Optical follow-up of 3 one-off FRB host galaxies

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1 Abstract

Fast Radio Bursts are bright, short duration, radio bursts which are extra-galactic in origin. Localisation of FRBs to host galaxies and characterizing the properties of hosts are the key to constraining FRB progenitors. Moreover, the redshift estimation of the host galaxy enables tightening of the Dispersion Measure-redshift (DM-z) relationship of FRBs and solving the missing baryon problem. One-off FRBs are harder to localise than repeating FRBs and thus their host galaxies are not well studied. We have identified potential host galaxies of 3 low-DM one-off FRB in the CHIME database. We request Gemini imaging and spectroscopy observations of these galaxies to estimate it's properties and redshift.

2 Scientific Justification

2.1 Importance of host galaxy localisation of Fast Radio Bursts

Fast Radio Bursts are highly energetic ($\sim$ Jy) μs - ms duration bursts of radio wavelength, most of which have known to have an extragalactic-origin (Lorimer et al. [2007], Masui and Chime/Frb Collaboration [2021]). The free-electron density encountered in the line-of-sight causes the FRB signals to be dispersed so that lower-frequencies arrive later than the higher-frequencies ($t_\nu \propto \nu^{-2}$). Dispersion Measure (DM) is the integrated electron density along the line of sight and has contributions from the Milky Way (MW) Interstellar Medium (ISM), MW halo, Inter Galactic Medium (IGM), and the FRB host such that $DM_{FRB} = DM_{MW,ISM} + DM_{MW,halo} + DM_{IGM} + DM_{host}$. While the DM contributions from the MW ISM, MW halo and the host galaxy can be estimated from existing models (Cordes and Lazio [2002], Yao et al. [2017], Zheng et al. [2014]), the DM_{IGM} is an excellent tracer of the baryonic matter in the IGM and helps solve the missing baryon problem. About three-quarters of the baryonic matter in the Universe predicted by the Cosmic Microwave Background is not observed directly and is thought to reside in a diffuse state in the IGM. Macquart et al. [2020] has recently shown that for 8 FRBs localised to host galaxies, the observed relationship between DM_{IGM} (DM_{cosmic}) and the redshift of the host (Fig 2) is in agreement with the relationship predicted by the CMB. Localisation of more FRBs to their host galaxies and redshift determination of the hosts will tighten this relationship.

The CHIME catalog listed 535 FRBs detected in the first year of operation (Masui and Chime/Frb Collaboration [2021]), but the progenitors of FRBs remain unknown. FRBs have been broadly classified into one-offs and repeaters based on whether there are one or more bursts observed from the FRB position. The CHIME/FRB sample reveals that the repeaters have narrower bandwidths and scattering times than one-offs (Fig 3), suggesting different progenitor channels for the two populations. Localising FRBs to host galaxies is vital to understanding their origin, and provide more clues to the different mechanisms with which these two populations occur. Repeating FRBs can be easily localised to arc-second angular position on the sky using Very Long Baseline Interferometery, but one-off FRBs are difficult to localise as they happen at random times and positions in the sky. Heintz et al. [2020] listed repeating and one-off FRBs localised to host galaxies which exhibit a broad range of color and Star Formation Rate (SFR).

Bhandari et al. [2020] list that the accretion-induced collapse of white-dwarfs, core-collapse supernovae, and compact merger events are the plausible mechanisms for one-off FRBs. Localising more one-off FRBs to host galaxies will help test the validity of these claims.

2.2 This proposal

We searched the CHIME/FRB database for low-DM one-off FRBs and identified 3 FRB candidates which have only one known galaxy in the the ∼arc-min localisation region. Here, we propose to use the Gemini North GMOS instrument for deep optical imaging of these localisation regions in the r-, i-, and z- bands and also to get the spectra of the identified host galaxies to estimate their redshift. These observations will provide a key understanding of one-off FRB host galaxies and progenitor channels.

