Localization of a Repeating Fast Radio Burst with Green Bank Telescope

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1 Short Abstract

We request 5.5 hours of Green Bank Telescope observation time to identify the host galaxy of FRB20181030A through a more precise localization.

2 Scientific Justification

2.1 Fast Radio Burst (FRB)

A Fast Radio Bursts is a constant amplitude radio pulse that can last from milliseconds to a few seconds. They are point source-like and broadband over a large range of radio frequencies. FRBs come from all over the entire sky and arrive on earth at a rate of roughly a thousand times per day[1]. An average FRB peak can release a huge amount of energy which is comparable to the amount that the sun releases in three days[14]. Many FRBs have frequencies near 1400MHz, but they may also be found in lower ranges of 400-800 MHz.

The first FRB, known as Lorimer Burst, was detected in 2007 by Duncan Lorimer and his student David Narkevic in archival pulsar survey data[11][2]. Since then, a dozen of FRBs have been detected by several radio telescopes (including CHIME), with the majority of them being classified as irregular repeaters.

The origin of the FRBs is not yet exactly identified but numerous candidates have been proposed ranging from high-energy astrophysical processes like rapidly rotating neutron stars and merging black holes to extraterrestrial intelligence. Although a few milky way FRBs have been detected, most of them are known to have extragalactic origins. The fact that these bursts are very short, constrains the size of the source to a few hundred kilometers or less. Moreover, a polarized FRB is the signature of a source with a strong magnetic field. [13].

In 2020, after a successful FRB localization to the same coordinates of a known gamma-ray burst, it was proposed that magnetars can be a source of FRBs[16][3]. Other suggested

[1] The distribution of FRBs is not concentrated on the plane of the milky way.

[2] First live detection of FRBs was reported in 2015 by Parkes Observatory.

[3] FRB 180916 was localized to magnetar SGR 1935+2154.

sources include supernovas or blitzars[8], explosive decays of axion miniclusters[15], decay of cosmic string cups[7], the collapse of the magnetospheres of Kerr–Newman black holes[10][17], black hole explosion (which would be the first detection of quantum gravity effects)[5], and superradiance phenomena for repeating FRBs[9].

FRBs are dispersed by the tenuous plasma that exists along the line of sight, leading to a smearing of the signal over time with a frequency dependence of $\delta t \propto \nu^{-2}$. This smearing is characterized by the dispersion measure (DM) of the FRB, defined as the integrated electron density along the line of sight. The milky way (MW), the FRB host galaxy, and the intergalactic medium (IGM) all add a contribution to the observed DM ($\mathrm{DM_{obs}} = \mathrm{DM_{MW}} + \mathrm{DM_{IGM}} + \mathrm{DM_{Host}}$).

In order to obtain a more precise description of the nature and behavior of FRBs, it is necessary to associate them with their hosts to obtain redshifts and host DM contribution estimates. The ability to link events to host galaxies will be an extreme advancement in our understanding of the FRBs which helps constrain source models, as well as more precisely reveal the electron density in the IGM.

2.2 CHIME Experiment

The *Canadian Hydrogen Intensity Mapping Experiment (CHIME)* is a non-steerable radio telescope located at the Dominion Radio Astrophysical Observatory research facility in British Columbia which was launched in 2018. The main purpose of this telescope is to form a 3-dimensional map of hydrogen density, that will be used to measure the expansion history of the universe. In addition to that, its high mapping speed, large instantaneous field of view (200 square degrees) and wide frequency coverage ($400 - 800 MHz$) make it a unique instrument for observing FRBs and pulsars.

By mid-2020, CHIME reported more than a thousand live FRB detections including the first milky way FRB and eight new repeating FRBs[3]. The spatial distribution of FRBs observed by CHIME from 28 August 2018 to 1 July 2019 are shown in figure 1.

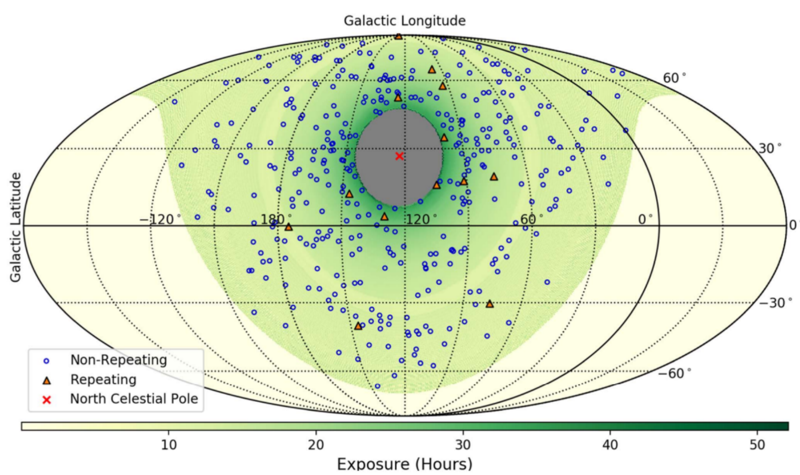

Figure 1: FRBs observed by CHIME in Galactic coordinates with locations of 474 nonrepeating and 18 repeating (62 bursts) sources[2]

2.3 Green Bank Telescope

Green Bank Telescope (GBT) is the world's largest steerable radio telescope, located in West Virginia, near the heart of *United States National Radio Quiet Zone*. The telescope began working in 2001 and it was constructed following the collapse of another radio telescope in the same location in 1988.

