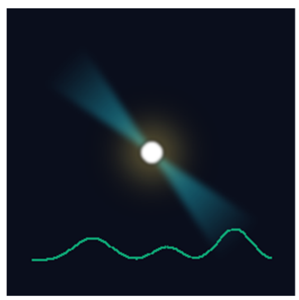
Six-Day Hydrogen Drift Scan

DSES Haswell 60-foot dish, 14-19 August 2026



Rev A

Richard M Hambly (K0GD)

DSES

August 2026

Contents

Six-Day Hydrogen Drift Scan

Between 14 and 19 August 2026 the DSES 60-foot dish at Haswell sat still and let the sky drift through its beam, while the DSES Spectrum Analyzer recorded a hydrogen-line spectrum every 25 seconds. The run produced **16,205 spectra covering nearly five complete days**, written by the drift-scan Raspberry Pi in the ezRA text format and analysed here with the ezRA toolchain (ezCon, ezPlot, ezSky, ezGal) plus an independent second reduction written for the purpose.

What the data show:

- **Neutral hydrogen is detected clearly, twice per sidereal day**, when the fixed beam crosses the plane of the Milky Way — once in Cygnus and once toward the anticentre. The strongest crossing raises the hydrogen line **23 % above the surrounding baseline**, and the profile resolves separate gas components out to −100 km/s: the spiral structure of our own Galaxy, measured from Haswell.
- **Cygnus A, the brightest radio galaxy in the northern sky, transits the beam every single day** and is detected at 27 % of the system noise power. Its transit time repeats to **one second of right ascension over five days**.
- Two further Cygnus sources — the Gamma Cygni supernova remnant and the DR 21 / Cygnus X region — come out of the same fold, at flux levels consistent with published catalogues.
- **Data integrity was perfect**: not a single dropped or late spectrum in 16,205 rows, and the total power held within 0.1 dB day to day. The midnight file-rollover feature added in Spectrum Analyzer 1.3.1 worked exactly as designed.
- The band is remarkably free of interference. Only one weak narrow carrier appears in five days, and it sits outside the velocity range where the Galactic hydrogen lives.

Two things should change before the next long run, both described in section 5: the receiver should be tuned slightly off the hydrogen line so that its internal DC artefact stops landing inside the line, and Cygnus A should be adopted as the site's routine pointing calibrator — the transit reported here shows that the dish is not looking exactly where the log says.

1. The observation

The dish was parked and the sky allowed to drift past. Because the telescope does not move, every source in the sky at that declination passes through the beam once per sidereal day — a “drift scan”, the oldest and most robust way to survey with a radio telescope.

Parameter	Value
Site	DSES Haswell, Colorado — 38.3808° N, 103.156° W, 4400 ft
Antenna	60-foot dish, parked at azimuth 0°, elevation 87° (declination +41.4°)
Receiver	Ettus USRP B210, 76 dB gain
Band	1418.4 – 1422.4 MHz, 3276 channels of 1.221 kHz (0.26 km/s per channel)
Cadence	one spectrum every 25.4 seconds
Recorded by	DSES Spectrum Analyzer 1.3.1, drift-scan mode, on the site Raspberry Pi
Span	14 Aug 21:19 UTC to 19 Aug 15:38 UTC (4.76 days; the scan was still running)
Volume	16,205 spectra, 425 MB of ezRA-format text in six daily files

2. Hydrogen

Hydrogen atoms throughout the Galaxy emit a faint line at 1420.4058 MHz. Because the gas moves, the line arrives Doppler-shifted, and the shift is the measurement: it tells us how fast each cloud is moving toward or away from us, and therefore — through the rotation of the Galaxy — roughly where along the line of sight it sits.

Each spectrum was corrected for the Earth's spin and orbital motion and placed on the standard astronomical velocity scale (the local standard of rest), then the instrument's own bandpass shape was divided out.

