FAST Proposal Coverpage

Last updated: 01/10/2019

Project Name:

Detecting radio counterparts of gravitational wave sources during LIGO O3 with FAST

Project Summary:

(A 1 paragraph summary of your project, including its scientific goals and how you will address them. This information will be potentially public.)

ALIGO/Virgo opened the door of gravitational wave astronomy by discovering the black hole-black hole (BH-BH) merger event GW 150914. Afterwards the detection of a nearby (distance ~ 40 Mpc) binary neutron star (NS) merger event GW 170817 provides an unprecedented opportunity to discover its electromagnetic counterpart, GRB 170817A/AT 2017gfo, by space missions and ground-based optical telescopes. Together with radio follow-ups, the comprehensive dataset allows to establish solid evidence of the physical NS-NS origin and the existence of the associated kilonova. Our team has access to a wide network, including a few optical telescopes inside and outside China, aiming to search and verify optical counterparts in the coming aLIGO/Virgo O3 period, which covers the FAST commissioning period. We propose to do radio follow-up observations with the FAST for O3 targets (NS-NS and NS-BH mergers) with a possible electromagnetic counterpart. The multi-wavelength data will allow to study their physical origins, energetics, velocities, jet structure, ejected mass, and can be even used to constrain cosmological parameters and evolution.

PI and Observer Contact Details:

(Contact details which other FAST observers can use to contact you about your project)

Name, Email, Cell number/Wechat account name

Bing Zhang, zhang@physics.unlv.edu, Wechat: bzhang_unlv

Project Type:

(tick all that apply)

- ❑ Spectral Line: pointing
- ❑ Spectral Line: Imaging
- ❑ Pulsar (fold/timing mode)
- ❑ Pulsar (search mode)
- ❑ Pulsar (single pulse)
- ❑ Continuum
- ❑ Other (please specify) (Yes)
    - ❑ __transients__

FAST ‘Shared-Risk’ Proposal Template (Required Language: English)

Observing Mode:

- ❏ Remote Oberving (Yes)
- ❏ Travelling to FAST to observe

Project Members

(just list the names here. A full table is required on later pages.)

Bing Zhang, Dong Xu, Di Li

Requested Contact Person/Collaborator from the FAST Project

(If none specified, one will be assigned to the project)

Pei Wang

Project Justification

(This should be at most two single-column pages long in a font of size no smaller than 11pts. Note that the source table should be in separate pages. the following sections are required.)

1. **Motivation**（Science background, related existing observations, state-of-art results and current references）

Gravitational wave astronomy. In 2015 aLIGO/Virgo discovered cosmic gravitational waves (GWs; Abbott et al. 2016, PRL, 116, 061102). One of the key theoretical predictions of general relativity, this finding was swiftly awarded the Nobel Prize in physics. Since then, six secure GW events have been announced, five of which originated by merging stellar-mass black holes (BH) systems, and only one event, GW 170817, from a binary neutron star (NS) merger (Abbott et al. 2017, PRL, 119, 161101). No electromagnetic emission is expected for systems without neutron stars, and indeed no credible counterpart was localized for these BH-BH events (e.g. Abbott et al. 2016, ApJ, 826, 13; Evans et al. 2016, MNRAS, 462, 1591).

