A 4.5-Meter Amateur Radio Telescope for Long-Term Radio Astronomy Observations

Author: Tim Cherrone (WK9P)
Affiliation: Deep Space 1420 MHz Radio Telescope
Location: Mishawaka, Indiana, USA

Date: August 6, 2026

Abstract

This paper describes the design, construction, instrumentation, and initial observational results of a custom-built 4.5-meter amateur radio telescope developed for long-term continuum and spectral observations of Galactic neutral hydrogen at the 21-centimeter wavelength. The observatory combines a precision prime-focus reflector, hydrogen-optimized receiving system, software-defined radio technology, and automated data reduction software to produce highly repeatable drift-scan observations.

Over several months of operation, the observatory has completed numerous daily continuum drift scans together with multiple full sidereal-day continuum and spectral surveys. Independent observations demonstrate excellent repeatability of the principal Galactic continuum crossing and demonstrate consistent repeatability during a six-day continuum survey. The results demonstrate that carefully designed amateur instrumentation can produce repeatable continuum observations suitable for long-term comparative studies.

1. Introduction

Neutral atomic hydrogen (HI) is the most abundant element within the Milky Way and naturally emits radio energy through the 21-centimeter hyperfine transition (1420.4057 MHz). Observations at this wavelength have long been used to investigate Galactic structure, spiral arms, and the large-scale distribution of interstellar hydrogen.

Advances in low-noise electronics, software-defined radio receivers, digital signal processing, and precision telescope control have enabled experienced amateur radio astronomers to perform observations that complement established radio astronomy surveys.

The observations presented in this paper represent one component of a broader amateur radio astronomy program. The work documents the long-term repeatability of continuum drift observations obtained with a 4.5-meter radio telescope. The observatory and associated software continue to support additional continuum and spectral-line investigations beyond the scope of this paper.

2. Instrumentation

Antenna System

- **Reflector:** 4.5-meter prime-focus mesh parabolic reflector
- **Feed Horn:** Resonant VE4MA feed tuned for 1420 MHz
- **Beamwidth (-3dB):** Approximately 3.3°
- **Gain:** Approximately 34 dBi
- **System Temperature (T_{sys}):** Estimated approximately 155 K

Receiver Chain

- **Front-End LNA:** DEMI low-noise amplifier, custom-tuned for 1420 MHz with an internally installed 1420 MHz bandpass filter
- **Transmission Line:** Low-loss LMR-400 coaxial transmission line
- **Post-Amplification:** DEMI 10 dB gain block
- **SDR Receiver:** SDRplay RSP1A 12-bit software-defined radio receiver

Mount and Control System

- **Mount Type:** Dual-axis elevation-azimuth mount
- **Encoders:** High-resolution optical encoders on both axes
- **Hardware Interface:** Custom-built RS-232 encoder interface driver boards utilizing SIPEX232 integrated circuits
- **Controller & Interface:** F1EHN antenna controller paired with EME System interface
- **Pointing Repeatability:** Better than 0.5° with a fixed calibration reference point