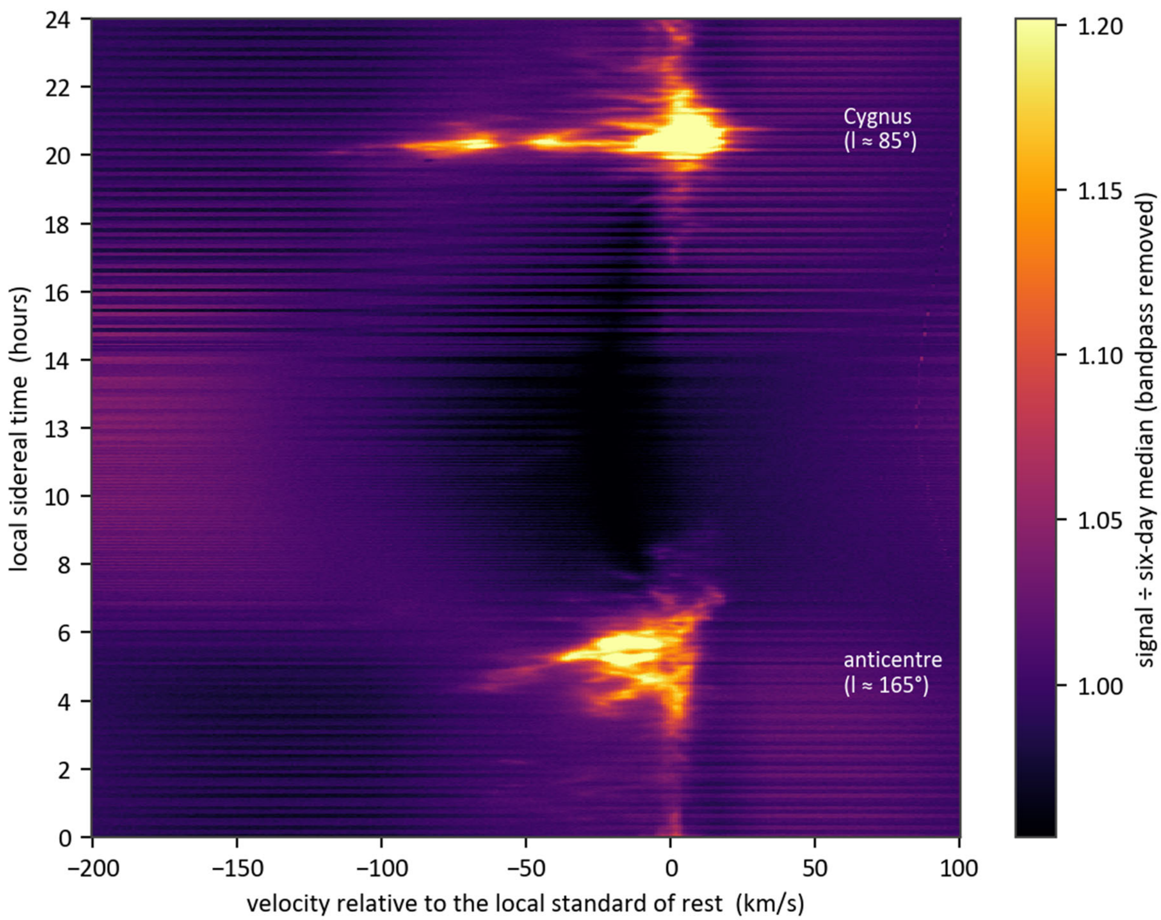


Figure 1 — Five days of hydrogen spectra, stacked by sidereal time. Two bright bands appear where the fixed beam crosses the plane of the Milky Way. Brightness is the signal divided by the six-day median, so a value of 1.20 means 20 % above the average sky.

The two bright bands in Figure 1 are the Galactic plane crossings. They repeat on every one of the five complete days, in the same place, at the same strength.

