Exploring the 3D Structure of the MilkyWay

Distribution of Galactic HI from Bayesian Distance Estimation

P.P Legodi, W.O Obonyo, C.J Ugwu, J.O Chibueze

UNISA Centre for Astrophysics and Space Sciences (UCASS), College of Science, Engineering and Technology, University of South Africa, Cnr Christian de Wet Rd and Pioneer Avenue, Florida 1709, P.O. Box 392, 0003 UNISA, South Africa

Abstract: The Milky Way's spiral structure remains uncertain despite extensive mapping of the Galactic plane. Using HI 21-cm absorption from the MeerKAT Absorption Line Survey (MALS), complemented by ALMA data, we probe Galactic structure through the velocities of 5,713 HI clouds, including 83 near the midplane. Applying Bayesian distance estimation (BDC; *Reid et al. 2016, 2019*), we convert V_{LSR}, RA, and Dec into 3D locations. We detect 1,061 clouds with significant absorption, clearly associated with known spiral arms. Preliminary distance results are presented, and we plan to extend this study to trace the spiral arms at higher Galactic latitudes.

Motivation

Neutral atomic hydrogen (HI) is a fundamental ISM component and tracer of Galactic structure. The 21-cm hyperfine transition penetrates dust, revealing the disk, spiral arms, and vertical gas distribution. Emission surveys map large-scale structure, while absorption probes the cold neutral medium, constraining spin temperature, optical depth, and column density. HI velocity distances are often ambiguous; as such, Bayesian methods with VLBI priors provide robust estimates. Our study maps spiral arms beyond the midplane to higher Galactic latitudes, extending Milky Way structure.