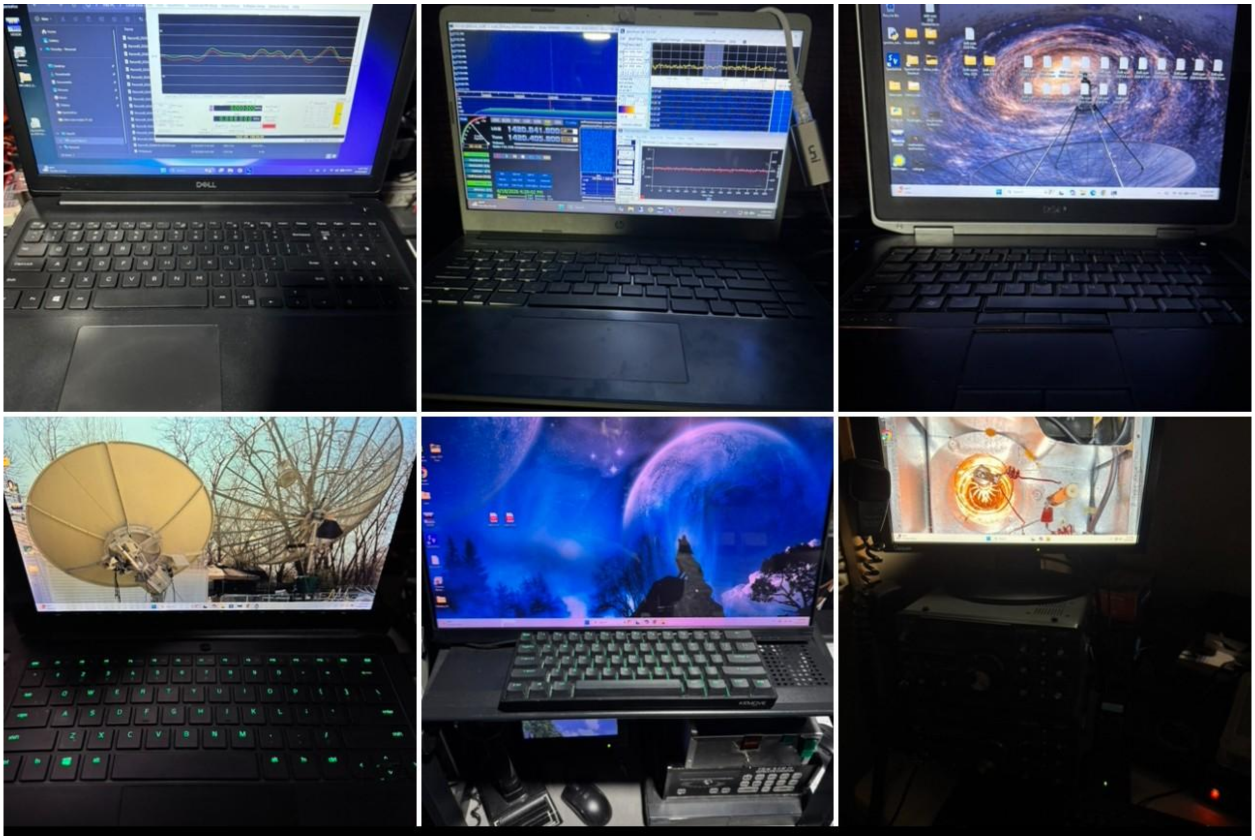
Data Acquisition and Software Pipeline

- **Acquisition Software:** HDSDR, SpectraVue, Spectrum Lab, and OBS Studio
- **Processing Pipeline:** Custom Python software leveraging NumPy, Pandas, Matplotlib, and AstroPy for automated data reduction, UTC to Right Ascension conversion, baseline normalization, 3D coordinate interpolation, and FITS cube visualization

The Deep Space 1420 MHz Radio Telescope has operated continuously throughout the duration of this study, allowing repeated observations under varying sidereal and seasonal conditions while maintaining a consistent observing and processing methodology.

Figure 1. (a) Physical 4.5-meter mesh dish assembly and feed setup. (b) Control instrumentation station and processing suite.

Figure 1. (b)



3. Observational Method

The Deep Space 1420 MHz Radio Telescope supports multiple complementary observing programs designed to investigate Galactic neutral hydrogen through both continuum and spectral observations. Each observing mode addresses a different aspect of the overall research program while utilizing a common instrumentation platform and standardized data reduction pipeline.

Daily Continuum Drift Surveys

Daily observations consist of approximately three-hour continuum drift scans performed with the telescope fixed at predetermined azimuth and elevation coordinates. As the Earth rotates, the sky naturally drifts through the antenna beam, producing repeatable continuum profiles suitable for long-term monitoring and comparison.

Each observation is processed using custom Python software that performs baseline normalization, removes transient radio-frequency interference (RFI), converts observation time to Right Ascension, and generates publication-quality plots, three-dimensional visualizations, and celestial location maps. These products provide both qualitative and quantitative evaluation of the observatory's long-term repeatability.

Figure 2. (a) Representative daily continuum drift observation following baseline normalization and conversion from UTC to Right Ascension. (b) Joined into a 3D surface rendering.

