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News and Views on

"J.L. Han, et al., RAA 2021 Vol. 21 No. 5, 107:

The FAST Galactic Plane Pulsar Snapshot survey: I. Project design and pulsar discoveries"

1. Comments by

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The newly commissioned Chinese radio telescope known as FAST is the most sensitive radio telescope in the world. The name FAST derives from its full title "Five-hundred-meter Aperture Spherical Telescope" giving a clue to why it is so sensitive. Even before the recent demise of the Arecibo radio telescope in Puerto Rico, it had the largest collecting area of any "single-dish" radio telescope. Its 300-m effective diameter, combined with a very sensitive 19-beam receiver operating in the "L-band" around 1.4 GHz, makes it more than an order of magnitude more sensitive than any other existing radio telescope operating in this band.

Discovery of previously unknown pulsars is one of the most exciting applications of this high sensitivity. Pulsars are relatively weak radio sources that are characterized by their highly periodic pulsed emission. They have pulse periods of between about 1.4 milliseconds and 23 seconds and are often found in short-period binary orbits about another star. Pulsar timing observations over decade intervals have shown that the long-term stability of the pulse period, especially for the short-period pulsars known as "millisecond pulsars" (MSPs), rivals that of the best atomic frequency standards on Earth. The existence of these highly stable clocks scattered through our Galaxy, far from the perturbations of a noisy Earth, has led to many exciting applications including efforts to detect low-frequency gravitational waves from distant galaxies and to some of the most stringent available tests of theories of gravitation. Their sharp pulses and high polarization make possible detailed studies of the interstellar medium between us and the pulsar. Finally, with their magnetic fields of billions of tesla and rapid rotation, they are highly efficient particle accelerators, generating ultra-relativistic particle streams that lead to the observed pulses through mechanisms that are still not fully understood after more than five decades of effort.

The paper by Han et al. in this issue of RAA describes a large-scale search for pulsars using FAST, known as the FAST Galactic Plane Pulsar Snapshot (GPPS) survey, and early results from it. This survey is one of five "key science" projects to be granted significant observing time on FAST over the next few years. The paper gives a detailed description of the survey observational methodology and signal processing systems. The survey utilizes an efficient scanning technique and concentrates on regions close to the Galactic plane where most pulsars are found. So far less than a few percent of the available area, albeit the richest part, has been covered, yielding a total of 201 previously unknown pulsars. At this early stage of the project, this is an impressive total, given that the most successful pulsar survey up to now, the Parkes multibeam pulsar survey, has resulted in the discovery of about 700 pulsars since it commenced in 1997, and that the total number of pulsars currently known is close to 3000. The FAST discoveries include many of the weakest and lowest luminosity pulsars known, giving new information about the low end of pulsar radio luminosity function. It is interesting that the great sensitivity of FAST for pulsar discovery is in some senses both a blessing and a curse – it is blessing in that it allows FAST to discover many weak pulsars with interesting properties, and a curse in that these pulsars can only be seen by FAST. Consequently, all follow-up observations of these faint pulsars require significant amounts of FAST observing time which is in high demand and very difficult to obtain.

About 440 MSPs are currently known. MSPs form a distinct class from the so-called "normal" pulsars with a very different formation history. Normal pulsars are typically relatively young, with ages of less than a few million years. MSPs are very old (probably dead) pulsars that have been given a second life (or "recycled") by being spun up to millisecond periods through accretion of mass and angular momentum in an evolving close binary system. We expect them to keep pulsing for billions of years. The recycling hypothesis is supported by the facts that more than two-thirds of known MSPs are in binary systems and more than 80 percent of known binary pulsars are MSPs. In addition to their intriguing formation history, MSPs have a wide range applications, most notably to tests of gravitational theories. With the discovery of 40 MSPs announced in these initial results, the GPPS survey has already increased the number of known MSPs by nearly 10 percent, a remarkable achievement. At least 14 of these are in close binary systems, and no doubt some of these will turn out to be excellent probes of gravitational theories.

The new results also include about a dozen pulsars which have exotic patterns of pulse emission. Some feature so-called "mode-changing" or "nulling" in which the mean pulse profile suddenly changes to a new quasi-stable state (mode-changing) or becomes undetectable (nulling) and then returns to the original state just as suddenly. These different states can last anywhere from a few pulse periods to months. Another extreme form of pulse modulation is seen in "rotating radio transients" or "RRATs". RRATs are characterized by the emission of single pulses separated by long intervals, typically minutes to weeks. Careful examination of the pulse arrival times can often reveal a periodicity, typically a few seconds, which is identified as the rotation period of an under-lying pulsar. About 100 RRATs are currently known. Only one RRAT is announced in this paper, but more discoveries are in the pipeline.