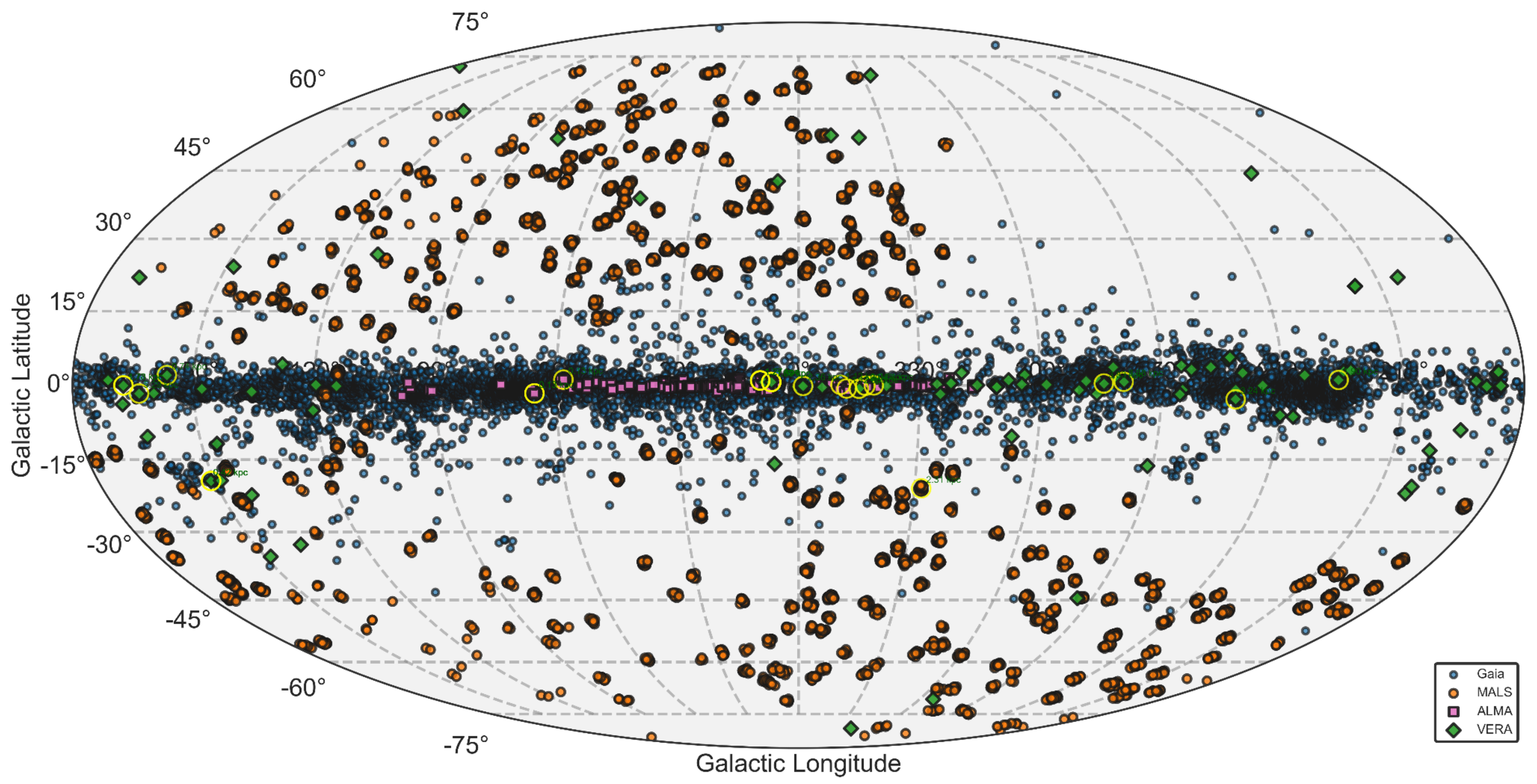

Figure: *All-sky distribution of HI absorption sources from MALS and ALMA[3] compared with Gaia, VERA[4], and catalogued matches. The map is shown in galactic coordinates, highlighting the concentration of sources along the midplane and the presence of high-latitude structures. Colored symbols denote different matched populations, indicating the spatial coverage of the combined dataset.*

Data and Method

Bayesian distance estimates are derived for all Gaussian components fitted to each HI absorption spectrum.

The data are drawn from the MeerKAT Absorption Line Survey (MALS) DR3[1], which comprises:

- 19,130 background radio sources brighter than 1 mJy at 1.4 GHz
- 390 MeerKAT pointings, each centred on a source > 200 mJy
- Spectral resolution of 5.5 km/s
- Median spatial resolution of ~9″
- Optical depth sensitivity: τ(3σ) = 0.381

Gaussian decomposition of the spectra produces 5,713 velocity components, of which approximately 30% have S/N > 3. The remaining spectra are affected by diffuse HI emission or elevated noise, which limits the reliability of component extraction.

Source Name	*l* deg	*b* deg	V_{LSR} km/s	d kpc	Δ d kpc	Prob	Arm
J195822.61-192335.8	22.1712	-23.1496	4.58	0.23	0.04	0.71	AqR
J200319.00-102438.0	31.5567	-20.6372	2.10	0.24	0.04	1.0	AqR
J032710.21-015452.7	185.588	-45.003	6.86	0.23	0.02	1.0	Loc
J080946.59-271512.9	245.9084	3.2330	52.92	4.44	1.1	1.0	Per
J163925.46+115132.1	28.7387	34.6196	155.15	8.68	1.81	1.0	- -
J195418.01-191557.8	21.9058	-22.2109	251.00	8.17	2.35	1.0	- -

Table: *Bayesian distance estimates for a subset of MALS HI absorption sources, showing Galactic coordinates, V_{LSR}, inferred distances with uncertainties, solution probability, and associated spiral arm.*

Spectral fitting

- Spectral fitting was performed by continuum-subtracting each MALS HI spectrum, locating the deepest absorption trough, and applying a single-component Gaussian fit (weighted least squares) to derive V_{LSR} and its uncertainty.
- Only spectra with S/N ≥ 3 and true negative absorption were retained for distance estimation.

Example: J165357.71–010213.0 shows a narrow absorption line, yielding $\mathbf{V_{LSR} = 2.24 \pm 0.07}$ **km/s**.