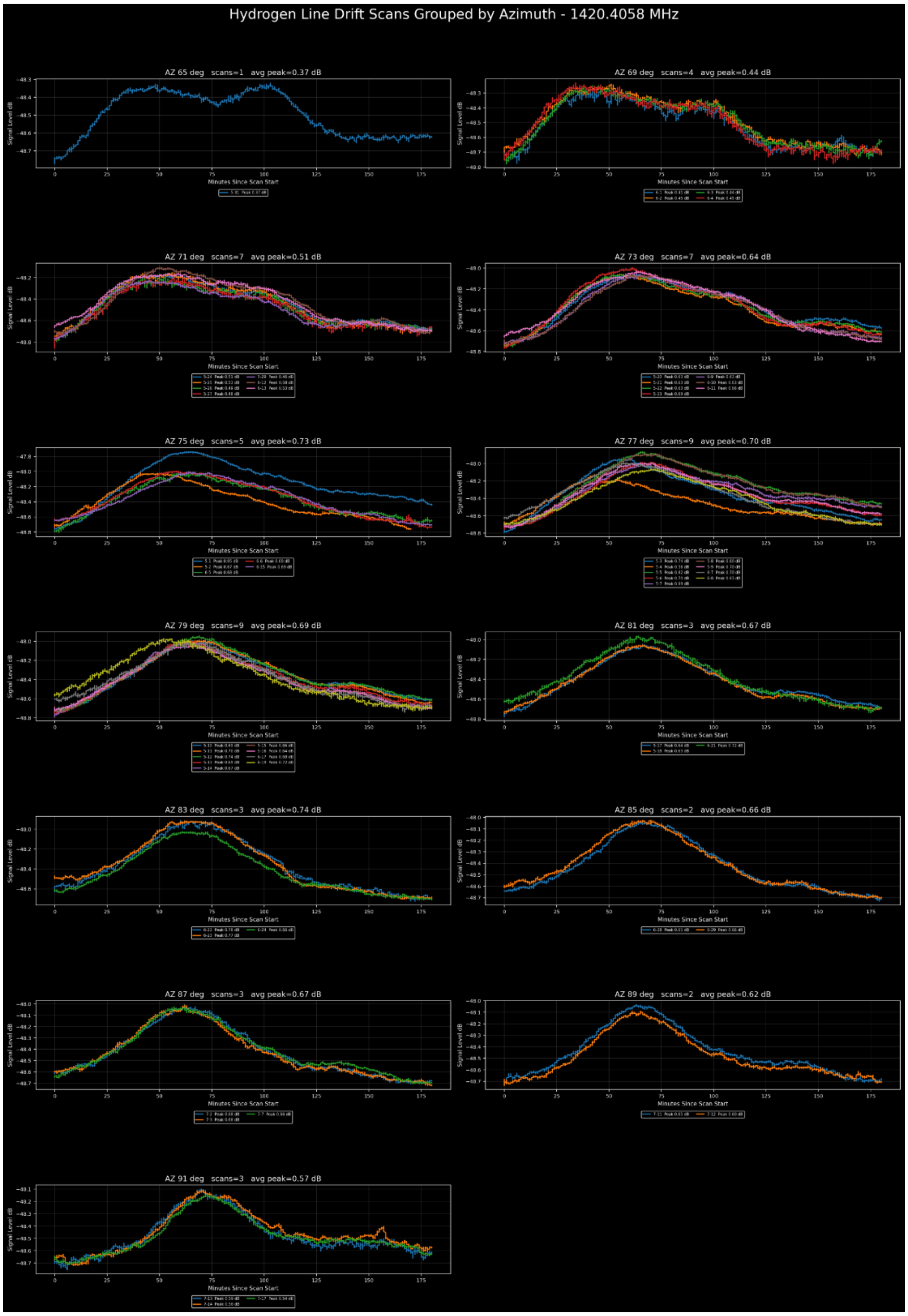
