Science Bulletin 67 (2022) 2398–2401

Contents lists available at ScienceDirect

Science Bulletin

journal homepage: www.elsevier.com/locate/scib

Short Communication

Circular polarization in two active repeating fast radio bursts

Yi Feng [a,1], Yong-Kun Zhang [b,a,c,1], Di Li [b,a,c,d,*], Yuan-Pei Yang [e,f], Pei Wang [b,g], Chen-Hui Niu [h,b], Shi Dai [i], Ju-Mei Yao [j]

[a] Research Center for Intelligent Computing Platforms, Zhejiang Laboratory, Hangzhou 311100, China
[b] National Astronomical Observatories, Chinese Academy of Sciences, Beijing 100101, China
[c] University of Chinese Academy of Sciences, Beijing 100049, China
[d] NAOC-UKZN Computational Astrophysics Centre, University of KwaZulu-Natal, Durban 4000, South Africa
[e] South-Western Institute for Astronomy Research, Yunnan University, Kunming 650500, China
[f] Purple Mountain Observatory, Chinese Academy of Sciences, Nanjing 210023, China
[g] Institute for Frontiers in Astronomy and Astrophysics, Beijing Normal University, Beijing 102206, China
[h] Institute of Astrophysics, Central China Normal University, Wuhan 430079, China
[i] School of Science, Western Sydney University, Locked Bag 1797, Penrith NSW 2751, Australia
[j] Xinjiang Astronomical Observatory, Chinese Academy of Sciences, Urumqi 830011, China

ARTICLE INFO

Article history:
Received 18 September 2022
Received in revised form 26 October 2022
Accepted 15 November 2022
Available online 15 November 2022

Fast radio bursts (FRBs) are bright millisecond-duration radio transients first discovered by Lorimer et al. [1]. While their cosmological origin and energetic nature make them ideal tools for probing a range of astrophysics [2], their progenitors and radiation mechanisms are still unknown. A particularly interesting subset of FRBs is the so-called repeating FRBs, which recurrently emit millisecond-duration radio bursts.

Polarization is a fundamental property of FRBs. Faraday rotation measure (RM) carries critical information about the intervening and circumburst environments. The polarization angle and degree of linear and circular polarization can be used to trace the radiation mechanisms and propagation processes [3]. For example, the polarization angle of FRB 20180301A showed various short-time-scale swings, which is hypothesized to originate within the magnetosphere of a magnetar [4]. Circular polarization has been detected in about half of non-repeating FRBs [5–7] [2], for which the polarization was detectable. Linear polarization has been detected in almost all repeating FRBs. In contrast, circular polarization is only seen in one repeating source FRB 20201124A [8].

Out of more than 600 published FRBs, only two, namely FRB 20121102A and FRB 20190520B, are found to coincide with a compact persistent radio source (PRS). We also revealed their extreme activity [9,10] and significant frequency evolution of linear polarization [7]. These facts suggest that these two sources are in complex plasma environment, either young in FRBs' evolution or a special sub-population of FRBs.

In this study, we reported new detections of circular polarization of both FRBs 20121102A and 20190520B by the Five-hundred-meter Aperture Spherical radio Telescope (FAST) [11], thus tripling the size of repeating FRB sample with circular polarization.

FRB 20121102A is the first precisely-localized repeating FRB [12]. FRB 20121102A has almost 100% linear polarization at 4–8 GHz [13]. In contrast, it has no linear polarization at 1.25 GHz [7,9] thus no measurable RM. The depolarization toward lower frequencies can be well explained by RM scatter due to multipath propagation [7,14]. In fact, such frequency evolution of polarization seems to be a unified feature of all active repeaters [7]. FAST detected 1652 independent bursts in 59.5 h spanning 62 days [9], resulting in a bimodal energy distribution. Further analyses of the same dataset revealed circular polarization in twelve bursts. The largest degree of circular polarization is about 64%. FRB 20190520B is the first persistently active FRB, discovered through the Commensal Radio Astronomy FAST Survey (CRAFTS) [15] and then localized by the Karl G. Jansky Very Large Array (VLA)-realfast system [10]. Similar to FRB 20121102A, FRB 20190520B has no linear polarization at 1.25 GHz [7] because of RM scatter. Further analyses of the FAST sample in Ref. [10] revealed circular polarization in three bursts. The details of the observations and data reduction can be found in Supplementary materials A. The time of arrival and the degree of circular polariza-

* Corresponding author.
E-mail address: dili@nao.cas.cn (D. Li).

[1] These authors contributed equally to this work.

