First light and characterization of the DSA-2000 test array

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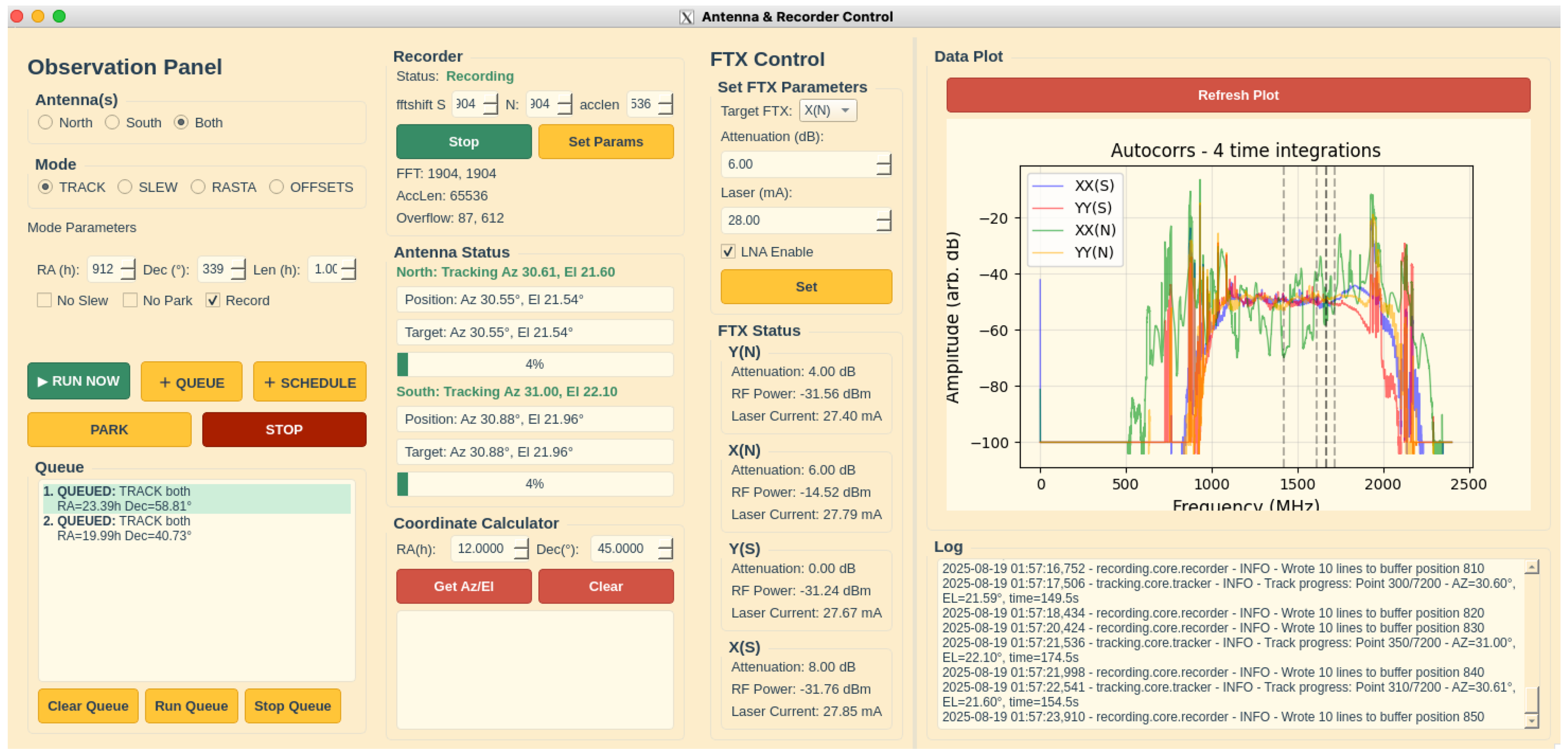
1. Introduction

The 2000-dish Deep Synoptic Array (DSA-2000) will be a large leap forward in radio telescope instrumentation, operating as a "radio camera" that produces reliable, high-resolution images. A two-dish test array has been commissioned at Owens Valley Radio Observatory ahead of construction of the full array in Nevada.

Our objective was to bring the test array to a usable state and characterize its performance, to inform design decisions for the full array.

