WARES

Wideband Array Roach-Enabled Spectrometer

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UMass

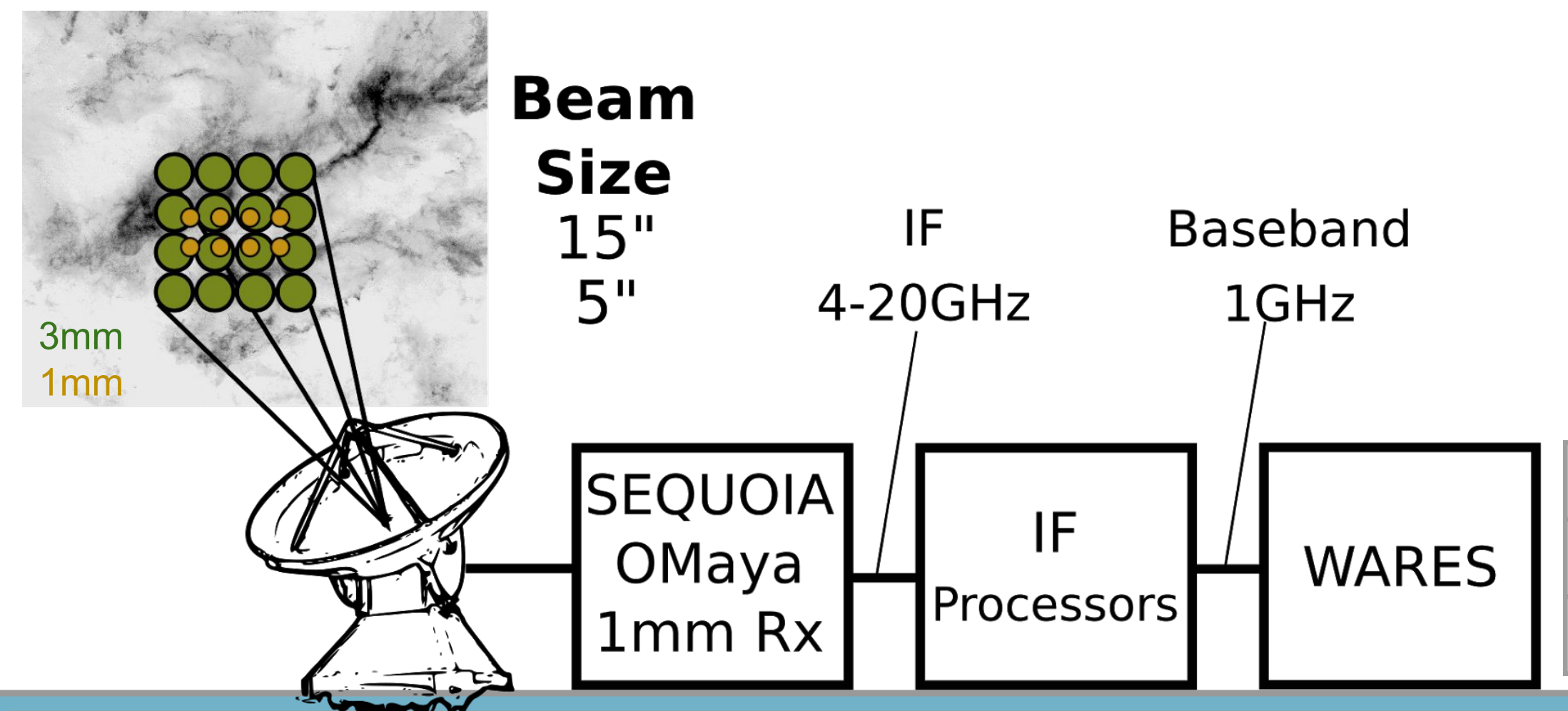
Abstract

WARES is a general purpose digital spectrometer for heterodyne receivers in use at the Large Millimeter Telescope (LMT).

We describe the FPGA programming, ADC noise characterization and mechanical design behind WARES.

