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Single Pulses from the Galactic Center Magnetar with the Very Large Array

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Abstract. Phased VLA observations of the Galactic center magnetar J1745-2900 over 8-12 GHz reveal rich single pulse behavior. The average profile is comprised of several distinct components and is fairly stable over day timescales and GHz frequencies. The average profile is dominated by the jitter of relatively narrow pulses. The pulses in each of the four profile components are uncorrelated in phase and amplitude, although the occurrence of pulse components 1 and 2 appear to be correlated. Using a collection of the brightest individual pulses, we verify that the index of the dispersion law is consistent with the expected cold plasma value of 2. The scattering time is weakly constrained, but consistent with previous measurements, while the dispersion measure $\mathrm{DM} = 1763^{+3}_{-10}$ pc cm^{-3} is lower than previous measurements, which could be a result of time variability in the line-of-sight column density or changing pulse profile shape over time or frequency.

Keywords. instrumentation: interferometers, techniques: interferometric, stars: neutron, pulsars: individual (J1745−2900)

1. Introduction

Interferometric radio telescope arrays offer a combination of a wider fields of view and higher resolution compared to single dish telescopes of comparable collecting area. These advantages come at the cost of significant computation, but enable techniques that allow us to both localize a transient source on the sky with high precision and extract pulse information on the time-frequency plane at the same time.

At the Karl G. Jansky Very Large Array, we have used fast-dump correlator modes that allow the recording on visibility data on millisecond timescales in two complementary ways (Figure 1). With fast imaging, (de-dispersed) visibilities can be used to produce a sequence of snapshot images at a series of dispersion measures, enabling a search for transient sources in the image plane (Law *et al.* 2015). With the same visibility information, we can also tile the field of view with phased-array beams, each of which can be searched in the time-frequency plane for pulsars and dispersed pulses from transient sources. We used a combination of these two approaches, for example, to localize the repeating fast radio burst source FRB 121102 and extract its dynamic spectrum (Chatterjee *et al.* 2017).