[2] See Table S1 in Ref. [7] for a summary of available circular polarization measurements of non-repeating FRBs.

https://doi.org/10.1016/j.scib.2022.11.014
2095-9273/

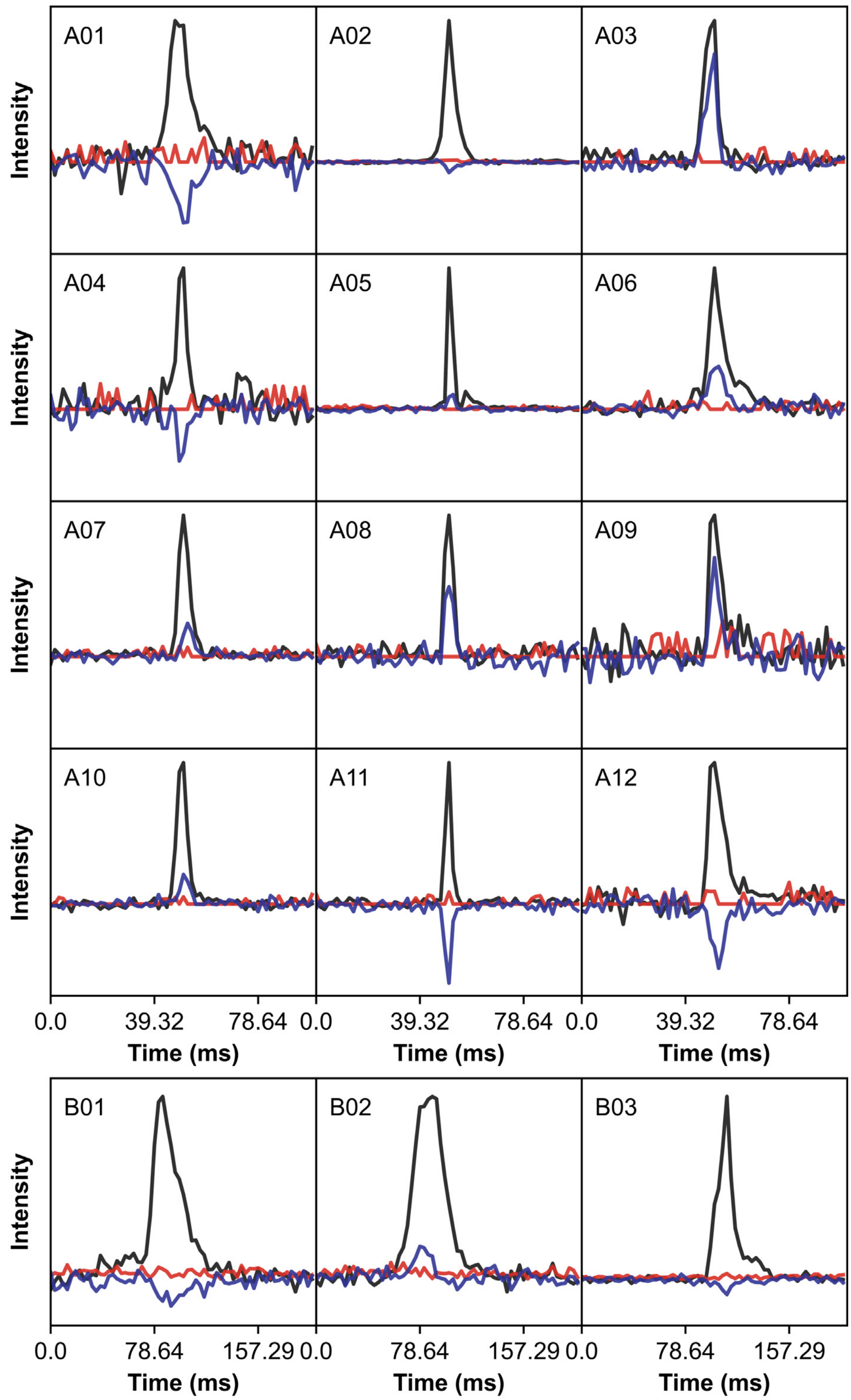

Fig. 1. Polarization profiles of twelve bursts with circular polarization of FRB 20121102A (A 01–12) and three bursts of FRB 20190520B (B 01–03) with FAST. The black, red and blue lines represent Stokes I, the linear polarization and Stokes V, respectively.

tion of each pulse can be found in Table S1 (online). The polarization pulse profiles are shown in Fig. 1.

We then present spectral and temporal properties of the circular polarization. We show the dynamic spectra of Stokes V and flux density of Stokes V over frequency for six bursts with significant circular polarization in Fig. S1 (online). We did not detect any oscillation or sign change of circular polarization over frequency. In our sample, the circular polarization remained rather constant during the duration of any single burst, no sign change nor other significant variation. For example, we show degrees of circular polarization across $\sim$2 ms of burst 3, 8, 11 of FRB 20121102A in Fig. S2 (online). The degrees of circular polarization remain relatively constant in $\sim$ ms time-scale and the variations are within the ranges of error bars.