3 Technical Justification

3.1 The CHIME/FRB low-DM one-off FRBs

CHIME telescope is a transit telescope operating in the 400-800 MHz frequency range and maps the entire northern sky everyday with it's ¿ 200 degree square field of view (Amiri et al. [2018]). The CHIME/FRB project has detected more that 95% of the known FRBs to date. From the CHIME/FRB database, we did an archival search of low-DM one-off FRBs (DM $<$ 150 pc cm^{-3}) to identify FRBs in the local Universe. We estimated the maximum redshift (z_{max}) of the FRB hosts from the extragalatic DM and the Macquart DM-z relationship (Macquart et al. [2020]) assuming all extragalactic DM to come from the IGM. Based on the z_{max} and localisation regions for these FRBs, we searched the known galaxy catalogs and found host galaxies in the Dark Energy Survey catalog (DES). Most FRBs had multiple candidate host galaxies in the localisation region, and thus require a more precise localisation to pinpoint their hosts. However, for 3 FRBs, there was only one galaxy in the localisation region (See Table 3.1). The probability of chance coincidence between these candidate hosts and FRBs are $< 10^{-2}$.

FRB	RA (deg)	DEC (deg)	DM_{total} (pc cm^{-3})	DM_{MW} (pc cm^{-3})	DM_{halo} (pc cm^{-3})	$DM_{extragalactic}$ (pc cm^{-3})	z_{max}	Host Galaxy
FRB1	46.87±0.02	86.81±0.04	119.45	60.78	30.0	28.67	0.03	DES J2144
FRB2	259.99±0.08	69.92±0.02	129.95	44.68	30.0	55.27	0.05	DES J0333
FRB3	189.49±0.07	35.65±0.04	134.56	48.67	30.0	55.89	0.05	DES J2167

3.2 Gemini Observing Strategy

Deep imaging in the r-, i-, and z- bands are required to obtain the galaxy luminosity and color, which will help us estimate the galaxy mass and age. In addition, it will also allow us to probe the size and structure of the galaxy. We propose to follow-up each of the 3 FRBs with a total exposure of 2700s each. The imaging observations will be centered on the source position listed in Table 3.1. Using the Gemini Integration Time Calculator (ITC), we calculated the exposure time required on each source in

900s observing windows for each filter. The fiducial target for each calculation was a Gaussian profile with a FWHM of one arcsecond, a spatially integrated brightness of $m_{r'} = 20.0$ AB mag, and the spectrum of a Sc type spiral galaxy mapped to $z = z_{max}$ for each of the sources.

GMOS spectroscopy of the host galaxies is required to estimate the redshift of the galaxy. This will set the energetics of the burst and will help strengthen the DM-z relationship of FRBs. Spectroscopy would also yield the metallicity and star formation rate of the galaxies, and thus help us better understand the progenitor channels of these one-off FRBs. We propose the spectroscopic observation of the host galaxies using the R400 grating in combination with a 1" slit, covering the wavelength range from 4650 to 8900 A^o, similar to what Tendulkar et al. [2017] did for the spectroscopy of the FRB 121102 host galaxy. The ITC returns a necessary total exposure time of 900s on the source. The observing conditions were set to the default Gemini observing conditions. The resulting exposure times for each observation is listed in Table 3.2.

Observation	Filter/ Grating	Exposure time
Imaging	r	900s
Imaging	i	900s
Imaging	z	900s
Spectroscopy	R400	900s