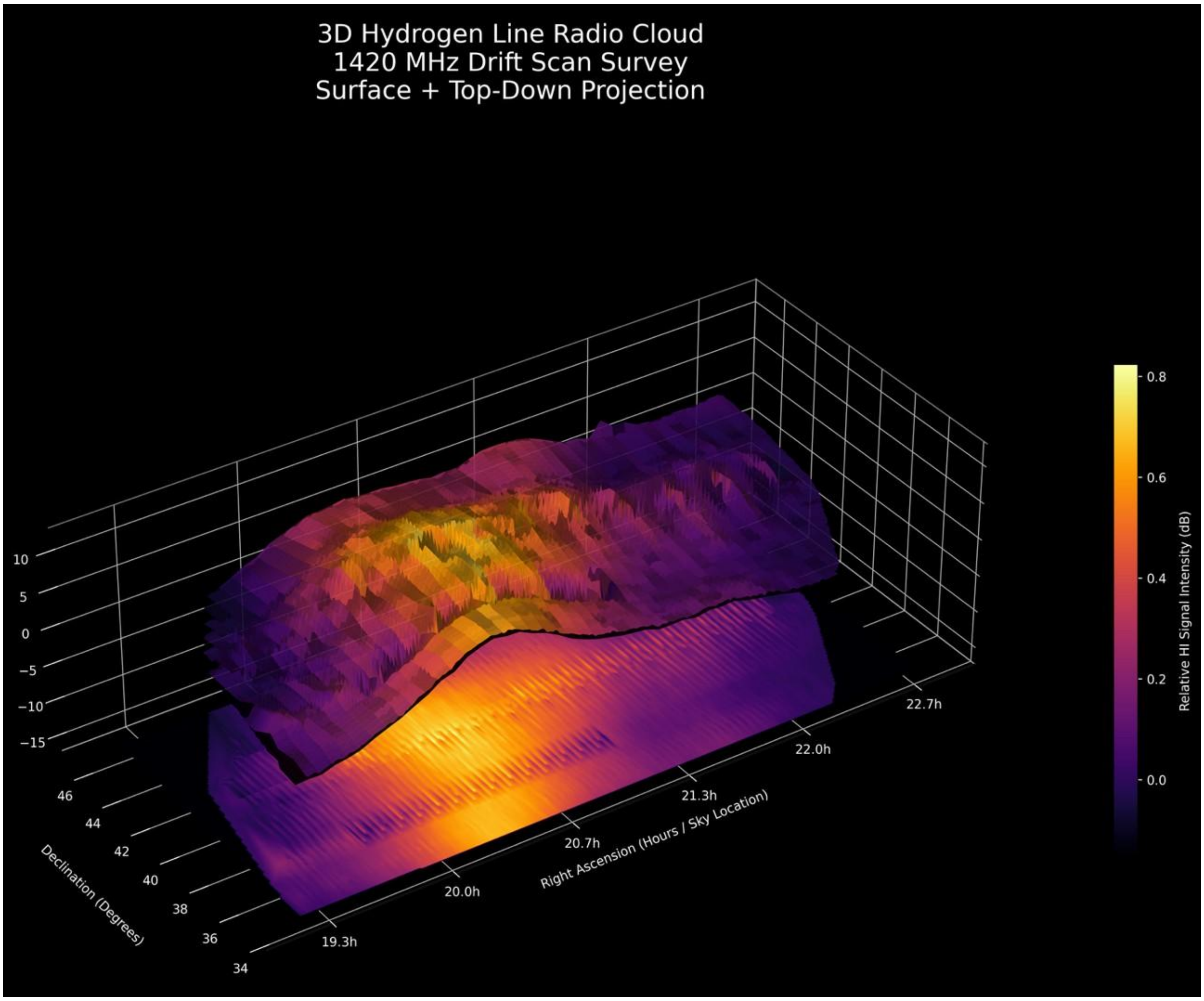