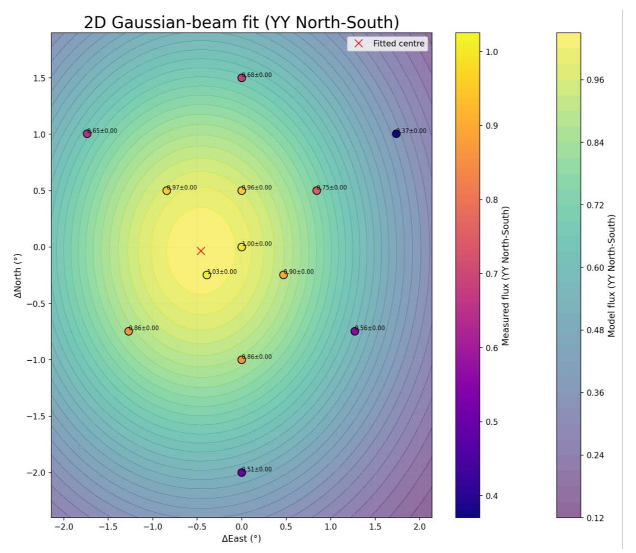
2. Control suite

We built an end-to-end control suite that automates source tracking and data recording through a graphical interface.

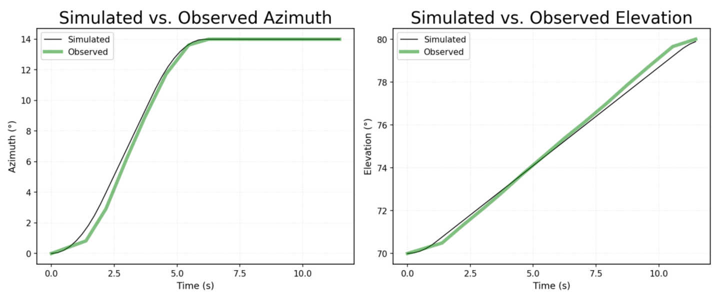


Tracking

We fit an on-sky-calibrated 11-parameter pointing model to translate celestial targets (right ascension and declination) into local azimuth and elevation commands for the antenna drives. This model accounts for factors such as sagging, encoder offsets, and collimation.

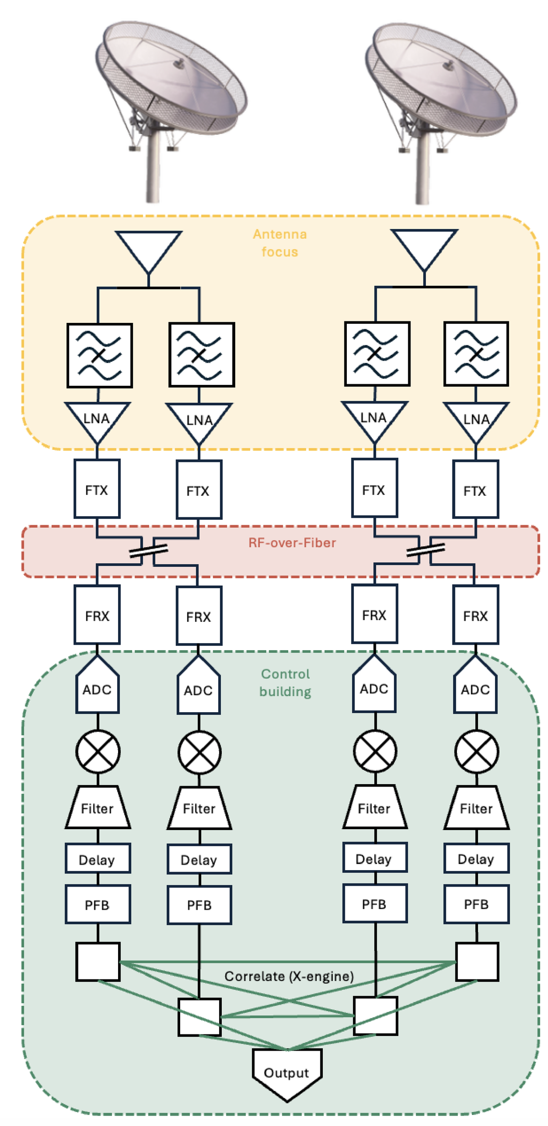


For safety, we must avoid pointing near the Sun (see 'Challenges'). Safe travel paths are generated by simulating and then checking the antenna trajectories.



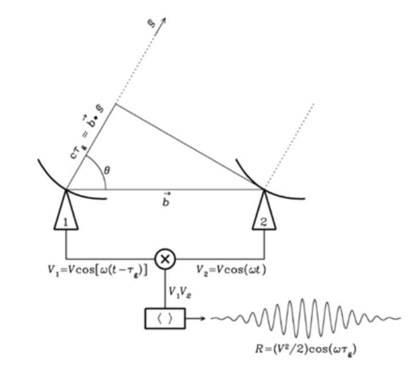
Recording

Light hitting the antenna dishes is collected, filtered, and digitized. We record raw digitizer outputs along with system metadata (e.g. attenuation, amplifier current, pointing information).