LMT Receivers

- SEQUOIA (3mm) and OMaya (1mm) are both focal plane array receivers that motivate the development of a wideband spectrometer.
- 1mm Rx is a single-pixel receiver used for Event Horizon Telescope Very Long Baseline Interferometry (VLBI).
- The EHT VLBI back-end can be used in conjunction with WARES.

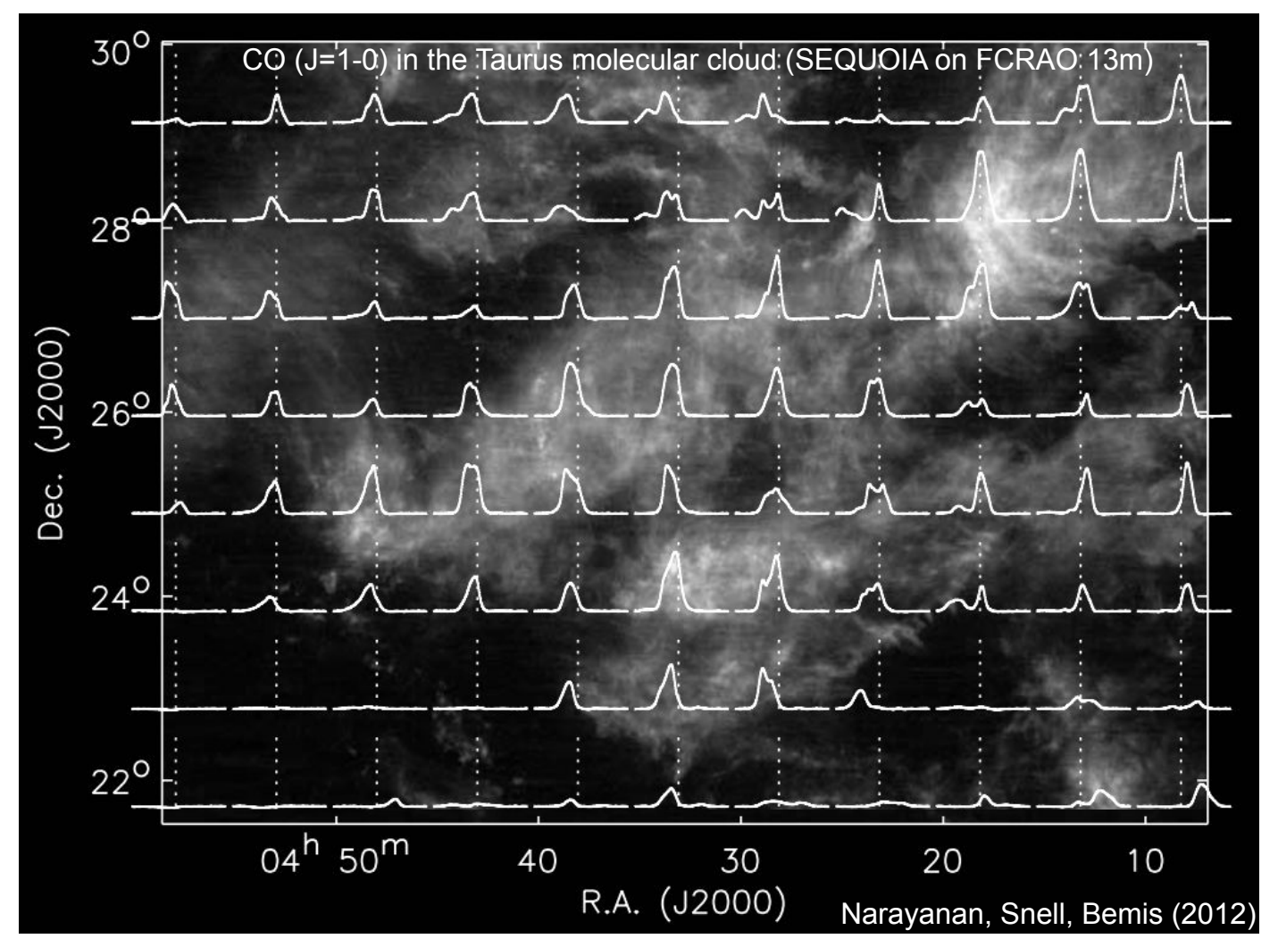


Spectrometer Modes

	BW	R
Wide	800 MHz	2048
Inter.	400 MHz	4096
Narrow	200 MHz	8192

Background