Figure 2. (b)

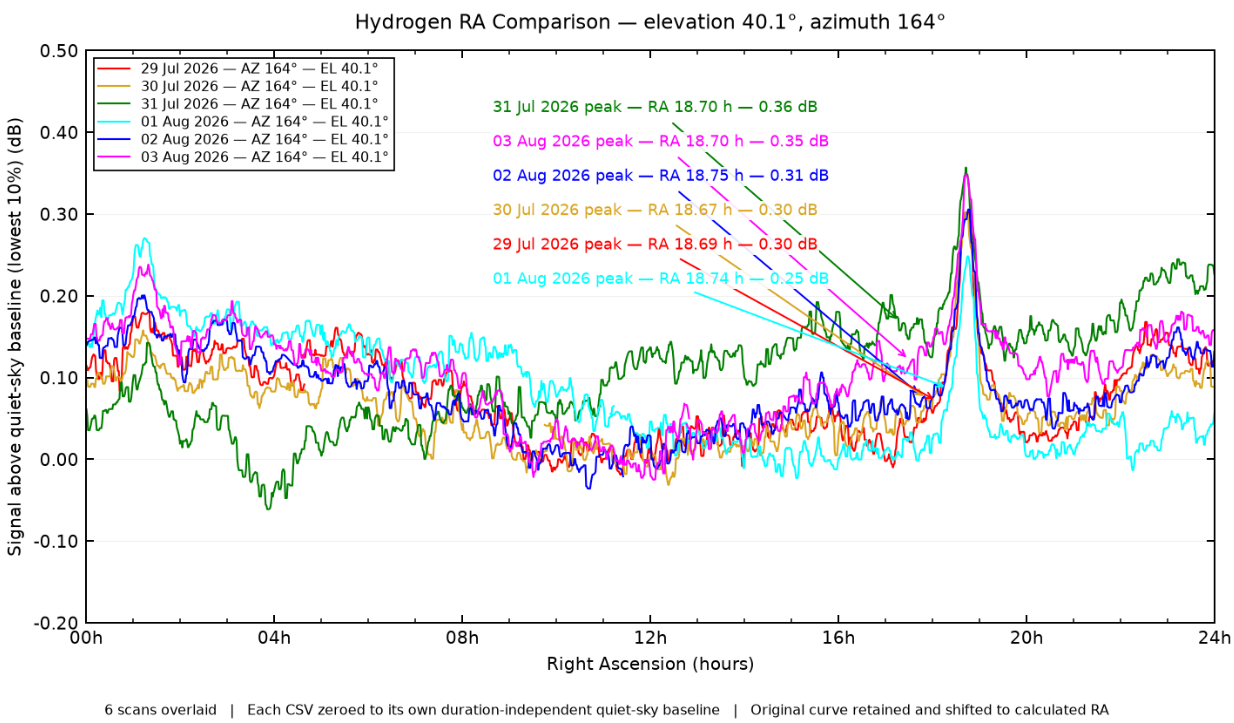

3D Hydrogen Line Radio Cloud
1420 MHz Drift Scan Survey
Surface + Top-Down Projection
10
5
0
−5
−10
−15
46
44
42
40
38
36
34
Declination (Degrees)
19.3h
20.0h
20.7h
21.3h
22.0h
22.7h
Right Ascension (Hours / Sky Location)
0.8
0.6
0.4
0.2
0.0
Relative HI Signal Intensity (dB)

Twenty-Four-Hour Continuum Surveys

Full sidereal-day continuum observations are conducted to provide continuous Right Ascension coverage at a fixed declination. These observations were initiated to compare results obtained with the Deep Space 1420 MHz Radio Telescope over a course of several days.

The resulting datasets are processed using the same software pipeline employed for the daily observations, producing Right Ascension intensity plots, three-dimensional renderings, and celestial location maps that facilitate direct comparison between observing sessions and historical survey data.

Figure 3. Alignment and comparison of the Deep Space 1420 MHz Radio Telescope continuum observations over 6 days during a continuum survey, demonstrating high baseline stability and profile repeatability.