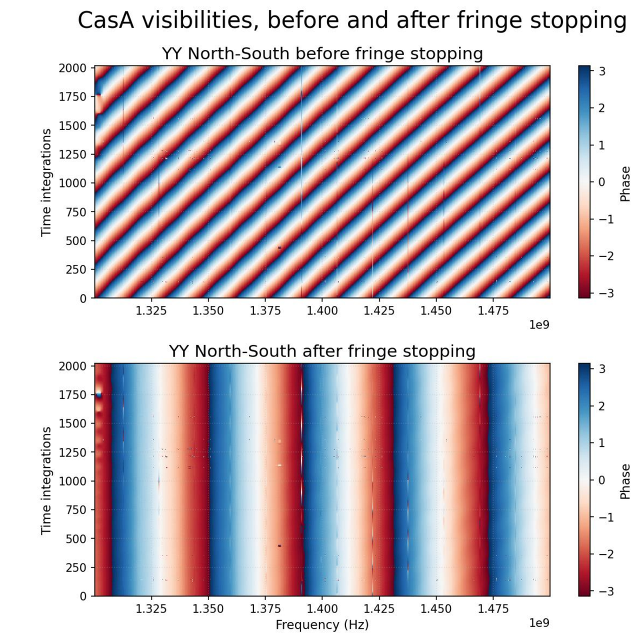
Corrections

The raw data is converted into standard CASA measurement sets by correcting for antenna geometry and Earth's rotation to keep signals in phase.



The phase of the complex visibilities wraps in both frequency and time (as the Earth rotates and $\hat{s}$ changes, so does the geometric delay). Correcting for the latter is called 'fringe stopping'.

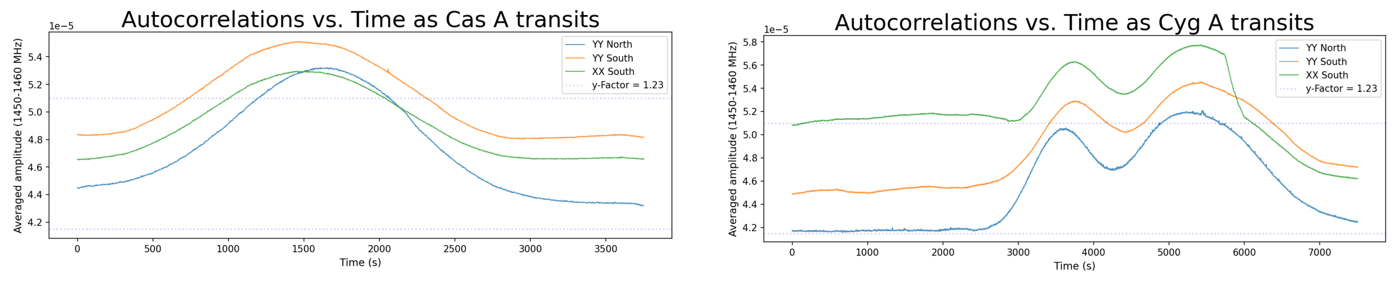
CasA visibilities, before and after fringe stopping



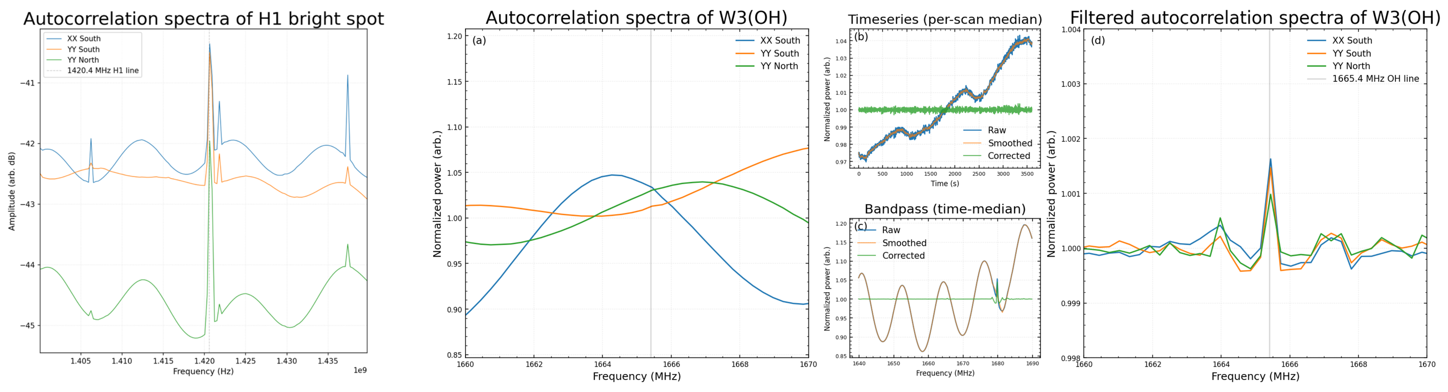
3. First light

Single dish

Autocorrelation power rises as radio sources Cassiopeia A and Cygnus A (double lobe!) drift across the beam.