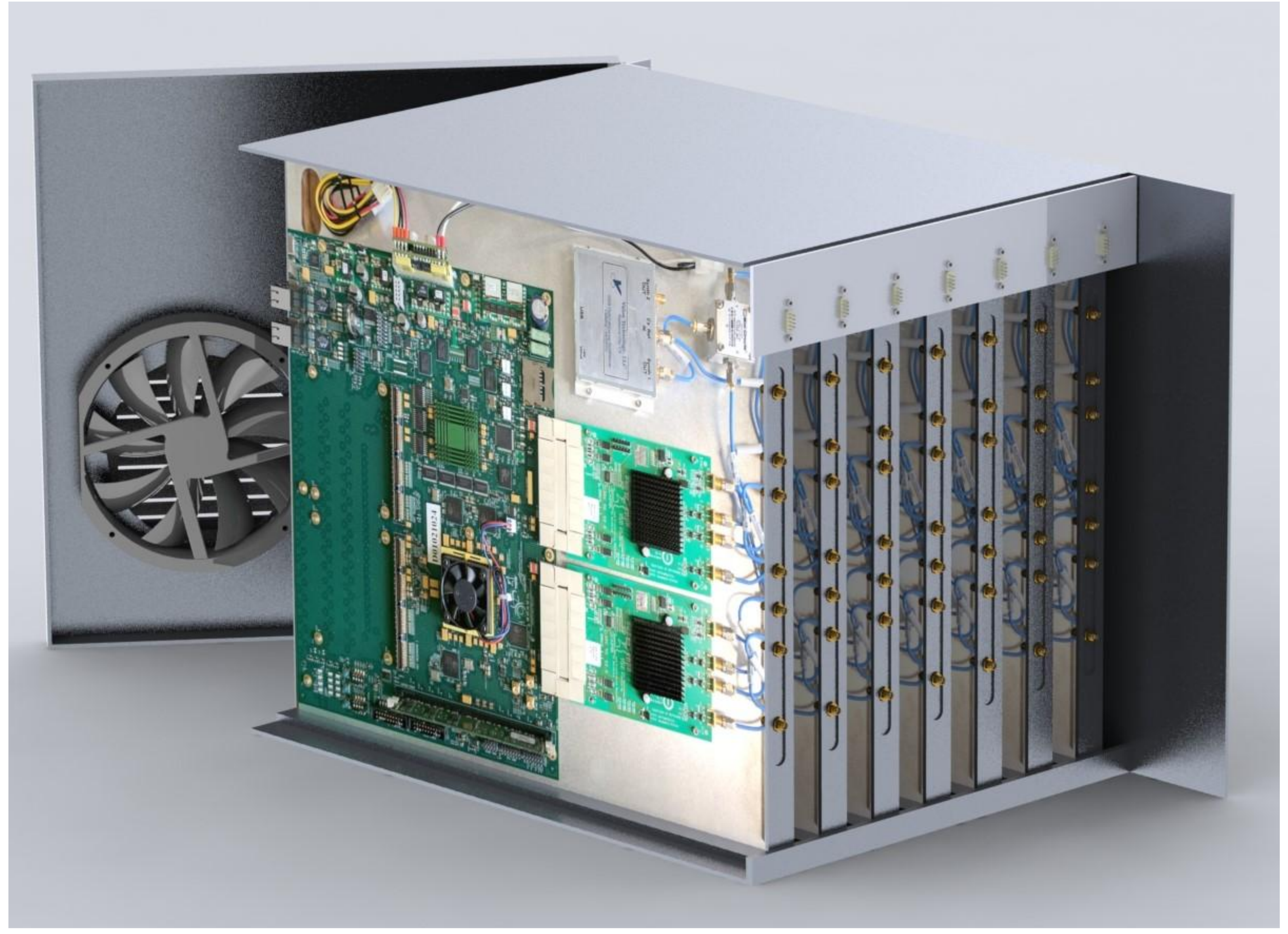
- At mm-waves, molecules in interstellar gas (CO, HCN, SiO and more) emit spectra from transitions between their lowest states of angular momentum (J).
- The Doppler shift in spectra are interpreted as the velocity of gas along the line of sight.
- Excitation conditions, molecular abundances, and the kinematics of star-forming regions in molecular clouds in our own galaxy, and external galaxies, are derived from spectral line cubes.