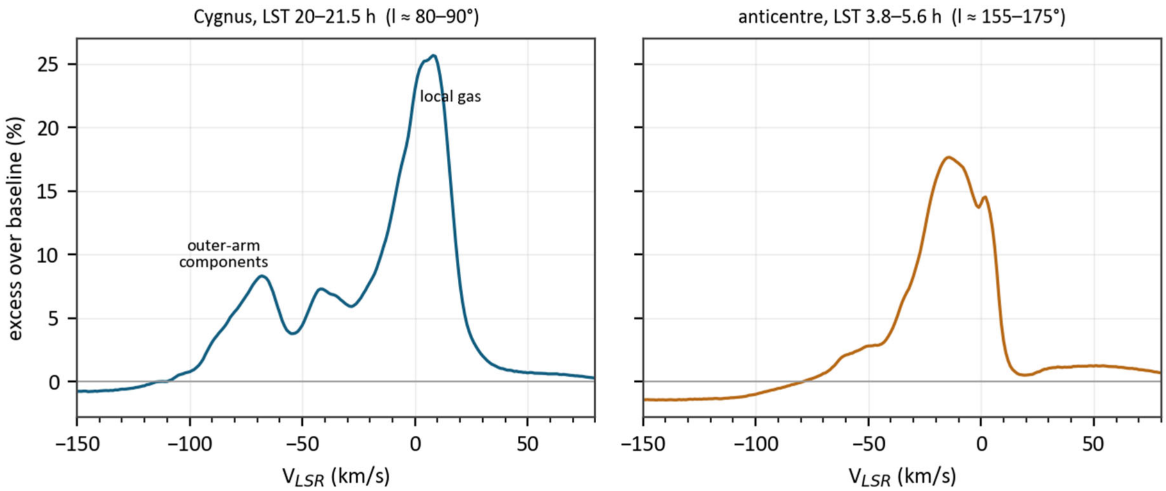


Figure 2 — Averaged hydrogen profiles at the two crossings. The Cygnus direction (left) resolves the local gas near 0 km/s and two further components near −45 and −70 km/s: gas in the outer spiral arms, seen through the disc of the Galaxy. The small notch at 0 km/s in the right-hand panel is the blanked receiver artefact discussed in section 5.

Sidereal time	Galactic longitude	Peak line strength	Velocity of peak
20–22 h	83° (Cygnus)	1.235 × baseline	+4 km/s
04–06 h	164° (anticentre)	1.176 × baseline	−9 km/s
02–04 h	147°	1.085 × baseline	+2 km/s
22–24 h	101°	1.080 × baseline	+1 km/s

Plotting the same data against Galactic longitude rather than clock time gives the classic longitude–velocity diagram (Figure 3). A single fixed-declination drift scan can only sample the plane where its track crosses it, which is why the emission appears in two vertical strips rather than a continuous band — the honest limit of this observing mode, and exactly what ezGal's independent version of the same plot shows.