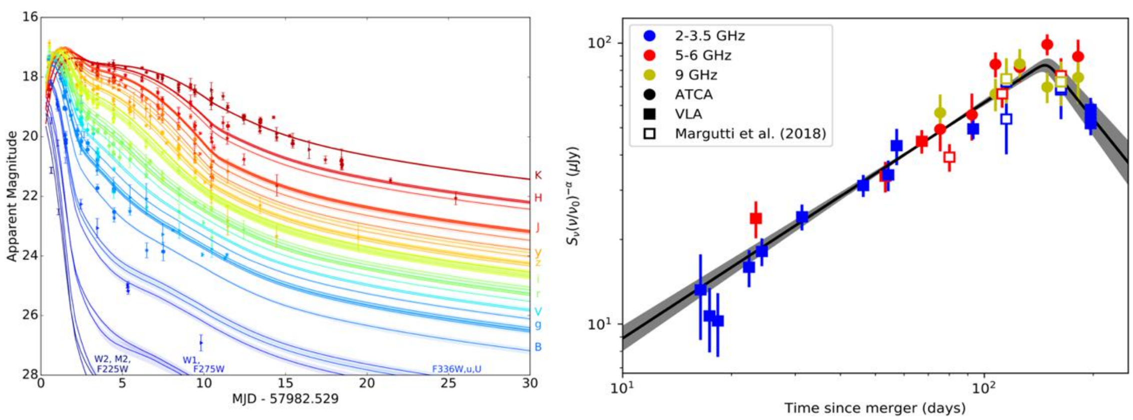

Figure 1: *Left:* UV-Optical-NIR light curves (LCs) from a comprehensive dataset from different publications, along with the spherically symmetric models to the LCs (Villar et al., 2017, ApJ, 851, L21); *Right:* Light curve of GW170817 from ATCA (circles) and VLA (squares) observations grouped by frequency band, with 2–3.5 GHz (blue), 5–6 GHz (red), and 9 GHz (yellow). The flux densities have been adjusted to 5.5 GHz (Dobie et al. 2018, ApJ, 858, L15).

GW170817 and the associated kilonovae. In 2017 August a high-S/N event was detected, this time consistent with the merging of two NSs, at a distance of ~ 40 Mpc. Independently, the Fermi and INTEGRAL satellites detected the short GRB170817A within 2 s of the GW trigger time (Goldstein et al. 2017, ApJ, 848, L14; Savchenko et al. 2017, ApJ 848, L15). Binary NS mergers have been considered for a long time the favorite progenitor for short GRBs, which was therefore spectacularly confirmed for this event. ALIGO/Virgo constrained the location of GW170817 to a relatively modest sky area (28 deg2), allowing effective searches for optical/NIR counterparts. Such a counterpart, AT 2017gfo, was in fact readily identified, as a bright, uncatalogued source with magnitude i = 17.5 (e.g. Coulter et al. 2017, ApJ, 835, 183), localized 10.5 arcsec (2 kpc in projection) off the nucleus of the galaxy NGC4993 at 40 Mpc distance. The coincidence between the distances, the lack of previous detection, and the very unusual spectral properties led to unambiguously associate AT2017gfo with GW170817. AT2017gfo is quickly dominated by the so-called kilonova (KN) and it transitioned from blue to red (see Figure 1 left panel; e.g. Pian et al. 2017, Nature, 551, 67; Tanvir et al. 2017, ApJ, 848, L27; Evans et al. 2017, Science, 358, 1565). This behavior has been interpreted as due to the presence of two separate components, a

fast-fading blue emission likely produced in ejecta launched from the accretion disk around the resulting compact object (“disk wind”), and a long-lived redder emission emitted in the “dynamical ejecta”, material expelled during the final inspiral phase (Tanaka et al. 2017, PASJ, 69, 1). Radio follow-ups started a bit later, but provide unique observational characteristics, last much longer, and are still on-going (see Figure 1 right panel). The radio data give raise to conclusions: (1) There exists a turnover in the LCs at ~ 149 days post-merger; (2) There is no evidence for evolution in the radio-only spectral index, which remains consistent with optically thin synchrotron emission connecting the radio, optical, and X-ray regimes; and (3) The temporal decay rate is most consistent with mildly
or non-relativistic material.

Our proposal. In short, we propose to do radio observations and analysis, as in GW 170817, for new aLGIO/Virgo counterparts in the commissioning phase.

2. Why FAST now？

Discoveries of electromagnetic counterparts of aLIGO/Virgo GW sources are of great scientific significance. Telescopes across the world will rush to observe. These extragalactic targets produce weak radio radiation, with flux densities from a few to tens of microJy at usual radio bands. Thus FAST, with its extremely high sensitivity, would be more suitable than Parkes, GBT, and/or Arecibo, to observe the radio counterparts of the GW events. Several observations will allow mapping the lightcurves of these events. With the improved flux calibration during the FAST commissioning phase and cross comparison with detections from other observatories, FAST observations can provide a complete flux lightcurve, which covers important data points not measurable from other observatories.