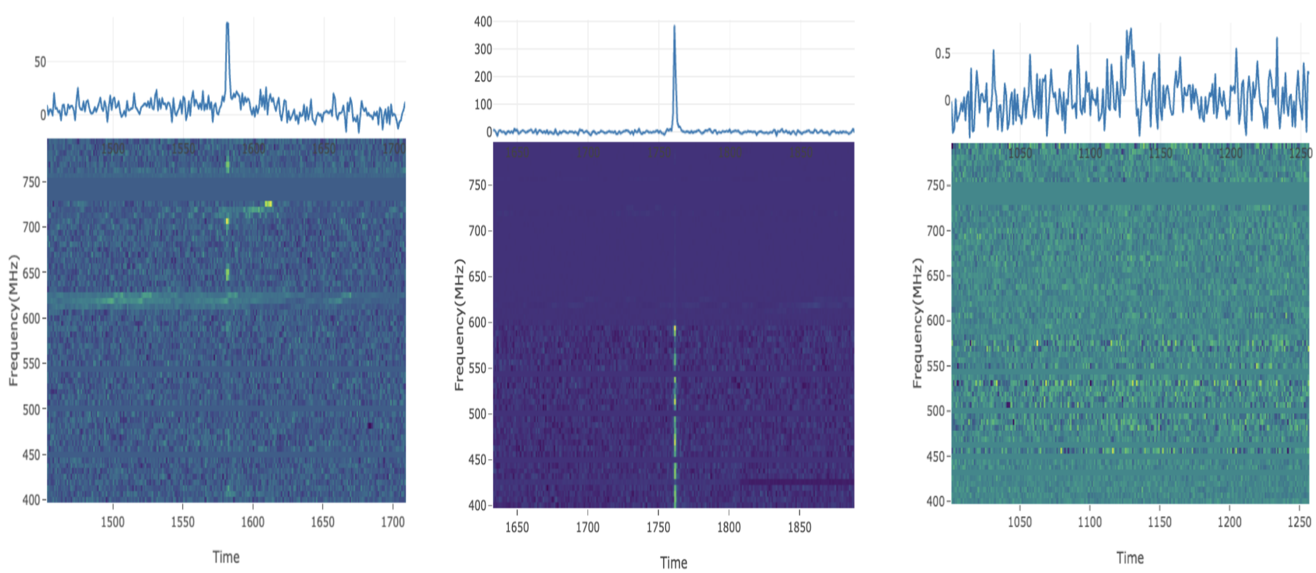

Figure 1: Plots showing the frequency-time dependence of the 3 FRB bursts.