Polarization data are recorded in the survey observations and these have been analyzed to obtain polarization parameters and Faraday rotation measures for eight pulsars. Importantly, the paper also reports improved parameters for 64 previously known pulsars.

This paper underlines the great promise of FAST for pulsar astronomy and especially for pulsar searching. The authors are to be congratulated on their prompt and comprehensive publication of the survey methods and results in a refereed journal. Regrettably, that is rather unusual in this field.

2. Comments by

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Neutron stars (NSs) are the collapsed cores of massive stars that explode as supernovae while pulsars are relatively young neutron stars that radiate period trains of pulses as a consequence of their rotation. Since their discovery more than half a century ago by Jocelyn Bell (Hewish et al. 1968), pulsars have served as laboratories for fundamental and extreme physics, providing constraints on the equation of state, superfluidity, and superconductivity of hyperdense matter and demonstrating the electrodynamics of relativistic, strong-field magnetospheres. Their pulses are superb probes of the interstellar magnetized plasma and of spacetime itself. Indeed, the Hulse-Taylor double neutron star binary gave us the first incontrovertible evidence for the existence of gravitational waves along with the bonus of precision mass determinations of the two NS (Taylor and Weisberg 1989). Current efforts include usage of millisecond pulsars as detectors of long wavelength (lightyears) gravitational waves produced by supermassive black hole binaries at cosmological distances.

Pulsars uniquely probe the ionized interstellar medium (ISM) by their dispersive pulse arrival times, which yield the integrated column density of free electrons, and by multipath propagation, which distorts their pulse shapes and causes intensity scintillations. Aggregation of propagation measurements has led to large-scale, Galactic models of the electron density and magnetic field in the ISM that, in turn, are necessary for understanding extragalactic fast radio bursts (FRBs) that are necessarily viewed through Galactic turbulence.

The incredible range of astrophysics provides the impetus for finding new pulsars in the Galaxy and in nearby galaxies. About 3000 pulsars are currently known (Manchester et al. 2005) after 50+ years of pulsar surveys using the largest available radio telescopes. This represents no more than about 10% of the estimated pulsar population in the Milky Way, raising the challenge of finding greater numbers for vastly improved interstellar modeling and also discovering rare objects in extreme situations, such as the so-far elusive pulsar-black hole binary, which would allow precision metrology of spacetime around a black hole or, more extreme, a pulsar in orbit around an active galactic nucleus (AGN), perhaps interacting with the jet from the AGN. Magnetars in their transitory radio-emitting states, along with more sporadic objects (perhaps additional Galactic FRB analogs along with 'classic' extragalactic FRBs) are additional survey yields. And perhaps there really are quark stars that are pulsar like but have very rapid spin rates disallowed for neutron stars.

The Five Hundred Meter Aperture Spherical Telescope (FAST) in southern China has the largest collecting area in the world. Han et al. report the initial results of their Galactic Plane Pulsar Snapshot survey, which is enabled by the FAST telescope's large collecting area combined with the 19-beam receiver system that provides large survey throughput. They have discovered 201 previously unknown pulsars and rediscovered another 330 pulsars in the first stage of the survey, which represents only 5% of the total planned survey, which will cover all directions within ten degrees of the Galactic plane accessible with FAST with its 40 degree zenith angle coverage. The new discoveries required development of a full end-to-end analysis pipeline comprising the best search methods for both periodic signals and single bursts. The FAST pipeline uses artificial intelligence implemented with graphical processing units to distinguish the astrophysical signals of interest from terrestrial and satellite interference. Such methods are crucial for future surveys amid the growing levels of interference. The final yield could exceed several thousand pulsars, thus more than doubling the known pulsar population and contributing greatly to a full Galactic census of pulsars.

Among the newly discovered pulsars are examples showing large amounts of scattering from turbulence in the ISM and a few objects behind HII regions. Several are associated with supernova remnants and are therefore relatively young. These and all other discoveries will greatly benefit ISM studies, including further measurements of Faraday rotation measures for magnetic field modeling. In addition, sixteen binary pulsars have been identified in the sample of 201 pulsars through orbital modulation of their periods. The nature of their companions remains to be reported, but after about a year of timing measurements, they will likely turn out to be white dwarfs and neutron stars. Some will be useful for mass determinations and gravitational wave detection and of course there is the tantalizing possibility that a black hole companion will emerge soon or eventually from the survey.

The timing of Han et al.'s report follows the recent collapse in December 2020 of the Arecibo telescope in Puerto Rico, a telescope that also made great contributions to pulsar and FRB science (including the Hulse-Taylor binary, the first extrasolar planets, and the first repeating FRB). The poignancy of this context is mitigated by the great promise, already demonstrated, that FAST has for the study of compact objects in the universe and what we will learn about fundamental physics and astrophysics. Readers of the Han et al. paper will gain a sense of excitement for these prospects.

References

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