SCIENCE CHINA
Physics, Mechanics & Astronomy

• News & Views •
Special Topic: Peering into the Milky Way by FAST

December 2022 Vol. 65 No. 12: 129706
https://doi.org/10.1007/s11433-022-2030-x

The GPPS HI survey—A deeper view of the Milky Way galaxy

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Received November 4, 2022; accepted November 7, 2022; published online November 23, 2022

Citation: J. M. Dickey, The GPPS HI survey—A deeper view of the Milky Way galaxy, Sci. China-Phys. Mech. Astron. **65**, 129706 (2022), https://doi.org/10.1007/s11433-022-2030-x

The paper in this volume by Hong et al. [1] describing a new survey of the radio frequency spectral line of hydrogen, that astronomers call the HI line, shows some dramatic images of the Milky Way galaxy. The Five-hundred-meter Aperture Spherical radio Telescope, FAST, has done this survey as part of the Galactic Plane Pulsar Snapshot (GPPS) Survey [2]. The primary goal is to find pulsars in the Galactic plane, 500 have been found already, but the survey has secondary applications to mapping the neutral atomic interstellar medium with the HI line [1], the ionized medium using recombination lines [3], and the magnetic field through measurement of Faraday rotation of pulsars [4]. This special edition includes papers describing results of all these projects; the background and significance of the HI data are considered in this News & Views piece.

The Milky Way HI line has been the target of many surveys by smaller telescopes in the past, going back to the early 1950's when it was mapped by astronomers in the Netherlands using a surplus radar dish [5]. The GPPS HI paper reviews and compares recent surveys, and it uses a recent combined German-Australian survey [6] to calibrate the receivers of the FAST telescope. But the improvement in angular resolution and sensitivity over all previous surveys is impressive. FAST can go deeper and detect fainter emission over wider areas than other telescopes both because it has a larger collecting area (aperture diameter 300 m within the reflector diameter of 500 m [7, 8]), and because it uses a sensitive, 19-beam receiver with $T_{\rm sys}$~22 K to collect the radiation.

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The colourful images of the sky shown in Figures 5-7 of Hong et al. [1] have wonderful detail and high dynamic range, i.e., contrast. Looking at the bottom panels of Figure 6 (120 km/s > V > 100 km/s at the bottom, 100 km/s > V > 80 km/s just above, and 80 km/s > V > 60 km/s above that) shows how the rotation of the Galaxy gradually shifts the line emission to low longitudes (right hand side of the figures). The effect is like dawn light spreading across the sky from the east before sunrise. What we are seeing is the rotation curve of the Galaxy, a function from which we can derive the mass of the Milky Way, including dark matter, from the centre to the solar circle and beyond. (The solar circle is a circle around the Galaxy that roughly traces the path of the Sun's orbit.) Looking at the top panels of Figure 6 shows how the outer part of the Galactic plane warps or bends upward toward northern Galactic latitudes far outside the solar circle. The band of bright emission shifts up from the middle to the top of the panels as we go from –40 km/s < V < –20 km/s in the third panel from the top, to near the top of the second panel (–60 km/s < V < –40 km/s), and finally it disappears off the top of the upper panel (–60 km/s < V < –80 km/s). As the survey continues, the area will be widened to follow the emission up in latitude as the warp bends the remote, outer edge of the Galactic disk even higher in latitude. The Galactic warp has been seen before in radio surveys [9], but never with this much detail.

The "exquisite HI structures" of the paper title can be seen in Figure 10 of Hong et al. [1]. This is where the advantage of better resolution and sensitivity of the FAST telescope is indispensable to the discovery of small and faint features in the interstellar gas. Three examples are shown in the three columns of the figure. In the top row, the spectra show what tiny line components these are compared with the overall Galactic emission line profile, but they stand out clearly enough to make maps, shown in the second row of the figure. Earlier single dish telescopes have seen some emission in these places, but not clearly enough to be certain of the detection. The Very Large Array telescope could see the small detail, but since it is an aperture synthesis telescope it could not see the surrounding, more widespread emission. Only FAST could map the structures with the detail shown in the images.

Small interstellar clouds like these "exquisite structures" are important because they show how the density of gas in the Galaxy is distributed: not smoothly, but in lumps and filaments that condense from warmer gas like raindrops condensing out of the air. In the cases shown in Figure 10, the clouds are at extreme velocities, beyond the bulk of the emission in the spectra. They may have been accelerated by interstellar shocks such as those around old supernova remnants. How they will decelerate back to the velocity of their surrounding gas is an interesting physics question; the medium is constantly being stirred into violent turbulence as illustrated by the structure and motion of these HI structures.

As the GPPS continues, many similar, exquisite structures will be found; in fact, there are probably more to be found in the data that has been taken already, which is available to the public as described in the paper. Meanwhile, the authors have bigger jobs to do. The stray radiation correction, described in the paper but not yet applied to the data, will help set the baselines and remove spurious line emission. A longitude-velocity diagram [10] of the emission will make a dramatic image that may help trace spiral features in the disk. By doing mathematical transformations on the survey data (e.g., ref. [11]) the structure of the Galactic magnetic field might be traced. Matching absorption and emission spectra, described briefly in sect. 4.4 of Hong et al. [1], will allow the temperature of the interstellar hydrogen to be measured. These subjects will surely be topics for future dissertations for Ph.D. theses, and there will be scope for creative, completely original research with the survey results. Meanwhile, publication of this first paper on the GPPS HI survey is a landmark accomplishment, worthy of celebration and international attention.

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