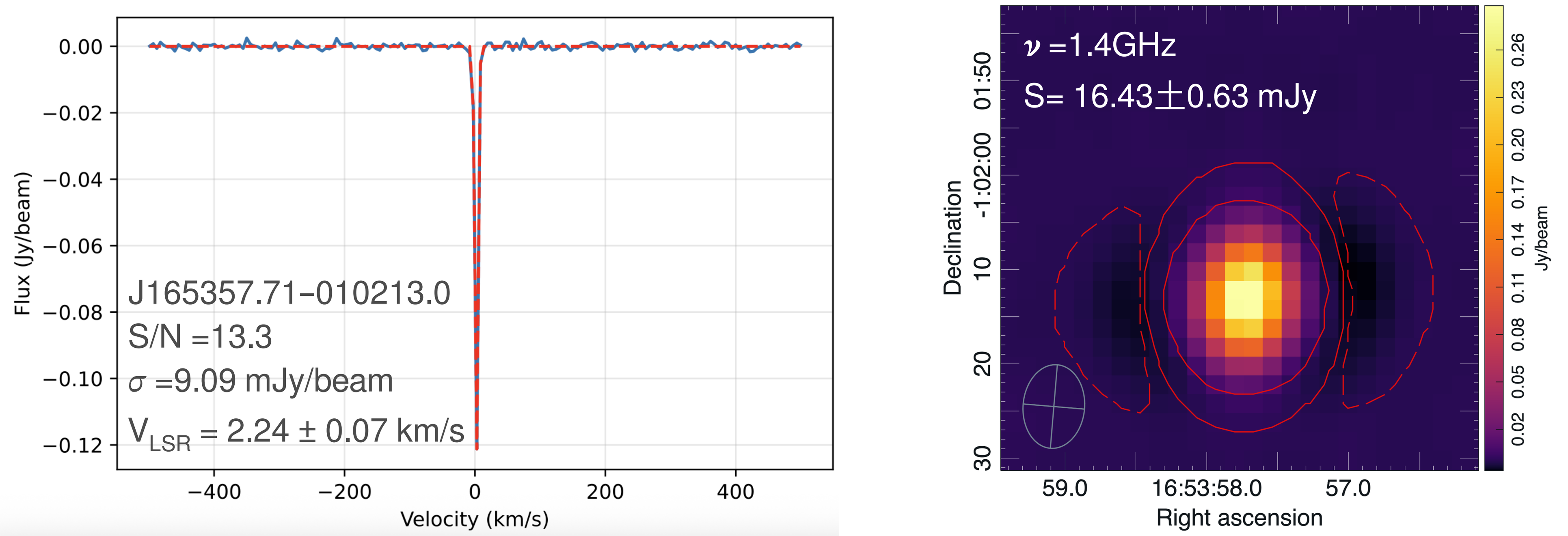

Figure: *Left – HI absorption spectrum of MALS J165357.71–010213.0 showing a deep, narrow feature fitted with a single-component Gaussian (V_{LSR} = 2.24 ± 0.07 km/s, SNR = 13.3, σ = 9.09 mJy/beam). Right – MeerKAT L-band continuum image at ν = 1434.43 MHz, restored with an 8.9″ × 6.5″ beam (PA = −4.8°). The colour map shows peak brightness (~0.26 Jy/beam) with red contours highlighting the compact core. The source has a total flux of 321 ± 2 mJy, resolved into three Gaussian components, centred at 0.0′, with continuum noise σ = 0.32 mJy/beam.*

Key Questions

- How many spiral arms does the Milky Way have, and what are their spatial extents?
- What is the structure and location of the Milky Way's off-plane (high-latitude) spiral arms?