Narayanan, Snell, Bemis (2012)

Mechanical Design

- WARES is housed in a custom chassis designed for cooling at high altitudes.
- The chassis is mountable in a 19" rack with enough slots for 8 modules.
- A single module is comprised of a ROACH-2 (Xilinx Virtex 6 FPGA + PowerPC), a pair of ASIAA ADC1x5000-8, and a Valon Synthesizer that generates the 1.6 GHz tone for the ADC clock.
- Each module takes 4 baseband channels as inputs



ADC Noise Characterization

- Each WARES channel is sampled independently by two cores within the Analog-to-Digital Converter (ADC)
- The samples are interleaved by the ADC to achieve the full 1.6 Gs/s sampling frequency.
- Uncalibrated, there is a relative offset (O), gain (G) and phase (P) between the two independent stream of samples.
- Correcting for OGP should improve the signal-to-noise and spurious-free dynamic range recovered by the ADC [1]
- Over the baseband, we calculated the Signal-to-Noise and Distortion (SINAD) and Spurious-Free Dynamic Range (SFDR) from the time-series ADC samples of test tones at different frequencies, F_s

$$\mathrm{SFDR} = \frac{A_{tone}}{A_{maxspur}}$$

$$\mathrm{SINAD} = \frac{A_{tone}}{NAD}$$

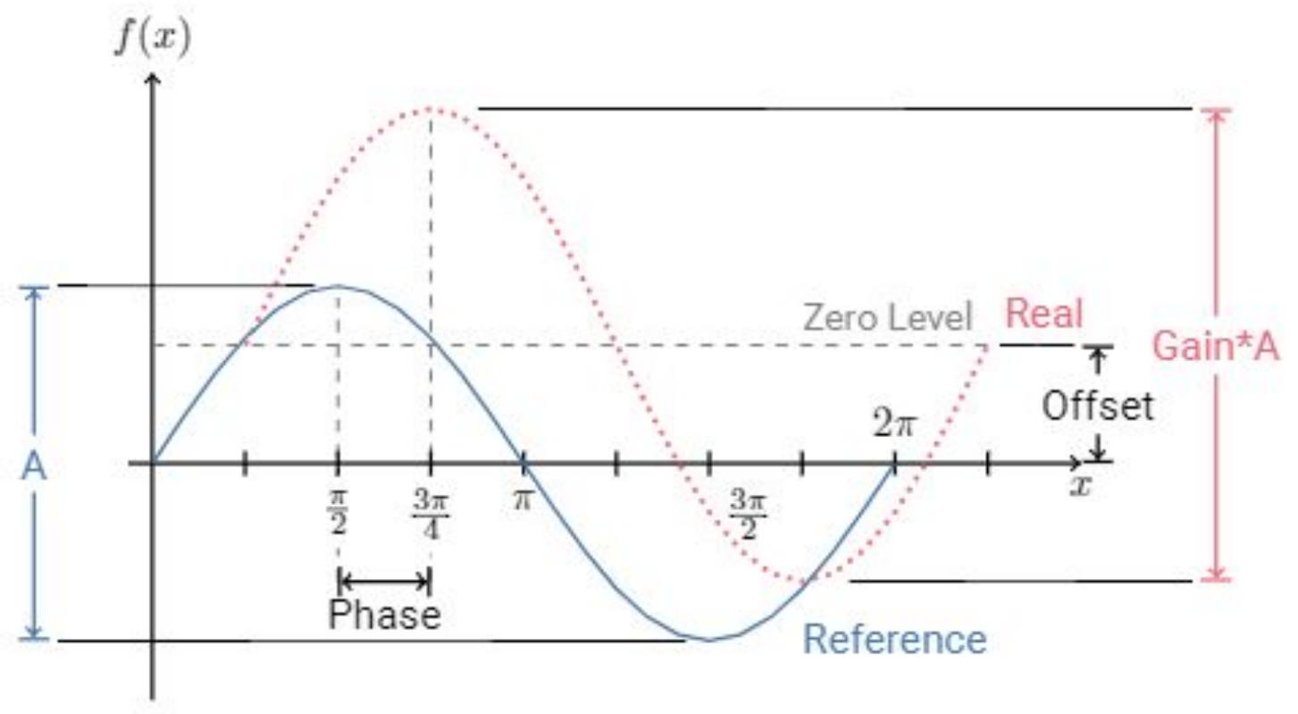
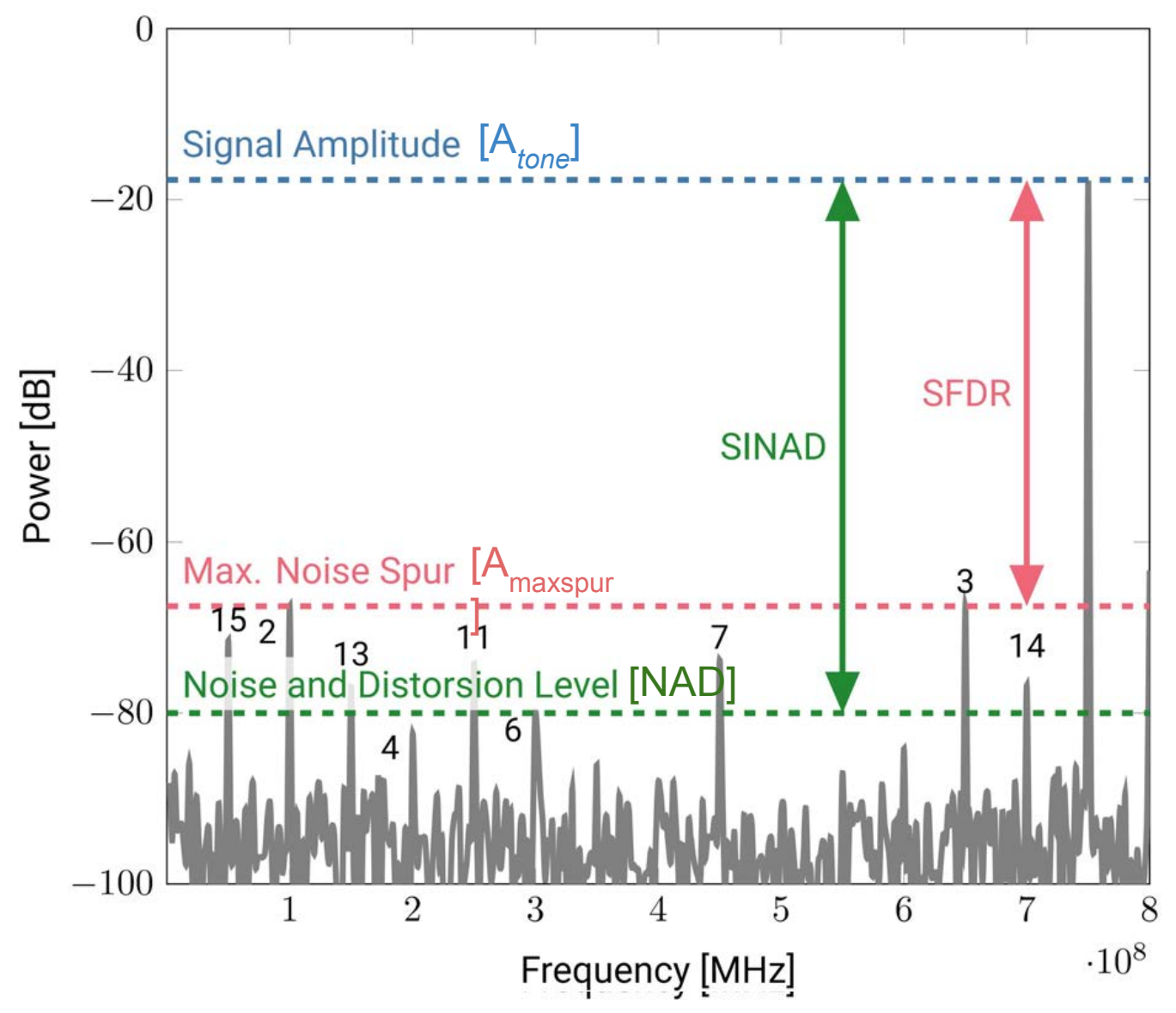
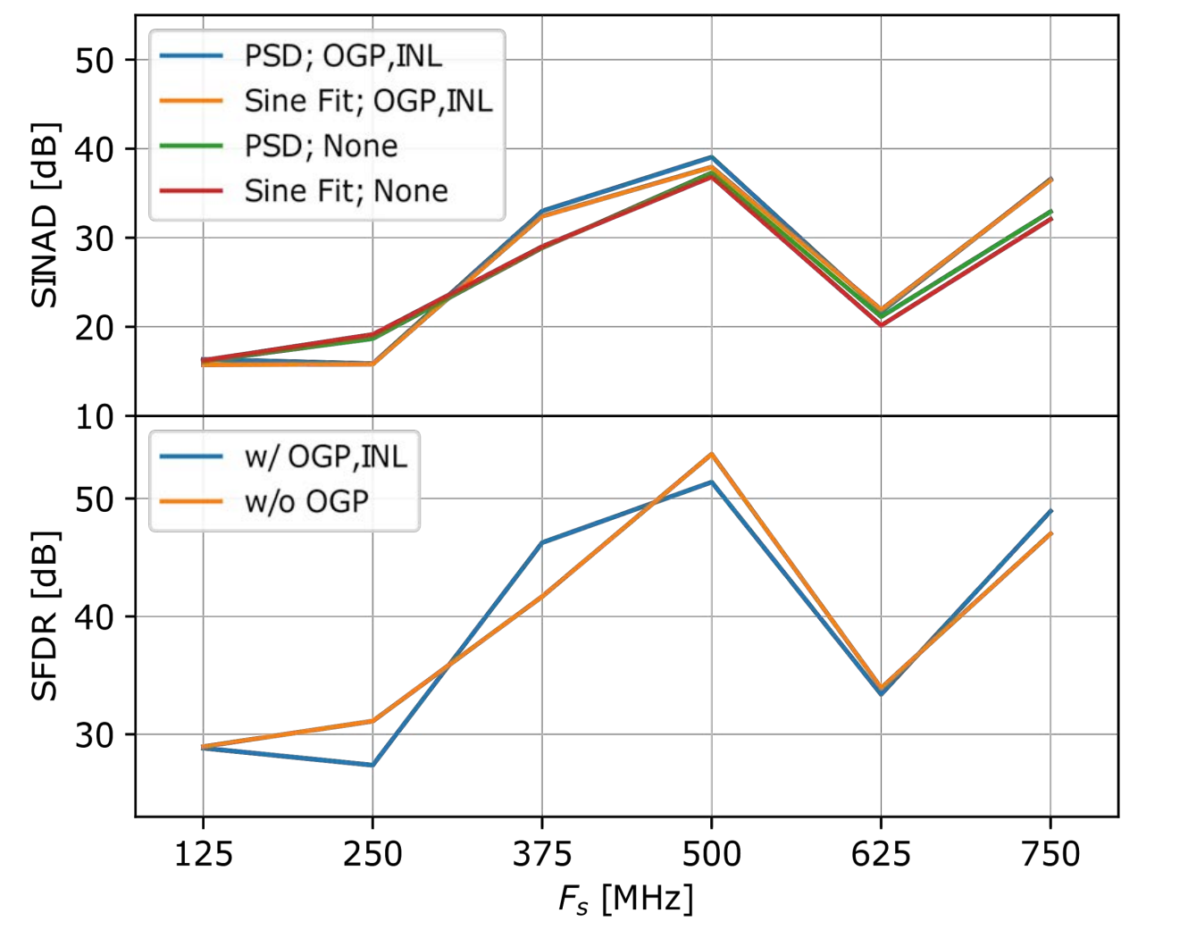


