# An Update on the Status of the Pulsar-ALFA Survey

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**Abstract.** The Pulsar-ALFA (PALFA) survey is designed to search the Galactic plane for pulsars at 1.4 GHz using the Arecibo Observatory's 7-beam ALFA receiver. The 64-$\mu$s sampling time, 0.336-MHz frequency resolution and 300 MHz bandwidth of the observations are allowing for the detection of millisecond pulsars (MSPs) 2-3 times more distant than previous surveys. To date, PALFA has discovered 55 pulsars, seven of which were discovered via searching for bright single pulses. Highlights include six high-DM MSPs ($P$ < 10 ms), a young relativistic binary pulsar, a young energetic pulsar, and a highly-recycled eccentric binary MSP in the Galactic plane. PALFA data analysis has recently added a distributed global volunteer computing program, Einstein@Home, which is already responsible for two discoveries. The PALFA survey has improved upon existing search algorithms and developed new techniques in response to the large amount of radio frequency interference encountered. The PALFA consortium has begun using a web-portal to enhance collaboration among its international membership, simplify data management and provide survey diagnostics in real time.

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## INTRODUCTION

The on-going Pulsar-ALFA (PALFA) survey is searching for pulsars in the plane of the Galaxy using the ALFA 7-beam receiver installed at the 305-m Arecibo Observatory in Puerto Rico. Telescope pointings are focused on low-latitude regions of the Galactic plane visible from Arecibo ($|b| \lesssim 5^{\circ}$, and $32^{\circ} \lesssim \ell \lesssim 77^{\circ}$ and $168^{\circ} \lesssim \ell \lesssim 214^{\circ}$). Observations are carried out at 1.4 GHz, with sample times of 64 $\mu$s. Typical integration times are 5 minutes for the inner Galaxy region and 2.5 minutes for the anti-centre region. For the most part, data have been recorded with the Wideband Arecibo Pulsar Processor[1], using 100 MHz of bandwidth and 256 frequency channels. However, in 2009, the new Mock spectrometer[2] was brought online, allowing data to be recorded with 300 MHz of bandwidth (ALFA's full observing band) divided into 960 channels.

In addition to a reduced-resolution search pipeline that is run in quasi-realtime with observing, data are analysed by three separate full-resolution search pipelines. Each pipeline is designed to provide maximal sensitivity to different pulsar systems, providing a complimentary look at the PALFA survey's data set.

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[1] `http://www2.naic.edu/~wapp/`
[2] `http://www.naic.edu/~astro/mock.shtml`

*Cornell Pipeline.* The fastest of the three PALFA pipelines is the one designed and run at Cornell University. This pipeline is designed to look for isolated pulsars and single pulses. Details of the single pulse search performed are described in [1].

*PRESTO Pipeline.* The second PALFA pipeline is based on the PRESTO suite of pulsar search programs[3] [2]. The PRESTO pipeline is sensitive to both isolated and binary pulsars. A Fourier-domain acceleration search [3] is used by the pipeline to increase sensitivity to binary pulsars with orbital periods larger than $\sim$1 hr. Searches for single pulses are also performed.

*Einstein@Home Pipeline.* While its main objective is to detect the signal of gravitational waves in LIGO data, the Einstein@Home global volunteer computing project[4] has been using one third of its computing capacity to search for pulsars in binary systems in PALFA survey data. Some of these systems are plausible sources of observable gravitational waves. As of today, more than 280000 individuals have contributed to Einstein@Home project and each week 100000 different computers provide compute cycles. The Einstein@Home pipeline increases its sensitivity to binary pulsars by using circular orbit templates to stretch and compress time-domain data. Templates accounting for orbital periods as short as 11 minutes are used. Additional details will be presented in an upcomming publication [4]. The Einstein@Home pipeline is also capable of detecting isolated pulsars, such as PSR J2007+2722 (period, $P$ = 24.5 ms, and dispersion measure, $DM$ = 125 pc cm$^{-3}$), which is the first pulsar discovered by a global volunteer computing effort [5].

## DISCOVERIES

Since the PALFA survey began in 2004, it has discovered 55 pulsars, including six millisecond pulsars (MSPs, in this case defined by $P < 10$ ms). Seven pulsars were discovered not through their periodic emission, but by using single pulse search algorithms [1]. Selected properties of the PALFA-discovered MSPs are shown in Table 1. It is important to note the high DMs of the MSPs discovered in the PALFA survey. The smallest DM among the six PALFA-discovered MSPs is that of PSR J1850+01, 119 pc cm$^{-3}$. None of the MSPs listed in the ATNF pulsar database has a DM larger than 115 pc cm$^{-3}$, if globular cluster MSPs are excluded[5] [6]. This is testament to the PALFA survey's sensitivity to highly dispersed MSPs, thanks to its high time and frequency resolution. The PALFA survey is capable of probing 2-3 times further into the Galactic plane for MSPs than previous surveys.