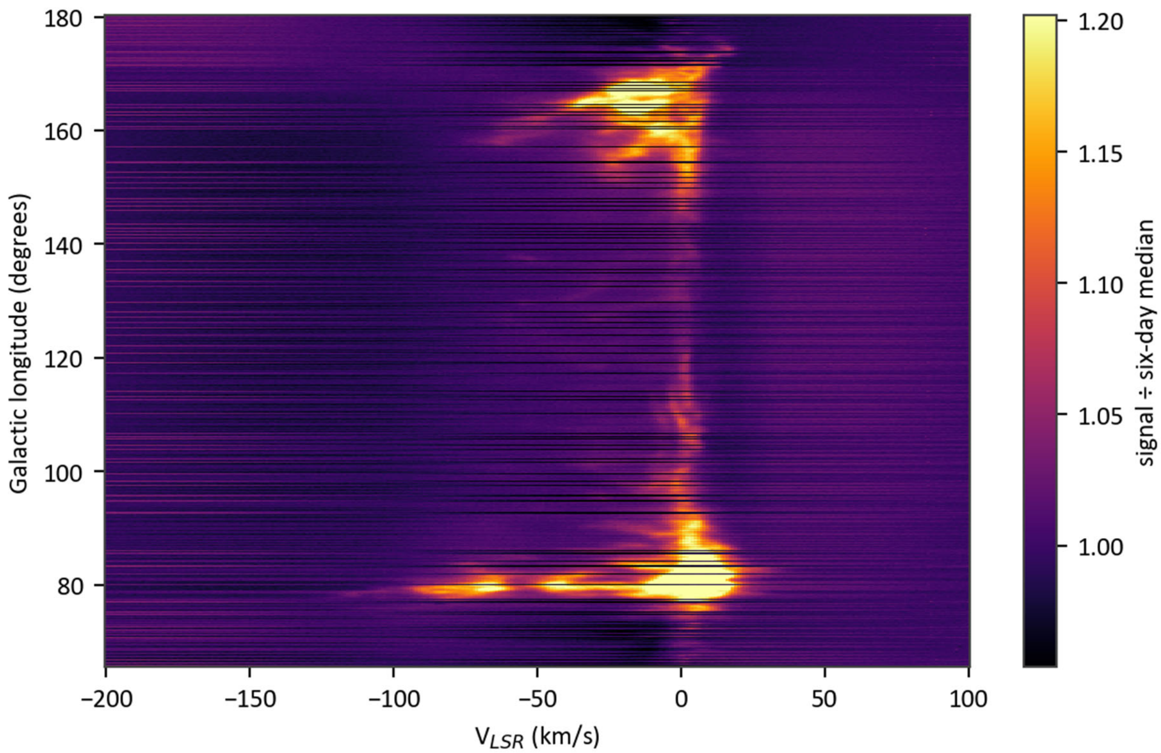


Figure 3 — Longitude–velocity diagram along the declination +41.4° track. The Cygnus crossing near l = 85° shows gas spread over 100 km/s; the anticentre crossing near l = 165° is narrower, as expected when looking away from the Galactic centre.

3. Continuum sources

Averaging each spectrum across the parts of the band away from the hydrogen line turns the same dataset into a continuum survey — a record of total radio power versus sidereal time. Folding five days together gives Figure 4.

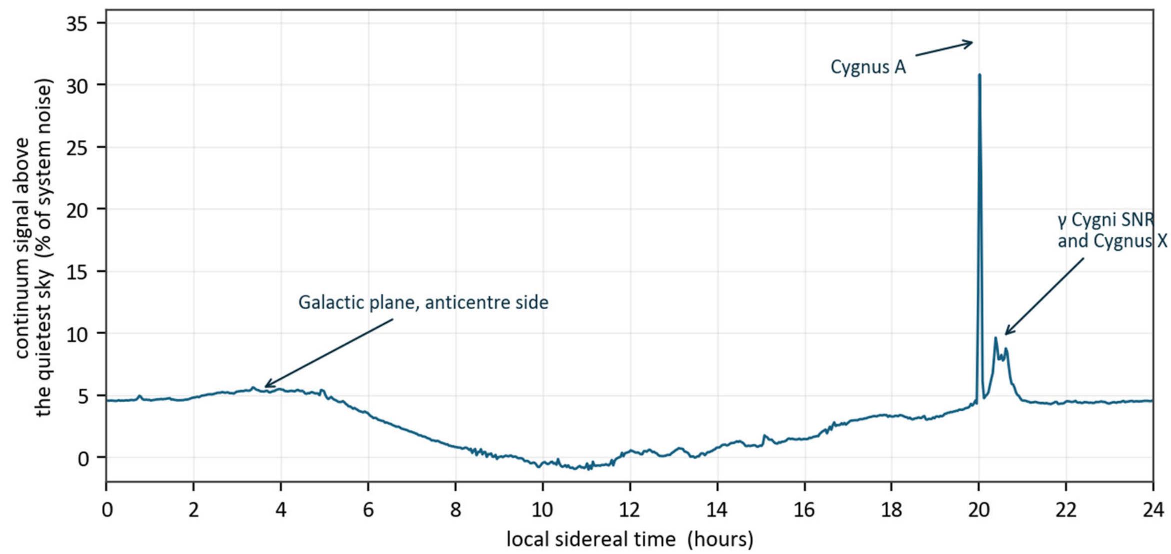


Figure 4 — The whole sky at declination +41.4°, folded on sidereal time. The spike at LST 20h is Cygnus A. The broad rise near LST 3–5 h is the Galactic plane on the anticentre side; the quietest sky is near LST 10–11 h.

Three discrete sources stand above the local background:

Measured transit	Strength (% of system noise)	Identification	Catalogue position
RA 20h01.0m	25.1 %	**Cygnus A** (1590 Jy at 1.4 GHz)	RA 19h59.5m
RA 20h23.0m	4.8 %	Gamma Cygni supernova remnant G78.2+2.1	RA 20h22.2m
RA 20h41.0m	2.6 %	DR 21 / W75, in Cygnus X	RA 20h39.0m

Scaling the two weaker sources against Cygnus A gives roughly 305 Jy and 167 Jy. The first agrees with the published Gamma Cygni flux (about 340 Jy) to better than 15 % — a useful check that the whole chain, from feed to file, is behaving linearly.