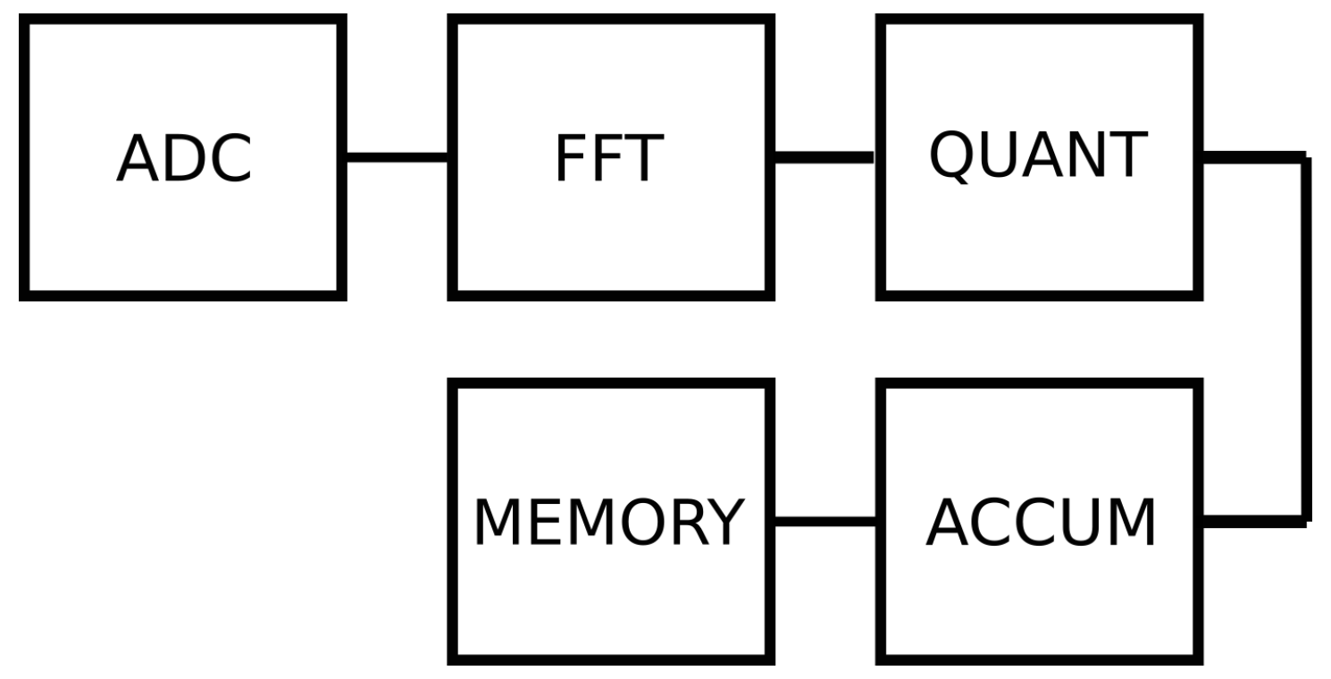
Figure 4.1: Graphical representation of the Offset, Gain and Phase (OGP) parameters that can be adjusted to achieve the alignment of the cores. The continuous blue sine wave represents the reference signal. The dotted cyan sine wave represents the samples acquired by the ADC.