Below we highlight a number of particularly interesting pulsars discovered in the PALFA survey.

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[3] http://www.cv.nrao.edu/~sransom/presto/
[4] http://einstein.phys.uwm.edu/
[5] http://www.atnf.csiro.au/people/pulsar/psrcat/

**TABLE 1.** Observed and calculated properties of six MSPs discovered in the PALFA survey.

| Name | Period (ms) | *DM* (pc cm$^{-3}$) | Distance* (kpc) | Orbital Period (days) |
|---|---|---|---|---|
| PSR J1844+01 | 4.19 | 148 | 4.0 | 50.6 |
| PSR J1850+01 | 3.56 | 119 | 3.4 | 85.0 |
| PSR J1900+03 | 4.91 | 250 | 5.8 | 12.5 |
| PSR J1903+0327 | 2.15 | 297 | 6.4 | 95.2 |
| PSR J1944+22 | 3.62 | 185 | 6.5 | – |
| PSR J1955+25 | 4.87 | 210 | 7.4 | – |

* As estimated by NE2001 model [7].

*PSR J1906+0746.* The highly relativistic binary pulsar J1906+0746 ($P$ = 144 ms, $DM$ = 218 pc cm$^{-3}$, $P_{orb}$ = 3.98 hr) is believed to be a double neutron star system [8]. PSR J1906+0746 is the youngest known binary pulsar with a characteristic age of $\tau_c = P/2\dot{P} = 112$ kyr. Detecting such a young pulsar is somewhat unlikely and thus could be an indication that the birthrate of this type of pulsar is larger than previously thought [8].

*PSR J1856+0245.* Another young pulsar discovered by the PALFA survey, PSR J1856+0245 ($P$ = 81 ms, $DM$ = 622 pc cm$^{-3}$), has a characteristic age of $\tau_c$ = 21 kyr [9]. This pulsar is highly energetic, $\dot{E} = 4\pi I\dot{P}P^{-3} = 4.6 \times 10^{36}$ ergs s$^{-1}$, and is coincident with the TeV $\gamma$-ray source HESS J1857+026, which is proposed to be powered by PSR J1856+0245's pulsar wind [9].

*PSR J1952+26.* The second Einstein@Home discovery, PSR J1952+26, is a 20.7-ms pulsar. Initial timing suggests the pulsar is in a 9.4-hr circular orbit around a massive companion ($m_c > 0.94\ M_\odot$) [10]. Additional observations are planned.

*PSR J1903+0327.* The first MSP discovered in the PALFA survey is a 2.15-ms binary pulsar in a 95-day, 0.44 eccentricity orbit, PSR J1903+0327 [11]. The standard picture of binary evolution cannot explain how a highly-recycled pulsar can be in a non-circularized orbit. In addition, infrared imaging and spectroscopic observations indicate the pulsar's companion is a main-sequence star [11, 12]. This leads to the interpretation that PSR J1903+0327 likely evolved from a triple system, but is currently in a binary system [12]. Finally, measurements of the relativistic effects on the PSR J1903+0327's binary motion (advance of periastron and Shapiro delay), along with spectroscopic observation of the companion's radial velocities, allow for a measurement of the pulsar mass and the mass ratio of the binary system, $m_p = 1.667 \pm 0.021\ M_\odot$ and $R = 1.54 \pm 0.16$, respectively [12].

## FUTURE OUTLOOK

The new sources described above have been discovered despite an unexpectedly large amount of radio frequency interference (RFI) encountered in PALFA survey data. The RFI environment at Arecibo at 1.4 GHz has been observed to produce large numbers of false-positive candidates in the search pipelines. This has hampered confirmation and follow-up. However, new techniques are being developed to mitigate this problem, such as a more reliable determination of candidate significance in periodicity searching and the use of improved lists of RFI-prone periodicites to excise from power spectra before searching them. Also, the new Mock spectrometer back-end improves sensitivity by tripling the observing bandwidth, and has improved resilience to RFI.

In order to deal with the excessive number of periodicity candidates, a series of heuristics have been developed to help separate promising candidates from RFI. These heuristics are currently being incorporated into an artificial intelligence system that will further help identify pulsar-like candidates. This is similar to the strategies used in re-analyses of Parkes Multibeam Survey data [13, 14].

Moving forward, the PALFA team will make a complete second observing pass of the Galactic plane with the new spectrometers. This will increase the odds of discovering transient sources, and will help in dealing with RFI, whose intensity is time-variable. A second pass will enable a search for spatially coincident signals at the same periodicity, allowing weak pulsars to be teased out of the data.

Finally, in 2010 the PALFA consortium has developed a greatly improved online hub for all survey information and a series of web-applications to efficiently view or rate search candidates, share results of follow-up observations, sign-up for observing sessions, access survey diagnostics and share documentation among its entire international collaboration. The portal is hosted by the CyberSKA project, whose goal is to prepare for future large-scale projects, and ultimately projects using the Square Kilometer Array.

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