3. Expected results

To reach tens of microJy at usual bands (e.g, L/S/C/X bands), the integration time would be a few hours. Since the radio lighcurves usually have a slow rise, there is no urgency to get to the target right away after the GW trigger. All targets are soft ToO targets, requiring to start observations within two days after the GW trigger. For each target, we plan to observe a few times, depending on the evolutions of flux densities. The observations will be nominally planned at 2, 10, 30, 100 days after the GW trigger, but can be adjusted based on the brightness of the target. We plan to publish the first detection result of each target to GCN shortly after the observations to alert the community of the FAST detection, and publish the bulk of the data in detail in peer review journals later.

4. References

Abbott et al. 2016, PRL, 116, 061102
Abbott et al. 2017, PRL, 119, 161101
Abbott et al. 2016, ApJ, 826, 13
Coulter et al. 2017, ApJ, 835, 183
Dobie et al. 2018, ApJ, 858, L15
Evans et al. 2016, MNRAS, 462, 1591
Goldstein et al. 2017, ApJ, 848, L14
Pian et al. 2017, Nature, 551, 67

Savchenko et al. 2017, ApJ 848, L15
Tanaka et al. 2017, PASJ, 69, 1
Tanvir et al. 2017, ApJ, 848, L27
Villar et al., 2017, ApJ, 851, L21

Technical Requirements:

*(Please fill out **all** fields)*

Receivers:

- ❑ 19-beam (all)
- ❑ 19-beam (central)
- ❑ Other (please specify)
    - ❑ ____________

Backends:

- ❑ 19-beam ROACH
- ❑ CRANE
- ❑ Other (please specify)
    - ❑ __________

Observing mode:

(Please refer to your earlier selection on Page 1 in order to complete the correct section)

- ❑ Pulsar (fold)
    - De-dispersion (coherent/incoherent):
    - Number of channels:
    - Bandwidth (MHz):
    - Number of profile bins:
    - Length of sub-integrations (s)

- ❑ Pulsar (search)
    - Number of channels:
    - Bandwidth (MHz):
    - Sampling time (μs):

- ❑ Spectral line / Continuum
    - Frequencies of interest
    - Observing mode (pointed, drift, m/x, mapping):
        - Details of observing mode

    - Dump time (i.e., how often should a spectrum be written to disk) (seconds):

2. Other Comments:

(Please feel free to provide additional comments here regarding the technical setup of your observations

FAST ‘Shared-Risk’ Proposal Template (Required Language: English)

Full list of Project Members:

(The Principal Investigator (PI) should be listed on the first (shaded) row. Additional rows can be added as needed. Please identify the observer(s) with an asterisks beside his/her name(s).)

Name	Email	Institution	FAST Observing Experience (Y/N)
Bing Zhang	zhang@physics.unlv.edu	NAOC/UNLV	N
Dong Xu	dxu@nao.cas.cn	National Astronomical Observatory of China (NAOC)	N
Di Li	dili@nao.cas.cn	NAOC	Y
Pei Wang	wangpei@nao.cas.cn	NAOC	Y
Zipei Zhu	zpzhu@nao.cas.cn	NAOC	N
Bangyao Yu	hunts@nao.cas.cn	NAOC	N

Source List & Observing Time Requirements:

*(Please complete the table below for all sources which you plan to observe. Be sure to include the required integration time of each source, and the number of times you plan to observe it (repeats). **In addition, you can also optionally attach your proposed observing schedule to your proposal)***

Name	RA	Dec	LST Rise	LST Set	Integration time (s)	Repeats
GW19XXXX	00:00:00	00:00:00				1-5

Total Integration Time:

(For each source, calculate “Repeats x Integration time”, then add together.)

All targets are soft ToO targets. Each target would require the longest tracking possible for each epoch, so could run from 1 - 5 hours.

20minutes are needed for each epoch for an independent flux calibration due to the emphasis on flux scales.

Estimated Overhead Time:

(The total time taken to setup the telescope, move between sources, calibrate, etc. Note that the source changing time of FAST is 10minutes..)

10 minutes setup time + 10 minutes pointing to the source + 10 minutes pointing to the calibrator = 30 minutes per epoch

Total Time Request:

(Total Integration Time + Estimated Overhead Time)

For a nominal target, the total observational time will be about 6-15 hours). Final total hour depends on the brightness of the target.

Final Time Allocation:

(DO NOT FILL IN THIS SECTION. This will be completed after your submitted proposal has been reviewed.)