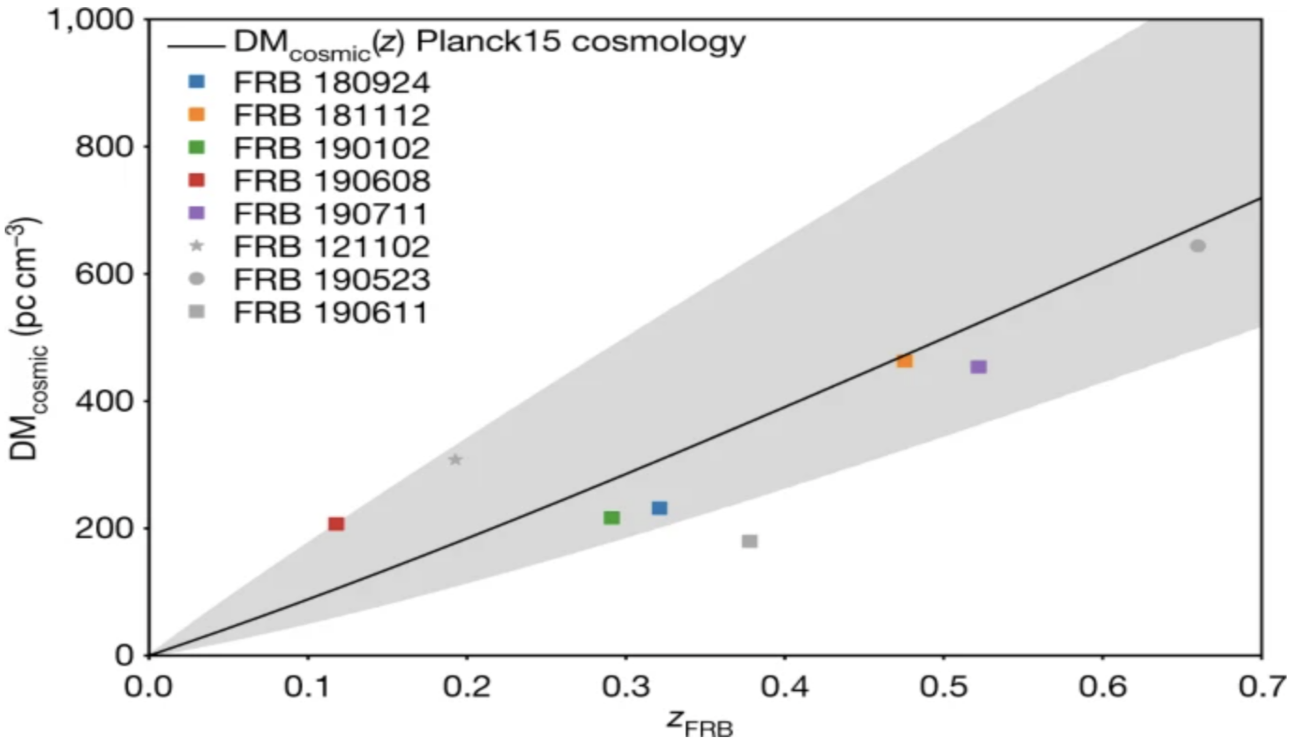

Figure 2: A plot showing the expected relation between DM$_{cosmic}$ and redshift for a universe based on the Plank15 cosmology and the data points derived from localised FRBs. (Figure is taken from Macquart et al. [2020]

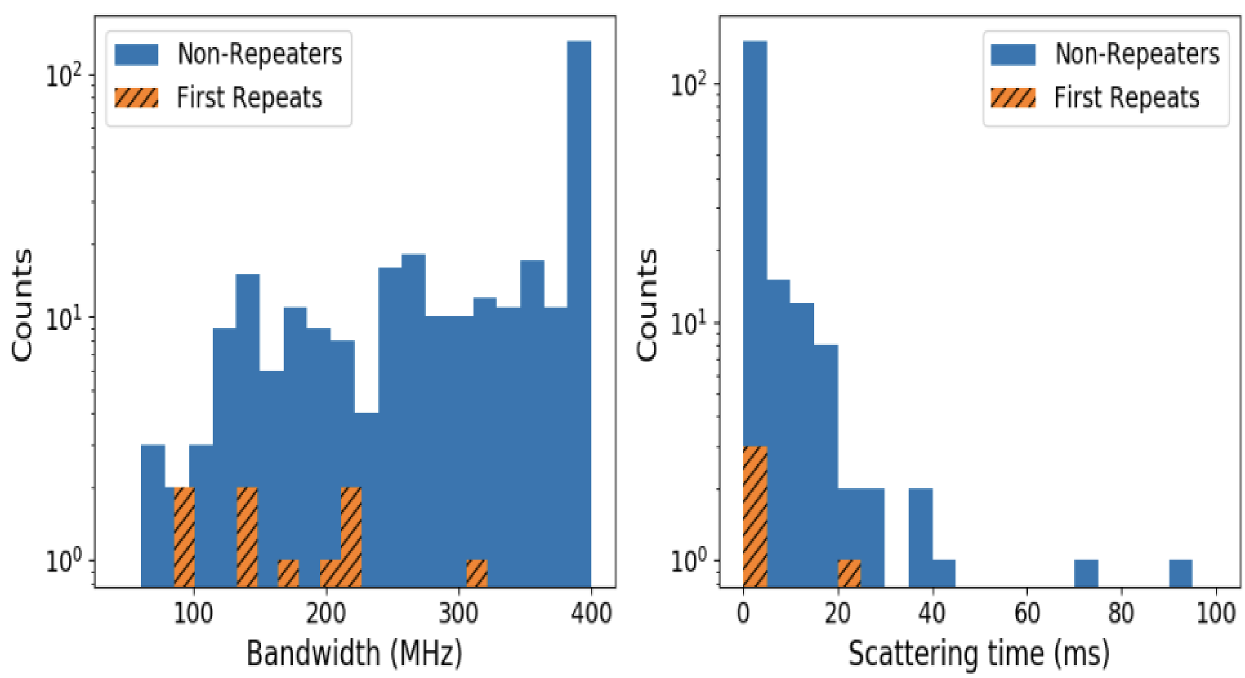

Figure 3: Plots showing the differences in bandwidth and scattering times observed for repeaters and non-repeaters in the CHIME/FRB catalog (Masui and Chime/Frb Collaboration [2021])

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