URSI-RCRS 2024, ARIES/GEHU, Bhimtal, India, 22 - 25 October, 2024

An FRB Population Synthesis for SPOTLIGHT and Its Cosmological Inference

Siddhartha Bhattacharyya* (1), Saptarshi Sarkar (1), SPOTLIGHT team members
(1) NCRA-TIFR, Pune 411007, India; e-mail: sbhattacharyya@ncra.tifr.res.in

Abstract

Fast radio bursts (FRBs) are short, energetic extragalactic radio pulses that can address key cosmological problems. The SPOTLIGHT [1] survey aims to increase the number of localized FRBs, essential for such studies. Through FRB population synthesis, we predict the detection of ~300 localized FRBs with redshifts up to 3.4 in the next three years of science operation. This paper presents the anticipated distributions of dispersion measure (DM), redshift, and fluence, while demonstrating the potential uses of this population of localized FRBs in cosmology.

1. Introduction

Fast radio bursts (FRBs) are short-duration energetic dispersed extragalactic radio pulses. FRBs being an extragalactic signal can be used to solve several cosmological problems (such as the missing baryon problem, understanding dark energy, the Hubble tension, etc.) [2, 3] and constrain the respective parameters. However, to use FRBs as cosmological tools, we need localized events for which the host galaxy of the source is well-constrained.

To date, 787 FRBs have been reported in the public domain [4]. Out of these, only 45 FRBs have been localized to their host galaxies, making the redshift known [4]. The SPOTLIGHT [1] survey is anticipated to greatly increase the number of localized FRBs available. This dataset offers significant potential for various cosmological applications. For example, FRBs experience dispersion as they traverse through the intergalactic medium (IGM), the interstellar medium (ISM) of their host galaxy and the Milky Way. The dispersion measure (DM), obtained through dedispersion techniques, is the column density of free electrons along the line of sight from the FRB source. Localized FRBs provide us with both DM and redshift measurements, thereby facilitating estimates of the distribution of intergalactic matter density. This data is crucial for understanding the distribution of "missing" matter in the universe which is expected to be predominantly located in the IGM [2]. Constraining the dark energy equation of state is another example of using FRBs as cosmological tools. Dark energy remains an important, yet incompletely understood component of the universe. Presently, the Cosmic Microwave Background (CMB) provides the most precise constraints on the dark energy equation of state [3]. However, because the CMB primarily probes the early universe, it cannot sufficiently constrain cosmological models where the dark energy equation of state either evolves with time (such as the Chevallier–Polarski–Linder (CPL) model) or is a constant not equal to -1 (such as the wCDM model) [3]. For such models, the CMB fails to provide a tight constraint on both the dark energy equation of state, and the Hubble constant.

A sizable dataset of localized FRBs offers promise as a late-time cosmological probe capable of addressing these problems and refining our understanding of the IGM matter distribution, and also dark energy. Macquart et. al [2] derived a value for the cosmic baryon density using 5 localized FRBs and found it consistent with the value derived from the CMB (Figure 1). This constraint can be significantly improved by using a larger sample of localized FRBs. Zhao et. al [3] showed that the combination of localized FRB and CMB data can be used to put tight constraints on the dark energy parameters as well as the Hubble constant, and hence can be helpful in solving the Hubble tension. They also show that if 10000 FRBs are detected and localized in the future, it would help break the parameter degeneracies inherent in the CMB data better than what is currently possible.

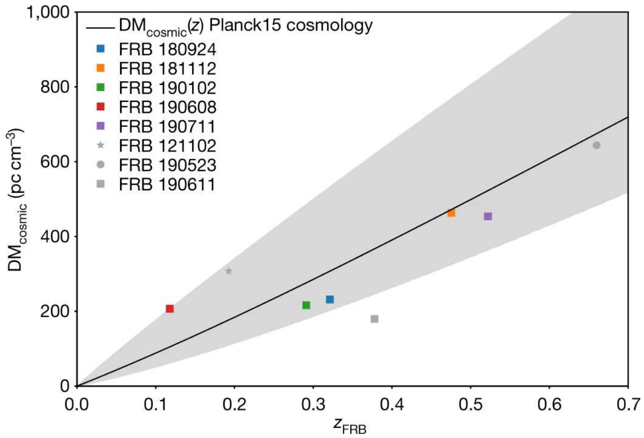

Figure 1. The cosmological contributions to the total DM as a function of localized FRB redshifts. Coloured points represent the gold-standard sample on which the primary analysis is based. The solid black line shows the expected relation between cosmological contribution to DM and redshift considering the Planck 2015 result [5]. Figure borrowed from [2].

2. FRB Population Synthesis

Since the SPOTLIGHT [1] is an upcoming FRB commensal survey, we have synthesized the population of FRBs which are supposed to be detected in the coming three years of the SPOTLIGHT [1] survey using a Python-based package called *frbpoppy* [6, 7]. This allows the comparison between simulated and real data to understand the underlying physics and selection effects. This further initiates the process by simulating the cosmic population of FRBs by providing various cosmological parameters such as FRB source number density, different DM contributions, luminosity functions, constraints on the maximum redshift, and size of the FRB population. It can be used to simulate a population of repeating or non-repeating FRBs, or even a combination of both. Following the creation of this intrinsic FRB population, *frbpoppy* proceeds to generate a simulated survey and combines the generated intrinsic FRB population with the simulated survey parameters. Integrating the cosmic population with the survey characteristics can provide insights into detected FRBs' expected distribution and properties. By tuning FRB parameters such as the bursts' intrinsic and scattering widths, DM, and fluence to match the simulated population with existing FRB surveys (e.g. CHIME/FRB, CRAFT at ASKAP), we find that the SPOTLIGHT [1] survey can yield ~300 localized FRBs in three years of operation with redshifts up to 3.4. Out of these 300 localized events, 87 FRBs will be detected at Band-3, 102 FRBs will be detected at Band-4, and 111 FRBs will be detected at Band-5, respectively.