Cygnus A is worth a closer look, because it is effectively a point source and therefore measures the telescope rather than the sky.

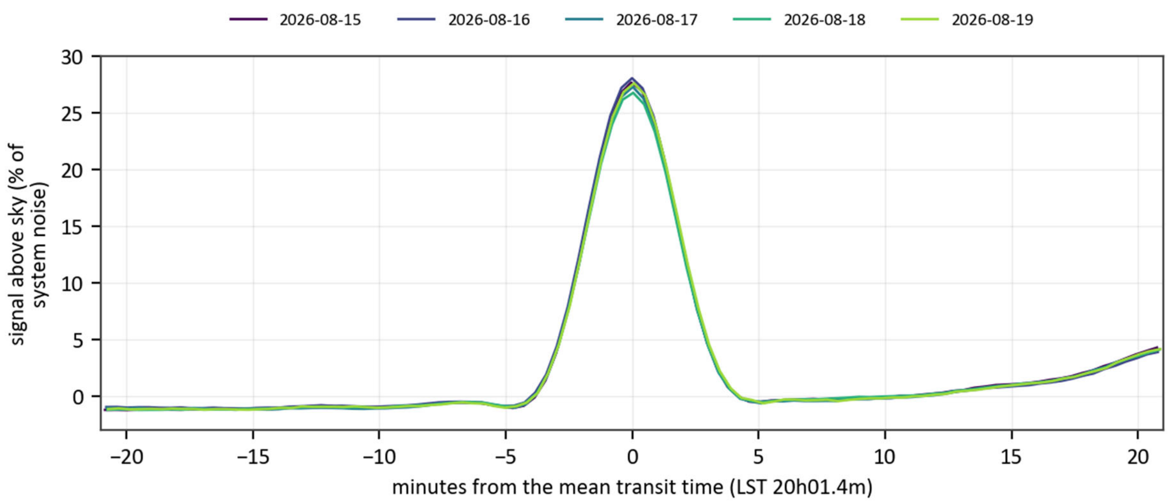


Figure 5 — The Cygnus A transit on five consecutive days, aligned on the mean transit time. The five curves are nearly indistinguishable.

Fitting each day separately:

```
2026-08-15   transit LST 20.0238 h   peak 27.7 %   width 3.6 min = 0.68 deg

2026-08-16   transit LST 20.0234 h   peak 28.0 %   width 3.7 min = 0.69 deg

2026-08-17   transit LST 20.0237 h   peak 27.3 %   width 3.7 min = 0.69 deg

2026-08-18   transit LST 20.0237 h   peak 26.7 %   width 3.7 min = 0.69 deg

2026-08-19   transit LST 20.0243 h   peak 27.5 %   width 3.7 min = 0.69 deg
```

Three numbers come out of that table:

- **Timing.** The transit repeats to about one second of right ascension across five days. The site clock, the software timestamps and the new midnight file rollover are all sound at that level.
- **Beam width.** The fitted transit width corresponds to a beam 0.69° across, against 0.81° predicted for a 60-foot dish at this frequency — the right ballpark, and confirmation that we are looking at a genuine point source rather than something diffuse.
- **Sensitivity.** Cygnus A's known brightness and its measured 27 % response give a system equivalent flux density of about 5800 Jy. That figure is an upper bound, because the source was not passing through the middle of the beam (section 5); a deliberate calibration run would tighten it.

4. Data quality

The recording chain was flawless over the five days:

- **No gaps.** All 16,205 intervals between spectra were 25 or 26 seconds. Nothing was dropped, delayed or duplicated.
- **Stable gain.** The daily median power was 10.836, 10.853, 10.849, 10.858, 10.758 and 10.830 dB — within 0.1 dB day to day, small compared with the sky signals being measured.
- **Clean rollover.** The daily UTC-midnight file changeover introduced in Spectrum Analyzer 1.3.1 produced exactly one cadence step at each seam, with no lost rows.
- **Quiet band.** Scanning all 3276 channels of the five-day median against a smoothed bandpass, only one genuine interference feature exceeds 0.05 dB: a two-channel carrier at 1419.9977 MHz, at most 0.16 dB, which corresponds to a velocity of about +96 km/s — outside the range where the Galactic hydrogen appears in these directions, so it did no harm.

