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Proposed VLBI Study on Pulsars Discovered by FAST

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Abstract

The Five-hundred-meter Aperture Spherical radio Telescope (FAST) is the largest single dish radio telescope in the word, which has discovered more than 40 new pulsars. EVN observations have been proposed to measure the astrometric parameters of three FAST pulsars, which are model independent and useful for pulsar timing and luminosity estimation. The FAST VLBI system has also been developed, which is being tested now and would significantly improve the sensitivity of the existing VLBI networks in the future.

1 Introduction

Pulsars are the laboratories for some of the most extreme physics in the universe. Many scientific questions rely on the distances of pulsars, such as the correction of the radio luminosity, the constraint of the size of the neutron star photosphere.

Most pulsar distances are estimated from their dispersion measures (DM), using a model for the Galactic electron density (Taylor and Cordes, 1993; Yao et al. 2017). However, uncertainty of the distance prediction from the electron density model could be a factor of up to several (Yao et al. 2017). Pulsar astrometry is a model independent method to get the precise values of these fundamental parameters.

The Five-hundred-meter Aperture Spherical radio Telescope (FAST) is a Chinese mega science project ïijĹFigure 1ïijĽ, and the main structure of the telescope had been completed in September 2016. Now the FAST is being busily commissioned (Li et al. 2018).

Pulsar is one of the key sciences of FAST, and more than forty new pulsars were discovered by FAST in the past two years (CRAFTS). For new discovered pulsars, it is crucial to obtain their accurate astrometric parameters, which are important for pulsar timing, luminosity estimation and improvement of the Galactic electron distribution models.

Figure 1. Bird's-eye view of FAST.

2 Astrometry for three FAST pulsars

2.1 Sample

Three pulsars are selected from these FAST-discovered pulsars (CRAFTS), among which these three candidates are with higher flux density and suitable phase reference sources can be found.

PSR J2338+48 is the first pulsar discovered by FAST on August 4th, 2017 which was confirmed by the Effelsberg 100-m radio telescope in Germany. The dispersion measure of PSR J2338+48 is 34 pc/cm^3 with period of 118.7 ms, corresponding to a 1.96 kpc distance, according to the latest electron density model (Yao et al. 2017).

PSR J2053+47 is discovered by FAST on February 7, 2018 and confirmed by the Effelsberg 100-m telescope on March 19, 2018. Its dispersion measure is 331.3 pc/cm^3 with period of 4.907s, corresponding to an 8.92 kpc distance from the YMW model.

PSR J1822+26 is also discovered by FAST on April 29, 2018 and confirmed by the Parkes 64-m telescope on May 25, 2018. Its dispersion measure is 64.6 pc/cm^3 with period of 591.4 ms, corresponding to a 7.89 kpc distance from the YMW electron density model.

2.2 Proposed EVN observations

We propose EVN observations in phase reference mode for these three pulsars to obtain their accurate position information at first. If these pulsars could be successfully detected, we would request more epochs to measure their parallaxes and proper motions.

For VLBI phase referencing, the astrometric accuracy is dependent on the separation angle between the target and reference source (Deller et al. 2018).

The closest calibrator for PSR J2338+48 with precise and reliable positions is J2325+4806, with a total flux of 0.17 Jy at S band and 2.11^{o} separation from the target. To improve astrometric accuracy, we would like to observe it in the style of in-beam mode, and calibrators in the primary beam are needed.

The closest calibrator for PSR J2053+47 is J2102+4702, with a total flux of 80 mJy at S band and 1.6^{o} separation from the target. The closest calibrator for PSR J1822+26 is J1827+2638, with a total flux of 230 mJy at S band and 1.28^{o} separation from the target.

Some follow-up observations with the 19-beam receiver of FAST have been done for these three pulsars. The bottom limits of average flux density of J2053+47 and J1822+26 are determined to be around 50 uJy with duty cycle of 1%, while the flux density of J2338+48 is 815 uJy with duty cycle of 3%. Their positon errors are less than 2 arcminutes.

From the NVSS catalog, two candidates at least have been found within 7 arcminutes separation from the target pulsars. Proposal for 2-hrs e-EVN observations (proposal code RSC04) has been proved to confirm if these NVSS candidates are compact to be the in-beam calibrators. If one candidate at least for each target is compact source, the proposed observations would be able to be made in the in-beam phase reference mode, by pointing to one of the middle points of the in-beam calibrator and the target.

Since the targets are steep spectrum sources, we proposed to observe these targets at the long wavelength (L band, 18 cm) of EVN to improve the sensitivity.

In this way and as detailed in the technical justification, we need on-source time of about 2 hours for each target to detect them with an SNR >20 with the help of pulsar gating.

The immediate goal of this proposal is to determine accurate positions of the three pulsars, and the final goal is to measure their parallaxes and proper motions. The number of these sources would increases rapidly as the FAST survey begins formally.

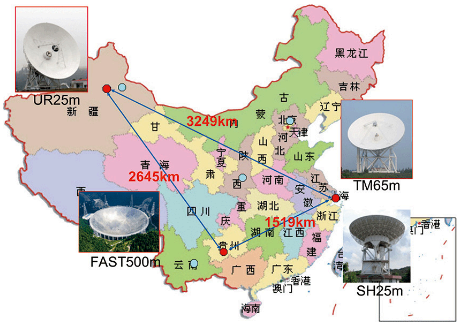

Figure 2. Telescopes with L band receivers in China.

3 FAST VLBI system

Very Long Baseline Interferometry (VLBI) research with FAST is one of the key science goals (Nan et al. 2011). As the most sensitive single-dish radio telescope, FAST could greatly improve the sensitivity of the current VLBI networks and detect weaker radio sources than before. For instance, the image sensitivity could be comparable to the value of the Full High Sensitive Array (HSA) (Zhang 2017) when FAST joins into the European VLBI Network (EVN).

The 19-beam receiver at L band has been installed at the FAST. The VLBI observations at L band have been carried out with Chinese VLBI networks including the Tianshan 26-m telescope in Xingjiang, the Tianma 65-m telescope and Sheshan 25-m telescope in Shanghai. FAST test observations with Chinese VLBI networks would be made in the near future, providing several 1500-3200km baselines (Figure 2.).

The VLBI system of FAST has been almostly established. All the seven sets of FAST receivers (70MHz to 3 GHz) would be used in the VLBI observations. ROACH2 is used to convert/sample the baseband data, which has been installed in the cabinet at the FAST site. The Hydrogen maser clock is used to provide the high-resolution time. Disk-based Mark VI has been installed for the data recording system, which has four disk modules with a total storage of 256 TB.

In the commissioning stage, several adjustment and early sciences goals have been considered, such as observing the satellite or strong calibrators to detect the first fringe, detecting strong OH and HI maser sources etc.

On the 5th of July in 2018, the interformetric test observation was conducted in the drift-scan mode between FAST in Dawodang (with ROACH2 and Hydrogen clock) and the 4.5-m telescope on the roof of the NAOC building (with ROACH2 and Rubidium clock). The satellite of AsiaStar 105E was observed at L band. The fringe was found successfully with offset time of about 3.4 ms.

More test observations would be done in the following days, such as observing the strong VLBA calibrators between FAST and these well established radio telescopes.

Acknowledgment

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