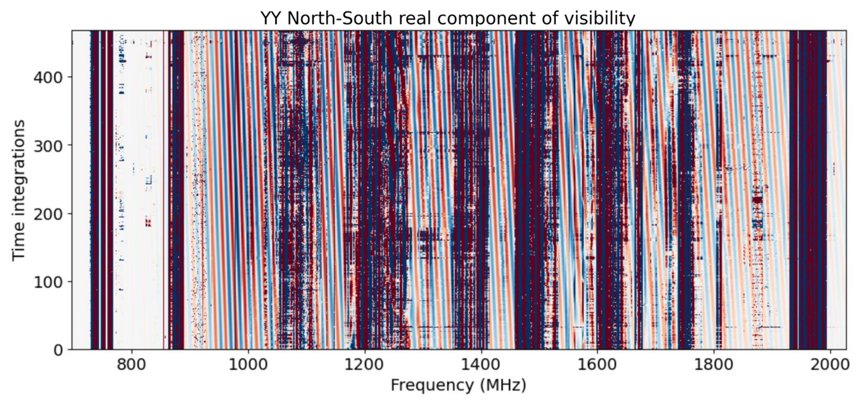


The characteristic 1420 MHz Hydrogen emission line is evident when observing a bright spot. Although the 1665 MHz OH emission line is not as conspicuous; it emerges in the filtered auto-correlation spectra of maser W3(OH).



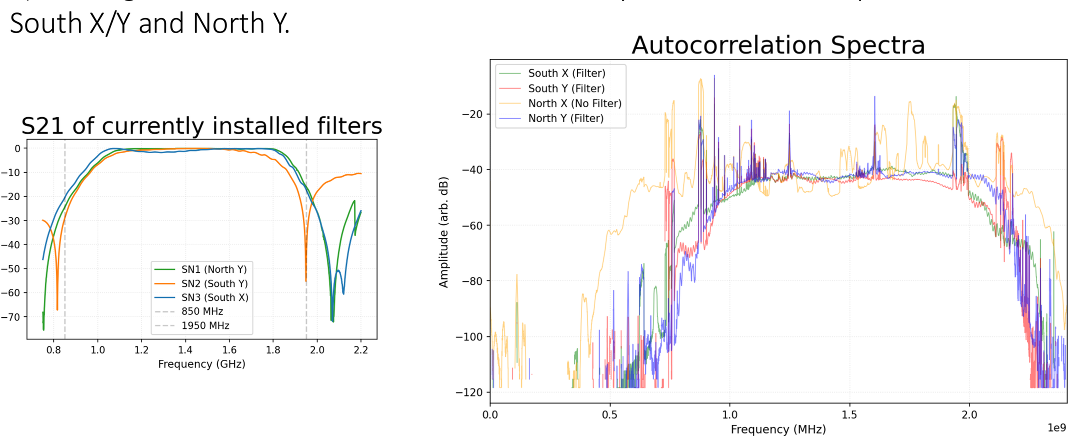
Interferometer

As the bright radio source Cassiopeia A drifts through our beam, fringes can be clearly observed.



4. Sensitivity

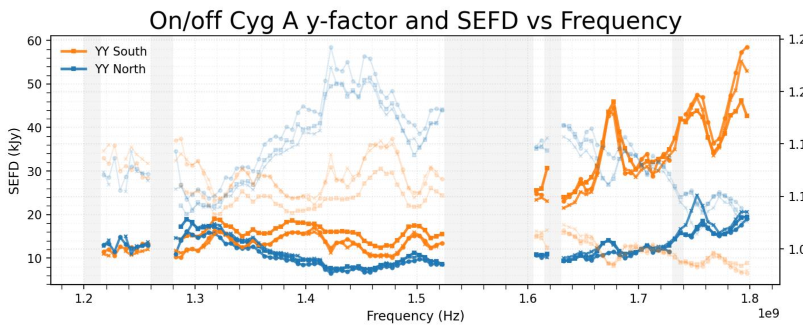
Significant RFI in the cellular bands (~800–900 and 1900–2000 MHz) saturates the LNAs, generating intermodulation products that appear as broadband noise (North X). Adding low-noise notch filters at these bands yields the cleaner spectra seen in South X/Y and North Y.