This is an unusually clean 1420 MHz dataset, and it says something good about the Haswell site as well as about the equipment.

5. Two recommendations

Tune slightly off the line. The receiver was tuned with the hydrogen line at the exact centre of the band. Every direct-conversion receiver, including the B210, produces a small artefact at the centre of its own passband, and here that artefact lands 6.4 kHz — 1.3 km/s — from the hydrogen rest frequency, i.e. inside the line itself (Figure 6). It appears in the data as one channel about 0.2 dB high with a 2 dB notch beside it, and it has to be blanked before the spectra can be used near zero velocity.

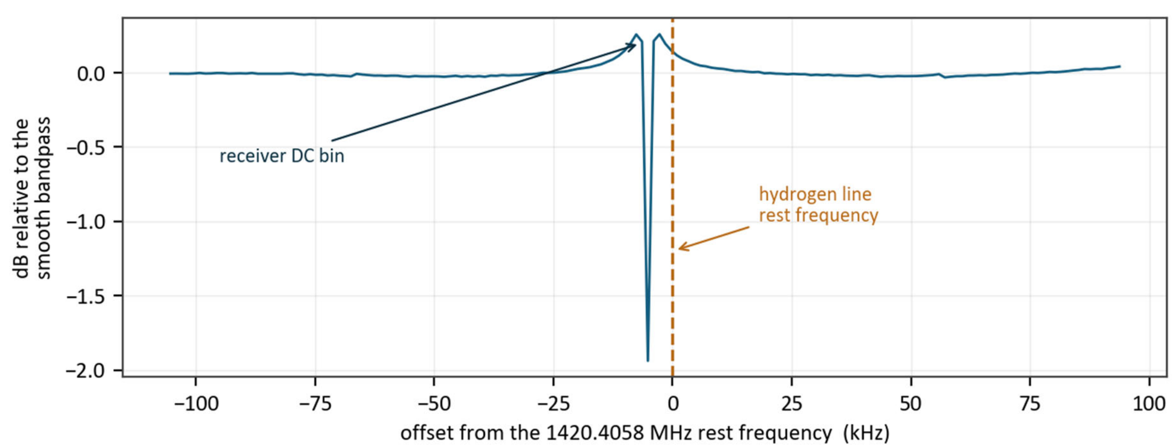


Figure 6 — The receiver's DC artefact sits 6.4 kHz from the hydrogen rest frequency, inside the line. Shifting the tuned centre by 1 MHz moves it out to about −210 km/s, harmlessly clear of any Galactic emission.

The fix costs nothing: tune the centre to 1421.4 MHz instead of 1420.4. The same 4 MHz span then covers 1419.4–1423.4 MHz, keeps the whole line, and pushes the artefact out to −210 km/s. Alternatively the Spectrum Analyzer could blank or interpolate the affected channels as it writes each row.

Use Cygnus A as the pointing calibrator. The observing log records azimuth 0°, elevation 87°, which corresponds to declination +41.375°. Cygnus A lies at +40.73°, two thirds of a beamwidth away, and a source that far off-axis should be strongly attenuated — yet it reads 27 % of the system noise. Every measured transit also arrives one to two minutes east of its catalogue position. Both point the same way:

the dish is not looking exactly where the log says. That is not a flaw in this dataset, it is a free calibration. Cygnus A is bright, unresolved, and passes near the beam every sidereal day at LST 20h; a short run with the dish stepped deliberately in elevation across the transit would map the beam and pin the true pointing, and would tighten the sensitivity figure at the same time.

6. Where the data and analysis live

The recordings and every analysis product are kept together, outside the Spectrum Analyzer source repository:

```
Documents\DSES\Science\HI_and_Drift_Scan\

  DSES_SA_Recordings\       the six daily .txt files from the site Pi

  analysis_2026-08\

      ANALYSIS.md            the full technical notes behind this report

      ezcon\                 ezCon per-day products (six days, ~105 plots each)
                             plus 197 multi-day ezPlot / ezSky / ezGal plots

      quicklook\             the independent second reduction and its figures

      report\                this report, its figures and their generator
```

Everything is scripted and re-runnable: the scan was still going when this analysis was made, and adding the later days is a single command.