We consider two categories of mechanisms for generating circular polarization, namely processes during propagation versus radiation mechanism intrinsic to the FRB source. During propagation, multipath propagation and Faraday conversion [16,17] could, in some circumstances, generate circular polarization. Multipath propagation occurs when the electromagnetic radiation propagates in an inhomogeneous magneto-ionic environment. As these two FRBs have the largest RM scatter [7] corresponding to substantial surrounding electron density and complexities, they would have a better chance to have multipath propagation induced circular polarization than other FRBs. However, we demonstrated that the observed significant frequency-averaged circular polarization is unlikely induced by multipath propagation (Supplementary materials B). Faraday conversion is a relatively weak effect and generates observable circular polarization only when propagating through an extremely magnetized region with magnetic field reversals or propagating through strongly magnetized plasma consisting of relativistic electrons. As the two FRBs have complex environments, Faraday conversion could take place, but should remain rare because only a small fraction of bursts have observable circular polarization.

Finally, we consider radiation mechanism intrinsic to the FRB source. The observed circular polarization may originate within the magnetosphere of a magnetar, an increasingly favored origin of FRBs. Circular polarization is commonly seen in pulses from magnetars. The rarity of circularly polarized FRB bursts indicate similar conditions should be rare in FRB sources, even if the generation of circular polarization goes through analogous processes. We note that there are some variations on circular polarization between two adjacent bursts, as shown in Table 1. The difference of circular polarization might be due to the different magnetic field configurations or different beaming directions deviating from the line of sight, if the radiation mechanism is the coherent curvature radiation [18–20].

We then compare the circular polarization properties of these two active repeating FRBs with those of non-repeating FRBs. It seems that the circular polarization of the non-repeating FRBs is different from the repeating FRBs. The variation time-scale of the circular polarization of the non-repeating FRBs can be smaller than 1 ms. For example, the degree of circular polarization of FRB 20190611B varies from 15% to 57% in $\sim$1 ms [6]. The degree of circular polarization of FRB 20181112A varies from $-$34% to 17% in less than $\sim$0.1 ms [5]. The variation time-scale of the circular polarization of the non-repeating FRBs is much smaller than that of the repeating FRBs. The circular polarization of the non-repeating FRBs has been attributed to intrinsic radiation mechanism or the result of propagation through a relativistic plasma close to the source [5]. The short, millisecond-scale variation of the circular polarization of the non-repeating FRBs seems to favor intrinsic processes as they are closer to the presumed compact object.

Our observations have tripled the size of repeating FRB sample with circular polarization. The observed circular polarization is unlikely induced by multipath propagation. Our observations favor circular polarization induced by Faraday conversion or radiation mechanism intrinsic to the FRB source. The conditions to generate circular polarization have to be rare in either case, as there are only about 1% and 4% of bursts being seen with circular polarization for FRB 20121102A and FRB 20190520B respectively, much less than the $\sim$50% for non-repeating FRBs. Further, systematic study of circular polarization will shed critical light on the environment and radiation mechanisms of repeating FRBs with this growing sample.

Data availability

The data of the fifteen bursts and the calibration files are openly available in Science Data Bank at https://doi.org/10.57760/sciencedb.04389.

Conflict of interest

The authors declare that they have no conflict of interest.

Acknowledgments

This work was supported by the National Natural Science Foundation of China (11988101, 12203045, and 11725313), the Key Research Project of Zhejiang Laboratory (2021PE0AC03), and the National Key R&D Program of China (2017YFA0402600). Yuan-Pei Yang is supported by the National Natural Science Foundation of China (12003028), the China Manned Spaced Project (CMS-CSST-2021-B11), and the National Key Research and Development Program of China (2022SKA0130101). Shi Dai is the recipient of an Australian Research Council Discovery Early Career Award (DE210101738) funded by the Australian Government. Pei Wang acknowledges support from the National Natural Science Foundation of China (U2031117), the Youth Innovation Promotion Association CAS (2021055), CAS Project for Young Scientists in Basic Reasearch (grant YSBR-006) and the Cultivation Project for FAST Scientific Payoff and Research Achievement of CAMS-CAS. This work made use of the data from FAST (Five-hundred-meter Aperture Spherical radio Telescope), a Chinese national mega-science facility, operated by National Astronomical Observatories, Chinese Academy of Sciences. We would like to thank Don Melrose for valuable discussions.

Author contributions

Yi Feng led the data analysis, interpretations and manuscript preparation. Yong-Kun Zhang led the data visualization. Di Li launched the FAST observation campaign and contributed to the writing. Pei Wang and Chen-Hui Niu carried out the data acquisition. Yuan-Pei Yang, Shi Dai and Ju-Mei Yao contributed to theoretical investigations. All authors discussed interpretations and commented on the manuscript.