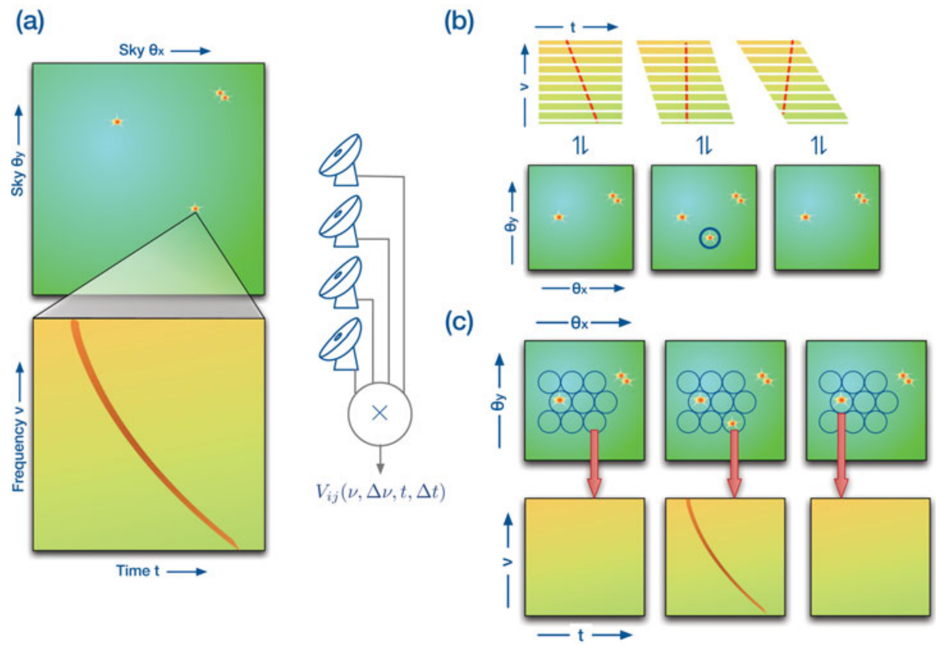

Figure 1. An illustration of the complementarity of fast imaging and beam-forming techniques. (a) Fast-dump visibilities are effectively sampling a 4-dimensional data volume: two spatial dimensions on the sky (θ_x and θ_y), as well as time (t) and frequency (ν) axes. A dispersed pulse (e.g., from a pulsar, magnetar, or fast radio burst) traces a dispersed track in the time-frequency plane at a particular position on the sky. (b) With fast imaging, we apply a trial dispersion measure to the visibility data at a given time (t), selecting a track in the (t, f) plane, and then search snapshot images created by Fourier inversion in the (θ_x, θ_y) plane for transient sources. (c) Beam-forming is a complementary procedure where we select specific positions (θ_x, θ_y) to extract phased and summed visibilities, and then search each resulting (t, f) dataset for dispersed pulses. For a known target like J1745−2900, we can form a single beam at the known position by phasing and summing the visibility data, and then analyze the resulting 2-dimensional (t, f) dataset, as shown here.

2. Observations of the Galactic center magnetar

The discovery of radio pulses from a magnetar in the Galactic center (Eatough *et al.* 2013, Shannon & Johnston 2013), only $\approx 2\farcs4$ from Sgr A* (projected distance of ∼0.1 pc at 8.5 kpc), is an unexpected opportunity. J1745−2900 offers a unique probe of the magneto-ionic environment in the Galactic center (GC) as well as puzzles about the GC pulsar population and the nature of the scattering environment (e.g., Bower *et al.* 2015).

Here we present observations of the Galactic center magnetar J1745−2900 using phased-array observations with the VLA. We used 4 GHz of bandwidth in two windows of 2 GHz each, centered at 8.2 and 11.1 GHz, with 4 MHz frequency channels and 200 μs time resolution. Comparison of our detected average pulse profiles with pulse profiles from other phased VLA observations (Bower *et al.* 2015) show dramatic time evolution over weeks to months (see Figure 2), in sharp contrast with the typical long-term stability of radio pulsar profiles.

A series of single pulses are shown in Figure 3. The pulses in the different profile components appear uncorrelated in amplitude and phase, though there is a small but significant correlation in the occurrence of pulses in two of the profile components. Using the

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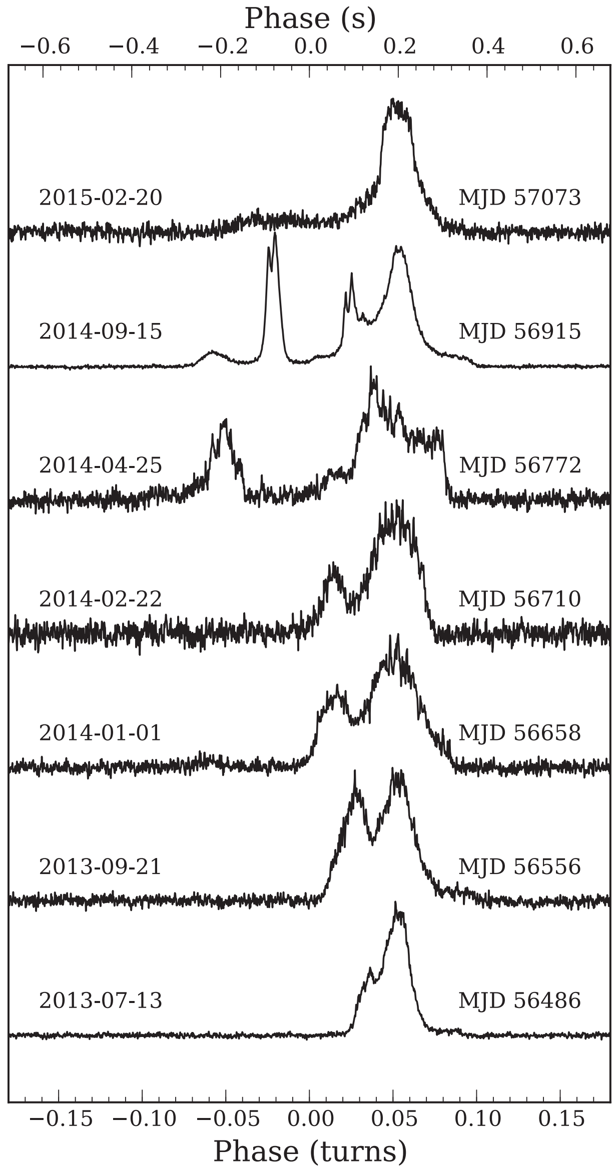