7. Methods and caveats

Each daily file was processed with **ezCon** (Ted Cline's ezRA suite), then **ezPlot**,

ezSky and **ezGal** were run across all six days together. To keep the conclusions from depending on one pipeline's baseline-fitting choices, a second, independent reduction was written: spectra converted from dB to linear power, the instrument bandpass removed by dividing each spectrum by the median of all 16,205 spectra, each sample Doppler-corrected to the local standard of rest using its own observing time and pointing, and the results regridded onto a common velocity axis. The two reductions agree on every result reported here.

Caveats worth stating plainly:

- Brightnesses are quoted as fractions of the system noise power, not in kelvins. Converting to a temperature scale requires a calibrated noise source or a beam-mapping run.
- The 5800 Jy sensitivity figure assumes Cygnus A passed through the centre of the beam, which section 5 shows it did not. The true figure is better than quoted.
- Dividing by the median spectrum removes the *average* hydrogen signal along with the bandpass, so the quoted line strengths are relative to the average sky at this declination, not absolute.
- The source identifications in section 3 are positional matches against catalogue positions, supported by the consistency of their relative fluxes; they were not confirmed by an independent pointed observation.

Appendix A. Pointing-calibration plan

Section 5 concluded that the dish is not looking exactly where the encoders say. This appendix lays out a short observing campaign — five unattended nights of ordinary drift scans — that measures the error directly, using the same recording mode and the same transit-fitting analysis already used in this report. It should be run before the next pulsar trip: at 420 MHz the inferred error costs under 10 %, but at the hydrogen line it costs a factor of about three, and if the underlying cause is a mount tilt the error may be larger at pulsar elevations.

The idea. Cygnus A passes near the beam every sidereal night. If the dish is stepped a little in elevation from night to night, the night that yields the strongest transit tells us where the beam really points, and the transit's arrival time tells us the east-west error. Pointing geometry at azimuth 0 (looking north of zenith): commanded declination = 38.38 + (90 − elevation). Cygnus A sits at declination +40.73, right ascension 19h59m28s, so its nominal pointing is **azimuth 0, elevation 87.65**.

Night	Azimuth	Elevation	Commanded declination	Offset from Cygnus A
1	0	87.65	+40.73	0 (nominal on-source)
2	0	88.15	+40.23	0.5° south
3	0	87.15	+41.23	0.5° north
4 (if needed)	0	88.65	+39.73	1.0° south
5 (if needed)	0	86.65	+41.73	1.0° north

The six-day run of this report (elevation 87.0, response 27 %) already provides a sixth grid point. As of 19 August 2026 the transit falls at about 11:00 pm MDT and arrives roughly 4 minutes earlier each night; recording from 10:30 to 11:30 pm local captures the transit and its baseline.

What the fits give. Fitting the peak amplitude against commanded elevation, the elevation at maximum minus 87.65 is the elevation pointing error — from the 27 % response seen in this report, the expectation is 0.3 to 0.6 degrees, with the dish pointing south of the commanded position. Each night's peak time minus 19h59m28s is the east-west error (already measured at +1.9 minutes, stable over five nights). The amplitude at maximum also gives the true system sensitivity — the figure quoted in section 3 was measured off-axis, so the real number is better — and the fitted width gives the true beam.

One caution. Near the zenith the azimuth axis barely moves the beam: the 0.36-degree east-west offset could be several degrees of azimuth-encoder error, or a small tilt of the mount, and Cygnus A alone cannot tell the two apart. Two more sources settle it:

Source	Azimuth	Elevation	Declination	Transit (local)	Notes
Cassiopeia A	0	69.6	+58.81	about 2:20 am MDT	~1700 Jy; north of zenith, lower elevation
Sun	180	about 64, falling daily	+12.3, falling 0.35°/day	about 12:56 pm MDT	south of zenith; ~100× system noise — reduce the gain well down

If the elevation error has the same sign on both sides of the zenith, it is an encoder zero offset — one pointing constant fixes it. If the sign flips, it is an azimuth-axis tilt and needs a tilt term in the pointing model. Three sources, at three elevations, on both sides of the zenith, is the smallest set that separates the two cases.