Appendix A. Supplementary materials

Supplementary materials to this short communication can be found online at https://doi.org/10.1016/j.scib.2022.11.014.

References

[1] Lorimer DR, Bailes M, McLaughlin MA, et al. A bright millisecond radio burst of extragalactic origin. Science 2007;318:777.
[2] Macquart JP, Prochaska JX, McQuinn M, et al. A census of baryons in the Universe from localized fast radio bursts. Nature 2020;581:391–5.
[3] Lu W, Kumar P, Narayan R. Fast radio burst source properties from polarization measurements. Mon Not R Astron Soc 2019;483:359–69.
[4] Luo R, Wang BJ, Men YP, et al. Diverse polarization angle swings from a repeating fast radio burst source. Nature 2020;586:693–6.
[5] Cho H, Macquart JP, Shannon RM, et al. Spectropolarimetric analysis of FRB 181112 at microsecond resolution: implications for fast radio burst emission mechanism. Astrophys J Lett 2020;891:L38.
[6] Day CK, Deller AT, Shannon RM, et al. High time resolution and polarization properties of ASKAP-localized fast radio bursts. Mon Not R Astron Soc 2020;497:3335–50.
[7] Feng Y, Li D, Yang YP, et al. Frequency-dependent polarization of repeating fast radio bursts—implications for their origin. Science 2022;375:1266–70.
[8] Hilmarsson GH, Spitler LG, Main RA, et al. Polarization properties of FRB 20201124A from detections with the Effelsberg 100-m radio telescope. Mon Not R Astron Soc 2021;508:5354–61.
[9] Li D, Wang P, Zhu WW, et al. A bimodal burst energy distribution of a repeating fast radio burst source. Nature 2021;598:267–71.
[10] Niu CH, Aggarwal K, Li D, et al. A repeating fast radio burst associated with a persistent radio source. Nature 2022;606:873–7.
[11] Nan R, Li D, Jin C, et al. The five-hundred aperture spherical radio telescope (FAST) project. Int J Modern Phys D 2011;20:989–1024.
[12] Chatterjee S, Law CJ, Wharton RS, et al. A direct localization of a fast radio burst and its host. Nature 2017;541:58–61.

[13] Michilli D, Seymour A, Hessels JWT, et al. An extreme magneto-ionic environment associated with the fast radio burst source FRB 121102. Nature 2018;553:182–5.
[14] Yang YP, Lu W, Feng Y, et al. Temporal scattering, depolarization, and persistent radio emission from magnetized inhomogeneous environments near repeating fast radio burst sources. Astrophys J Lett 2022;928:L16.
[15] Li D, Wang P, Qian L, et al. FAST in space: considerations for a multibeam, multipurpose survey using China's 500-m Aperture Spherical Radio Telescope (FAST). IEEE Microwave Mag 2018;19:112–9.
[16] Vedantham HK, Ravi V. Faraday conversion and magneto-ionic variations in fast radio bursts. Mon Not R Astron Soc 2019;485:L78–82.
[17] Gruzinov A, Levin Y. Conversion measure of faraday rotation-conversion with application to fast radio bursts. Astrophys J 2019;876:74.
[18] Wang WY, Yang YP, Niu CH, et al. Magnetospheric curvature radiation by bunches as emission mechanism for repeating fast radio bursts. Astrophys J 2022;927:105.
[19] Tong H, Wang HG. Circular polarization of fast radio bursts in the curvature radiation scenario. Res Astron Astrophys 2022;22:075013.
[20] Wang WY, Jiang JC, Lee K, et al. Polarization of magnetospheric curvature radiation in repeating fast radio bursts. Mon Not R Astron Soc 2022;514:5080–9.

Yi Feng is a research fellow at the Zhejiang Laboratory. He received his Bachelor's degree in Physics from Tsinghua University in 2013 and Ph.D. degree in Astrophysics from University of Chinese Academy of Sciences in 2021. His research focuses on the fast radio bursts, pulsars, and gravitational waves.

Yong-Kun Zhang is a Ph.D. candidate at National Astronomical Observatories, Chinese Academy of Sciences. He obtained his Bachelor's degree in Physics from University of Chinese Academy of Sciences in 2019. His current research interest includes fast radio bursts, star formation, and applications of machine learning in astronomy.

Di Li is the Chief Scientist of the Radio Division of the National Astronomical Observatories, Chinese Academy of Sciences. He has been the chief scientist of FAST since 2018. He received his Bachelor's degree in Physics from Peking University in 1995 and Ph.D. degree in Astrophysics from Cornell University in 2002. His research work includes star formation, fast radio bursts, pulsars, gravitational waves, astrochemistry, and radio astronomy techniques.