Figure 2. Folded pulse profiles of J1745−2900 from phased-array VLA observations. The profile for MJD 56915 comes from a 6.5 hour observation using 4 GHz of bandwidth. The remaining profiles are from data taken during a monitoring campaign of the magnetar at 8.5 GHz using 256 MHz of bandwidth and observing times of about an hour (Bower *et al.* 2015).

brightest single pulses, we measure the dispersion and scattering parameters of J1745−2900, and find that the index of the dispersion law is consistent with the expected cold plasma value of $\alpha = -2$. The best fit dispersion measure is $\mathrm{DM} = 1761.5^{+1.8}_{-2.1}$ pc cm^{-3}, slightly less than previous measurements. The discrepancy could be caused by a time-variable dispersion measure for J1745−2900 or be the result of changing profile shape in frequency or time. The scattering time is only weakly constrained, but is consistent with previous measurements. These results are presented in detail by Wharton *et al.* (2017, submitted).

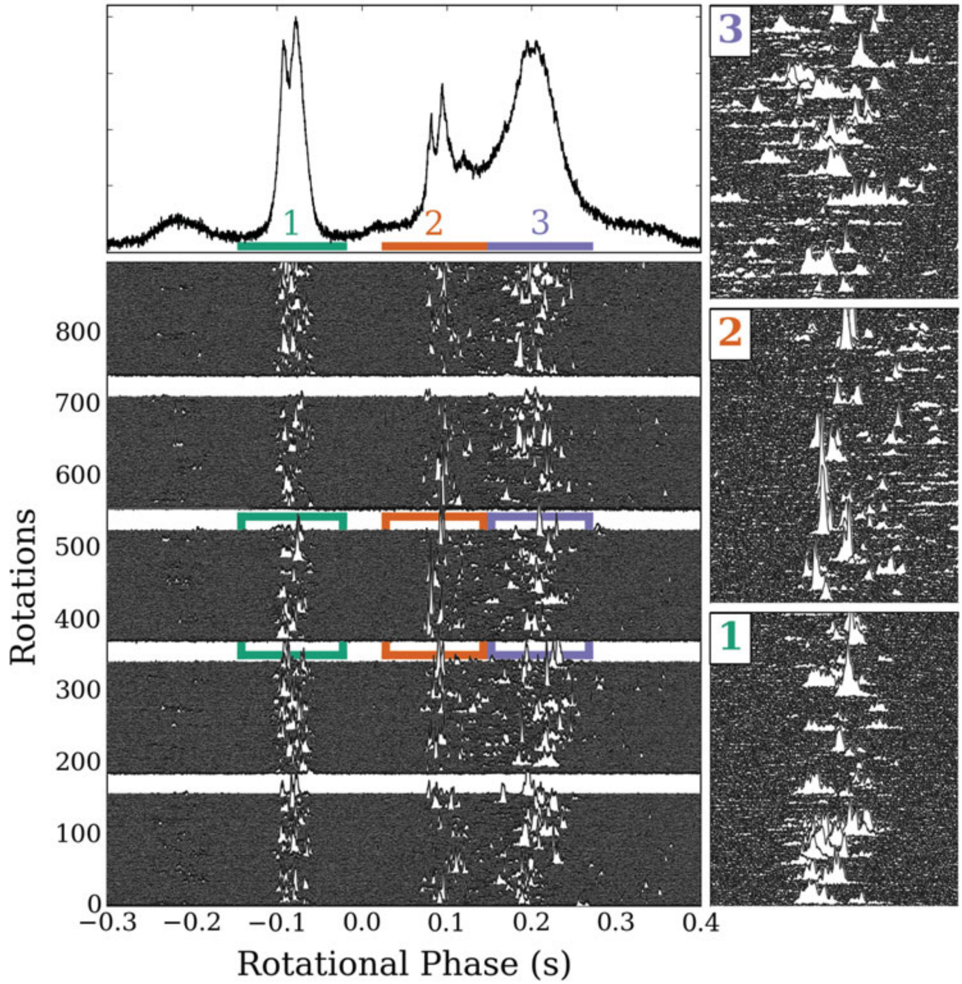

Figure 3. Stacked single pulses from 900 rotations (≈3400 s) of J1745−2900. The 100 s calibrator scans are seen as gaps in between the 600 s on source scans. The upper panel shows the mean profile from the full observation. Panels on the right give a zoomed in view of the pulses showing 120 ms of rotational phase over one 600 s on source scan.

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