System-Equivalent Flux Density (SEFD)

We allowed bright radio sources to drift across the beam and calculated y-factors (Pon / Poff), allowing for an estimate of SEFD:

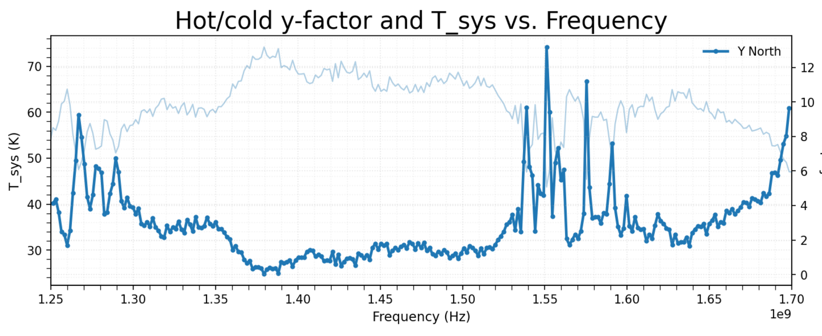
$$SEFD = \frac{S_{source}}{y-1}$$



System Temperature (T_{sys})

We strapped a hotbox to the feed, and calculated y-factors (P_{hot} / P_{cold}), allowing for an estimate of T_{sys}:

$$T_{sys} = \frac{T_{hot} - T_{cold}}{y-1}$$



We can also use the known column density (η_H) of H1 [1] and the measured power increase at its 1420 MHz spectral line to estimate T_{sys}:

$$\eta_H\,[cm^{-2}] = 1.82 \times 10^{18} \int T_b(v)\,dv\,[K\,km\,s^{-1}] \text{ [2]}$$

$$T_{H1} = \frac{\int T_b(v)dv}{2\Delta v} \qquad T_{sys} = \frac{T_{H1}}{y-1}$$

Using a bin size of 61.9 km s^{-1}, a y-factor of 2.1 for Y North (see 'First light'), and assuming the H1 line fills 2 bins:

$$T_{sys}(1420\,MHz) = 37\,K$$

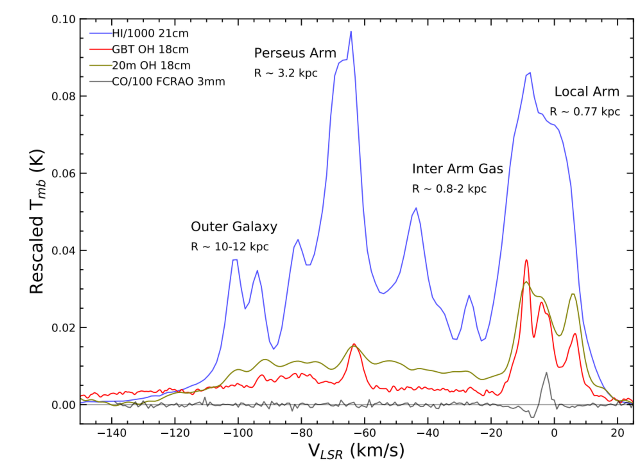
This roughly agrees with the hotbox measurement!

Mapping dark molecular gas

'Dark' molecular gas describes the H_2 not captured by the standard CO tracer. The 18cm OH lines provide an optically thin, low-critical-density tracer for this dark gas.

Recent observations with the 20m and 100m telescopes at the Green Bank Observatory show faint, very broad OH emission in the outer Galaxy, suggesting the existence of a previously undetected thick (~ ±200 pc) disk of diffuse molecular gas [3].

We hope to use our 5m dish to extend these findings and map the scale and structure of OH in this region, and subsequently, H_2.



Challenges

- Incorrect LNA biasing
- Drifting antenna clocks
- Sun damage to radome
- Loose SMA connections
- North antenna 'crashes'
- RFI intermodulation products
- Networking & configuring NTP
- Cross-talk

...and more!

References

[1] Hydrogen column density calculated using NASA's High Energy Astrophysics Science Archive Research Center (HEASARC) nH tool.

[2] Condon, J. J., & Ransom, S. M. (2016). *Essential Radio Astronomy*, Ch. 7, Eq. 7.155.

[3] Busch, M. P., Engelke, P. D., Allen, R. J., & Hogg, D. E. (2021), *Observational Evidence for a Thick Disk of Dark Molecular Gas in the Outer Galaxy*, arXiv:2104.06538.