron stars - Most models of gravitational emission resulting from single neutron stars would most likely produce signals too weak to detect at the distance scales suggested by the dispersion measures under consideration. However, if FRBs result from extreme SGR events as has been suggested [528], if future observations result in a lower dispersion measure event, or if some subset of FRBs is much closer than estimates due to the bulk of the dispersion happening close to the source rather than in the intergalactic medium, this class of models is still worth considering.

Transient gravitational wave emission can occur when a temporary deformation of a rapidly rotating neutron star creates a quadrupolar moment. Typically, this is believed to happen as a result of crust cracking from magnetic, gravitational or superfluid forces, dubbed a starquake [538], or from other asteroseismic phenomena resulting in shifting of the neutron star's crust [539]. While asteroseismology may result in several distinct types of quasinormal oscillatory modes of the neutron star, the f-mode is the most promising for the purpose of gravitational wave detection. Gravitational emission resulting from f-mode oscillation typically peaks around 2 kHz, although the exact emission depends on several factors, including the neutron star equation of state and the mass of the emitting neutron star [465]. The amplitude of the GW emission even in optimistic cases, however, is small enough that sensitivity to this type of source will be limited to our own galaxy even in the advanced detector era.

Radio pulsars result from beamed emission from the poles of a rapidly rotating, highly magnetized neutron star sweeping past the Earth, producing reliably periodic radio signals. The asteroseismic events described above may result in a distinct increase in the rotation rates of these neutron stars, typically followed by a gradual return to their original period. This phenomenon, called a pulsar glitch, has been observed across a large number of pulsars, especially younger ones (see e.g. [540] and references therein). A search for gravitational wave emission from quasinormal modes in coincidence with the observed glitching of pulsar was the subject of a previous LIGO publication [472]. Models for neutron star asteroseismic phenomena similar to those under discussion have also motivated previous gravitational wave searches in coincidence with SGR flares [541].

The standard indication of an asteroseismic event in an isolated neutron star is a pulsar glitch, but there are are plausible mechanisms that could result in the observation of a transient radio pulse. This could simply be through the pulsar radio emission coming into view from the Earth as the pulsar's orbit shifts slightly, but there is also some evidence that pulsar-like radio emission can be "switched on" in coincidence with with a glitching mechanism [542, 543, 544]. We therefore consider single neutron stars as a possible source of coincident GW and radio transient events.

3.20.3 Search Description

- **HTRU** が提供するイベントについての **ToO** 型のサーチを行う。イベントレートはひと月に1イベントも無いだろう。
- **GRB-burst** サーチと類似しているので、**GB-type X-pipeline** を用いる。
- コードの変更は必要ないので、レヴューもいらない。が、重力波源のモデルに応じたパラメータチューニングは必要。
- **GRB** と類似して、**on-source** の時間窓は4分。**ToO** サーチでは **Parkes** による到来方向制限ができるので、その制限を用いる。
- バックグラウンド **rejection cut** をチューニングするために、いくつかのモデルに応じたインジェクションを行う。
- **Single neutron star** 起源の重力波ー電波の同時 **emission** メカニズムも検討しており、そうすると **3kHz** まで探査領域にしたい。

3.20.4 Publication Plan

No publications are planned regarding specific FRBs or sets of FRBs in O1 regarding upper limits set on FRB triggers. “Evidence” or “detection” of a GW, according to standards agreed to by LIGO and Virgo, would merit a publication, however. Members of the HTRU collaboration would be included as authors in this paper. If detections were made in both an FRB triggered search and another analysis over the same data, a single “detection” paper would be written in collaboration with the other searches. The collaborations involved would reach a decision about dedicated follow-up papers focused on implications of specific analysis.

A collaboration paper regarding archival initial detector era burst searches for GWs in coincidence with short duration radio transients is currently under preparation. The bulk of radio triggers analyzed for this paper are from the Green Bank telescope drift-scan survey [545] and appear to occur at galactic distance scales based on observed dispersion measures. The paper will contain discussion of Fast Radio Bursts, including description of plans to continue monitoring for GW signals in coincidence with FRBs in O1 and beyond. However, this paper will not refer to specific FRBs coincident with advanced LIGO/Virgo (O1) data.

3.20.5 Resources

Computing needs - Requirements on a per-trigger basis are similar to the burst analysis of a Swift GRB. We estimate that 300 CPU-days would be required for each FRB event based on previous events occuring in initial LIGO/Virgo data. Since these FRBs are identified by Parkes infrequently (less than one event per month) the overall use of computing resources is negligible relative to the most computationally intensive all-sky all-time searches. While we anticipate conducting these FRB-coincident searches with turnaround times on the order of days rather than months as for archival searches, in the case that computational resources were required for an externally triggered event at a higher designated priority level, the FRB analysis could be temporarily delayed upon request without a significant loss of scientific value.

Detector Characterization and Calibration - As the FRB search primarily utilizes X-Pipeline and other existing low-latency infrastructure no additional effort should be required for purposes of detector characterization or calibration. (The possible exception to this statement would be a statistically significant event which would require exercising the burst detection checklist.)

Review - Most of the code utilized was already reviewed in the context of S6/VSR2-3 GRB searches [546]. Supplemental review for minor code adjustments and analysis procedures specific to radio-coincident analyses was performed as part of the Green Bank analysis (see G1200800, M1100024) . Therefore no additional code review is required for ongoing FRB searches.

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