GBT is designed to operate at meter to millimeter wavelengths. Its 100-meter diameter collecting area, unblocked aperture, and excellent surface accuracy provide superb sensitivity across the telescope's full 0.1–116 GHz operating range (corresponding to an angular resolution of 6.5-9 arcsec). About 85 percent of the local celestial hemisphere is accessible through GBT observations.

Since 2001, it has detected several significant objects including three new millisecond pulsars, 28 new complex molecules in IGM, and a new massive neutron star. On top of these breakthroughs, GBT has also been used to detect FRBs [1].

3 Technical Justification

3.1 Source of Observation

Among all the FRBs, repeating ones are of great importance since the observations needed to localize their host galaxies are done more conveniently[4]. In 2018, CHIME reported the detection of two periodic FRBs named FRB 20180916B and FRB20181030A[3]. The first one has been precisely localized to a nearby spiral galaxy[12][5], but the host galaxy of the latter is still under further investigation (details of the specifications and location of FRB20181030A is available in table 1 and figure 2).

Later studies were able to localize FRB20181030A to a sky area of $5.3 arcmin^2$, resulting in seven host-galaxy candidates, among which NGC 3252 seems to be the most promising one[6]. However, there still remains the demand for a more precise localization and a multi-wavelength follow-up on this FRB. Therefore, it makes sense to again observe this source with a telescope possessing a higher angular resolution on the desired frequency range. Considering these two factors, the *Green Bank Telescope* sounds to be the right choice for our purpose.

3.2 Observation Specifics[6]

According to the calculations done by the *GBT Sensitivity Calculator*, we need $1.62 \times 10^4 s$ to observe FRB20181030A with the sensitivity of 3 arcmins to achieve a minimum SNR of 5σ (The observation will be focused on the coordinates indicated in table 1). However, considering the time spent on pointing and calibration (5-10 minutes), setup time at the

[4]Currently, we are also able to localize non-repeating FRBs (e.g. FRB 180924 which was the first non-repeating FRB to be localized[4]).

[5](Galaxy SDSS J015800.28+654253.0)

[6]based on *Proposer's Guide for the Green Bank Telescope*, GBT Support Staff, August 25, 2022

RA (degrees)	158.35±0.18
DEC (degrees)	73.79±0.31
dispersion measure pc/cm^3	103.3960±0.0058
peak frequency (MHz)	703.7
Lowest frequency band of detection (MHz)	400.2
Highest frequency band of detection (MHz)	800.2

Table 1: Characteristics of FRB20181030A as reported by CHIME

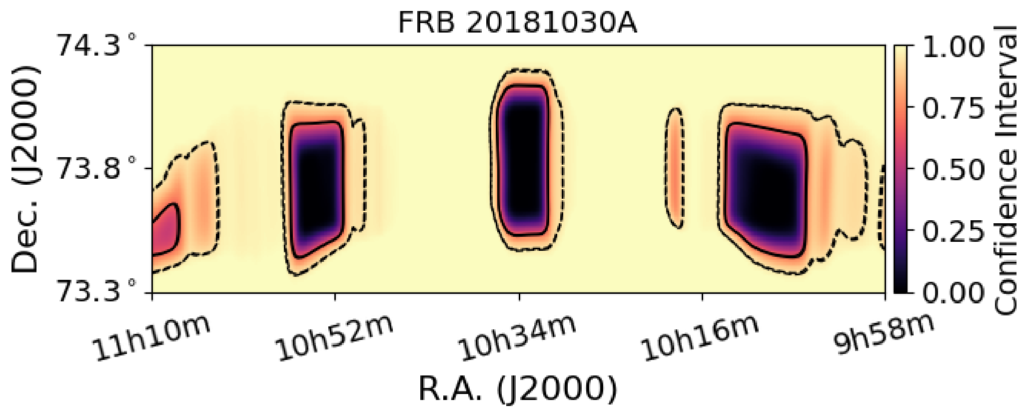

Figure 2: Location of FRB20181030A on sky, From CHIME catáloge

start of the observations (15 minutes), GBT slew times[7], and the recommendation of using a 10 percent higher period estimate as an overhead time for observations of low frequencies, it seems reasonable to request at least five hours and a half of GBT time.

We do not foresee any huge difficulties on the noise reduction of the data, since the FRB spike is pretty well detectable compared to the background. We demand to use the *PF1* receiver with the frequency band of 680 - 920 MHz, which is going to be available during 2023 observing schedules (according to the *proposer's guide*). The back end needed for this observation is *Versatile GBT Astronomical Spectrometer (VEGAS)*. The *Standard Observing Mode* and *Switching Method* are chosen to be "Track" and "Position Switching" respectively.

As we are working on the low-frequency range, atmospheric opacity is not much of a concern and the requested observation slot is not dependent on the weather forecast. Since this observation is defined to be performed on one session focusing on only one source, there are no large changes in motion that occur on timescales less than 30 seconds apart. Therefore, there exists no concern about stressing the GBT structure.

This observation proposal falls within the *Regular Fixed and Monitoring proposals* in GBT classification, requesting less than 200 hours and lasting less than 1 year.

[7]The GBT slew rate is 35.2 deg/min in Azimuth and 17.6 deg/min in elevation during warm weather. When the temperature is below 17 Fahrenheit (-8.3 Celsius), the slew rates are half of the warm values.

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