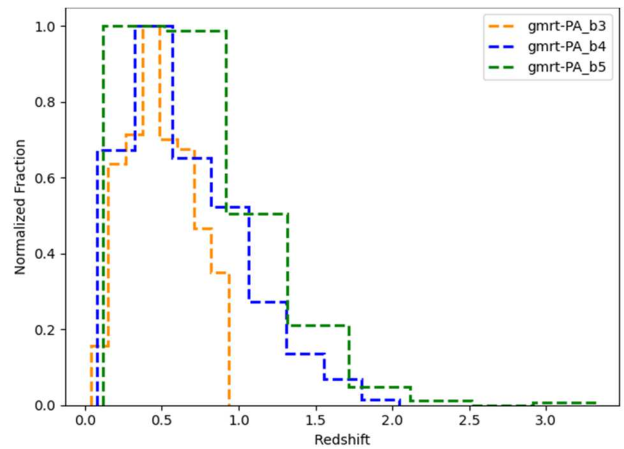

Figure 2. The redshift distribution of the FRBs that are expected to be detected at the different frequency bands of the SPOTLIGHT [1] project over the coming three years.

Figure 2 shows the predicted redshift distribution of the non-repeating FRBs supposed to be detected at three different frequency bands of the SPOTLIGHT [1] project over the coming three years. We used *frbpoppy* for this prediction for the given survey parameters of the different frequency bands. We see that the redshift distribution peaks near 0.5, which is nearly the same for all of the bands considered here. However, the redshift distribution spreads up to 1 for Band-3, 2.6 for Band-4, and 3.4 for Band-5, respectively. This implies that Band-3 can probe the weaker low-DM FRB population whereas both Band-4 and 5 are capable of detecting a brighter high-DM FRB population. This kind of redshift distribution is very helpful in constraining the parameters for the different cosmological problems stated earlier, such as missing baryon, dark energy equation of state, Hubble tension, etc. In addition to the redshift distribution, other FRB parameters relevant to the SPOTLIGHT [1] project can also be estimated using *frbpoppy*. These estimates are not included in this paper but will be discussed during the presentation. Until now, we have discussed the predicted parameter distributions for the non-repeating FRBs supposed to be detected in the SPOTLIGHT [1] project; a similar prediction can be done by considering either only repeating, or both repeating and non-repeating FRBs. This will also be highlighted in our presentation.

3. Summary

In this presentation, we will highlight the predicted DM, redshift, and fluence distributions of the FRBs which are supposed to be detected in the coming three years of the SPOTLIGHT [1] survey. We will also discuss how these predicted distributions can be useful in solving different cosmological problems discussed above. Our study underscores the importance of the FRB population synthesis and its applications in the solving of several cosmological problems with a well-constrained parameter space.

4. Acknowledgements

The authors would like to acknowledge Ms. Harshini Paranjape, an integrated M.Sc. Physics student from Indian Institute of Technology, Roorkee, for her invaluable discussions on this project. The authors also would like to acknowledge Ms. Afifa Jamal, a B.Sc. Physics student from Aligarh Muslim University, Uttar Pradesh, for her invaluable contribution to *frbpoppy*. We thank the National Centre for Radio Astrophysics (NCRA) and the Department of Atomic Energy (DAE) for their support and resources.

5. References

[1] J. Roy, J.N. Chengalur and the SPOTLIGHT team, “SPOTLIGHT: A Probe of the Fast Radio Transient Sky”, Abstract, URSI-RCRS, 2024.

[2] J.-P. Macquart et al., “A census of baryons in the Universe from localized fast radio bursts,” Nature, vol. 581, no. 7809, pp. 391–395, May 2020, doi: 10.1038/s41586-020-2300-2.

[3] Z.-W. Zhao et al., “Cosmological Parameter Estimation for Dynamical Dark Energy Models with Future Fast Radio Burst Observations,” ApJ, vol. 903, no. 2, p. 83, Nov. 2020, doi: 10.3847/1538-4357/abb8ce.

[4] E. Petroff and O. Yaron, “Fast Radio Burst Catalogue on the TNS,” Transient Name Server AstroNote, vol. 160, p. 1, Aug. 2020.

[5] P.A.R. Ade et al., “Planck 2015 results - XIII. Cosmological parameters,” A&A, vol. 594, p. A13, Oct. 2016, doi: 10.1051/0004-6361/201525830.

[6] D. W. Gardenier, J. van Leeuwen, L. Connor, and E. Petroff, “Synthesising the intrinsic FRB population using frbpoppy,” A&A, vol. 632, p. A125, Dec. 2019, doi: 10.1051/0004-6361/201936404.

[7] D. W. Gardenier, L. Connor, J. van Leeuwen, L. C. Oostrum, and E. Petroff, “Synthesising the repeating FRB population using frbpoppy,” A&A, vol. 647, p. A30, Mar. 2021, doi: 10.1051/0004-6361/202039626.