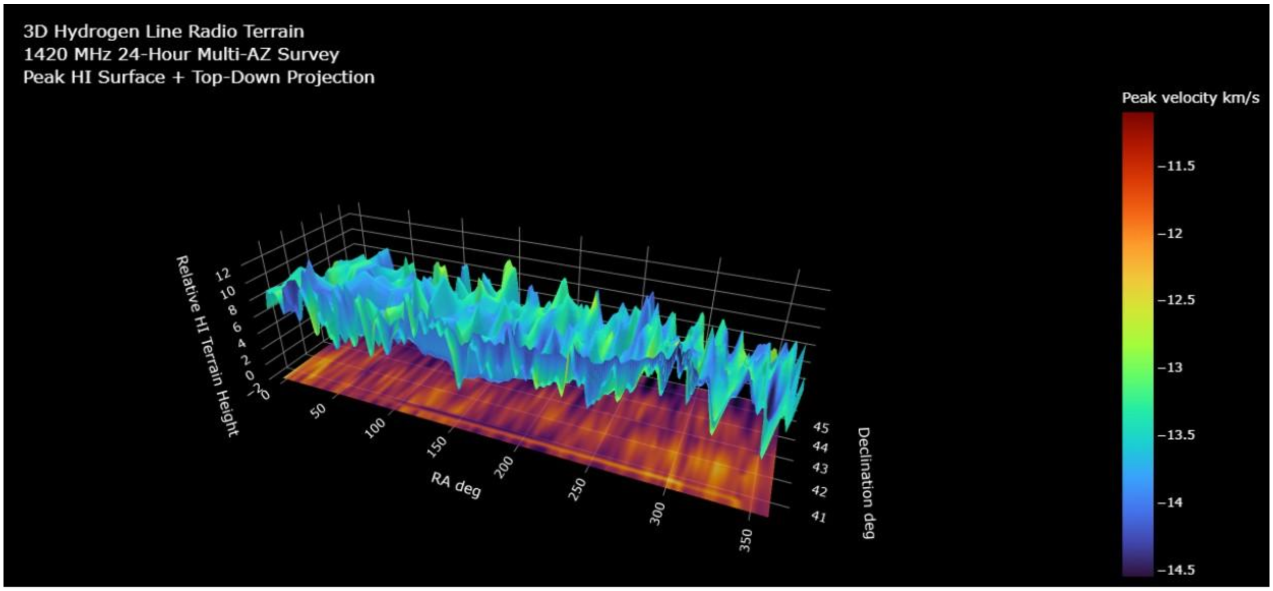


Twenty-Four-Hour FFT Spectral Surveys

In addition to continuum observations, full 24-hour FFT-based spectral surveys are routinely conducted. Successive surveys are acquired at azimuth positions separated by approximately two degrees (advancing northeast towards lower azimuth steps), allowing adjacent regions of the sky to be sampled while maintaining identical processing techniques.

Custom Python software converts these observations into spectral displays, velocity plots, three-dimensional renderings, and celestial location maps. These visualization products provide an intuitive representation of the spatial distribution of Galactic neutral hydrogen and assist in identifying repeatable structures across adjacent observing positions.

Figure 4. Three-dimensional rendering generated from a 24-hour spectral survey illustrating Galactic neutral hydrogen structure as a function of Right Ascension and spectra intensity.



Data Reduction

Raw receiver output is converted into comma-separated value (CSV) format and processed using custom Python software developed specifically for this observatory. The automated reduction pipeline includes:

- Baseline normalization
- Automated removal of transient radio-frequency interference
- Reconstruction of removed interference using surrounding baseline interpolation
- Conversion of observation time to Right Ascension
- Multi-session alignment and comparison
- Automated generation of publication-quality plots
- Three-dimensional renderings
- Celestial location mapping

The objective of the reduction process is to preserve persistent astronomical structure while removing transient terrestrial interference that could influence repeatability. The processing software has evolved throughout the observing program as additional visualization techniques and quality-control methods have been developed. Maintaining a consistent reduction workflow has been essential for ensuring meaningful comparison between observations acquired over extended periods.

Data Availability

This investigation is conducted as an open and ongoing observing program. Observatory operation, telescope control, and many observing sessions have been documented through a continuous public YouTube livestream. Processed observational products, including CSV datasets, PNG plots, three-dimensional renderings, and derived analysis products, are routinely shared through a public Google Drive repository to encourage independent review, comparison, and collaboration within the amateur radio astronomy community.

The open availability of observational data and processed results provides transparency, allows independent verification of the processing methodology, and enables future comparison with observations obtained by other amateur and professional observatories.

https://www.youtube.com/@Backyard_4.5m_Radio_Telescope

https://drive.google.com/drive/folders/17JhGsPBFxXecTJqHEjSD96UQDZtLI1b-

Results

Repeated observations demonstrate a high degree of consistency between independent observing sessions.