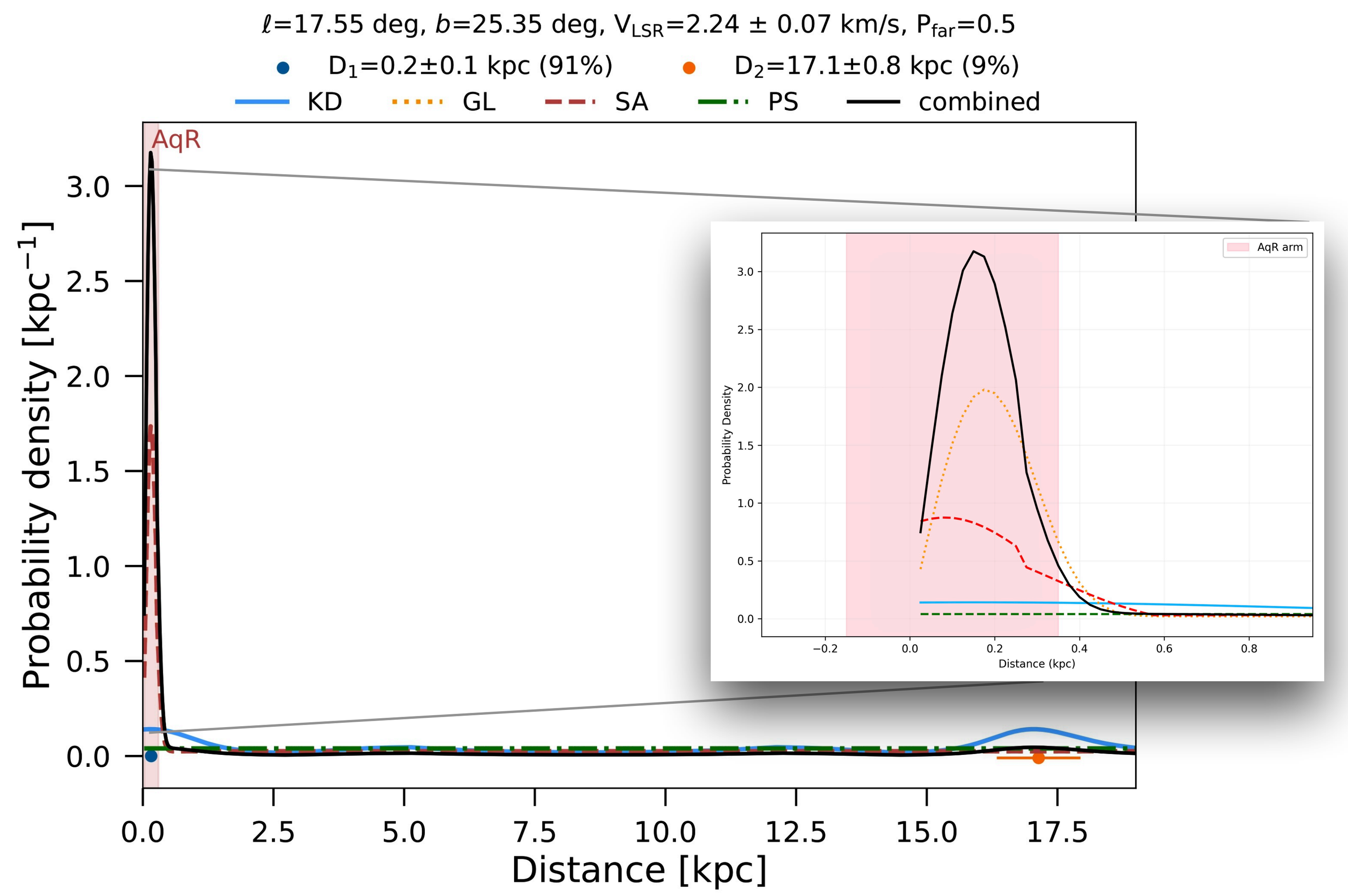

Figure: *For J165357.71–010213.0 at l= 17.55 and b=25.35 and V_{LSR} =2.24 ± 0.07 km/s, the probability is strongly concentrated at* ***D ≈ 0.16 ± 0.09 kpc****, indicating a nearby location on the near side of the Galactic disk.*

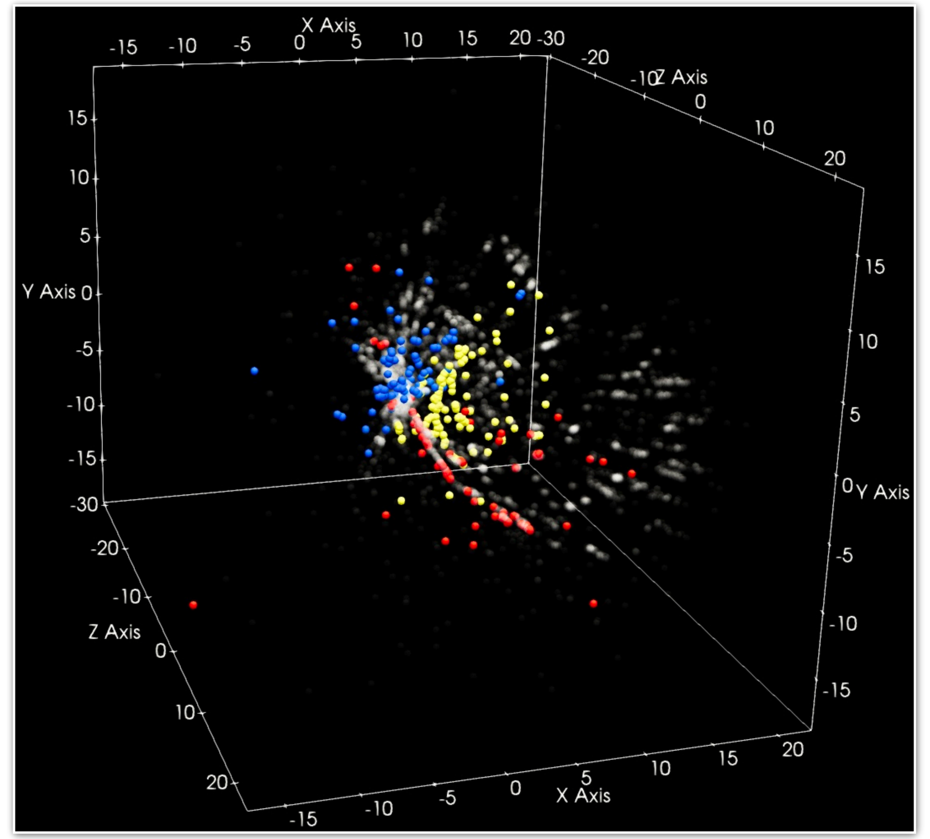

Figure: *Three-dimensional distribution of Galactic HI absorption sources. The grey background points represent the full MALS catalogue. The yellow points mark ALMA detections, the blue points correspond to VERA parallax sources, and the red points indicate MALS sources with independent parallax measurements. The Axis are in kpc.*

Some of the MALS HI clouds align with known spiral arms, but many, especially at higher Galactic latitudes, do not follow the expected arm structure. This suggests that a substantial fraction of high-latitude HI may trace local or off-plane gas rather than major arm features.

Reference: 1.Gupta et al. (2025), A&A, 698, A120; 2. Reid et al. (2016), ApJ, 823; Reid et al. (2019), ApJ, 885, 131; 3. Liu et al. (2024), RAA, 24, 02500; 4. VERA Collaboration et al. (2020), PASJ, 72, 50

legodpp@unisa.ac.za