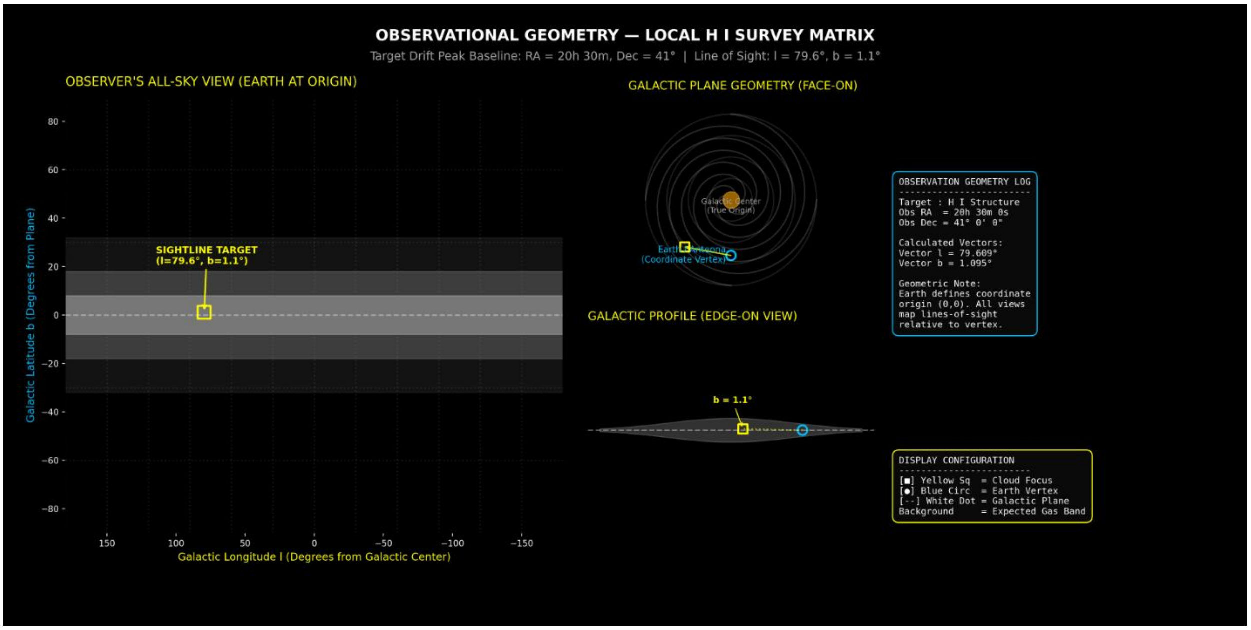
Independent daily drift surveys exhibit similar profile morphology (Figure 2), providing confidence in both the stability of the instrumentation and the repeatability of the observing methodology.

The 24-hour spectral surveys further demonstrate the observatory's capability to generate repeatable three-dimensional representations of Galactic neutral hydrogen structure from adjacent observing positions separated by approximately two degrees in azimuth (Figure 4). These visualization products provide an additional means of examining spatial continuity while complementing conventional continuum plots.

The 6-day continuum survey (Figure 3) shows encouraging agreement in the position and overall morphology of the principal continuum across consecutive 24-hour observing runs.

The continued acquisition of observations under varying sidereal conditions has further strengthened confidence in the long-term stability of both the instrumentation and the data reduction pipeline.

Figure 5. Observational Geometry — Local HI Survey Matrix showing sightline target, Galactic plane geometry, and edge-on profile.



Discussion

The observations presented here demonstrate that a modest-aperture amateur radio telescope can produce stable and repeatable continuum and spectral measurements when combined with optimized instrumentation, precise telescope positioning, and standardized digital data reduction techniques.

One objective of this work has been to determine the practical capability of modern amateur instrumentation for long-term radio astronomy observations. The consistency observed throughout multiple months of operation indicates that reliable measurements can be obtained using commercially available components integrated with custom-designed receiving, control, and analysis systems.

Equally important has been the development of an automated processing pipeline capable of transforming raw observational data into calibrated plots, Right Ascension displays, three-dimensional renderings, and celestial location maps. Automating these processes has improved repeatability while reducing the possibility of operator-induced processing differences between observing sessions.

Although the observations presented here represent only a portion of a larger observing program, they establish a foundation for continued continuum and spectral investigations, expanded sky coverage, and future comparisons with additional historical and contemporary astronomy surveys.

4. Conclusions & Future Work

The operational results from the Deep Space 1420 MHz Radio Telescope demonstrate that a carefully calibrated 4.5-meter amateur radio telescope can execute high-repeatability continuum and spectral line surveys of Galactic neutral hydrogen. Long-term continuum drift scans confirm excellent stability across multi-day observation windows.

Future work will focus on, but is not limited to, expanding both observational capability and scientific analysis, the spectral survey sky coverage, refining multi-track 3D coordinate interpolation for full galactic plane slice modeling, performing further continuum surveys, solar observations, strong radio galaxy surveys and seasonal sky comparisons.

5. References

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Author Biography

Tim Cherrone (WK9P) is an Extra Class amateur radio operator with over 32 years of experience in amateur radio operations, radio frequency systems, and Earth-Moon-Earth (EME) communications. Professionally, he works as an industrial process engineer specializing in process development and systems engineering. His current radio astronomy research focuses on long-term 21-cm continuum and spectral drift surveys, signal processing automation, and custom observatory hardware integration at the Deep Space 1420 MHz Radio Telescope in Mishawaka, Indiana.