Spectrometer

- The ROACH has an embedded Field Programmable Gate Array (FPGA) that is programmed with MATLAB Simulink using CASPER's digital signal processing libraries.
- The time-series samples from the ADC are transformed into power spectra by an implementation of the Fast Fourier Transform (FFT) algorithm.



- The 'Wide' mode is optimal for high dispersion in more massive extragalactic systems (outflows, late-type galaxies, supermassive black holes)
- The 'Narrow' mode is optimal for high velocity resolution observations of cold cores in Giant Molecular Clouds in our galaxy.

Results

- An astronomical signal, *s(t)*, is dominated by the sky (uncorrelated noise).
- The standard deviation of the signal is given by the radiometer equation:

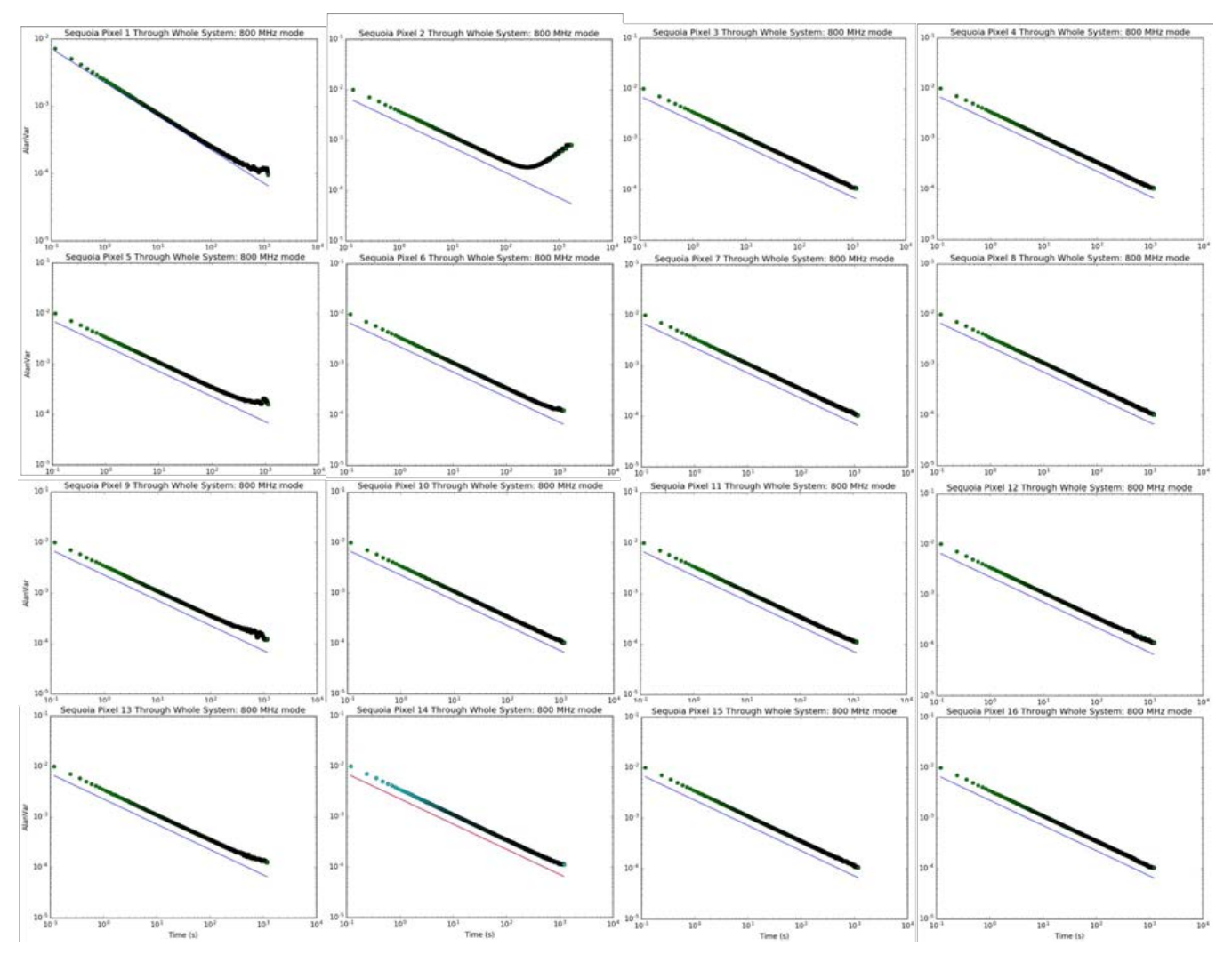
$$\sigma^2 = \frac{\langle s(t)^2 \rangle}{2\Delta\nu\tau}$$

- Increasing the integration time, τ, will decrease the std. dev. and increase the signal-to-noise of S(ν)
- On some integration time scale, *T*, drift noise due to gain variation within the system will begin to dominate the noise.
- The Allan variance is for the differential between two contiguous signals, *d(t)* (i.e. ON-OFF):

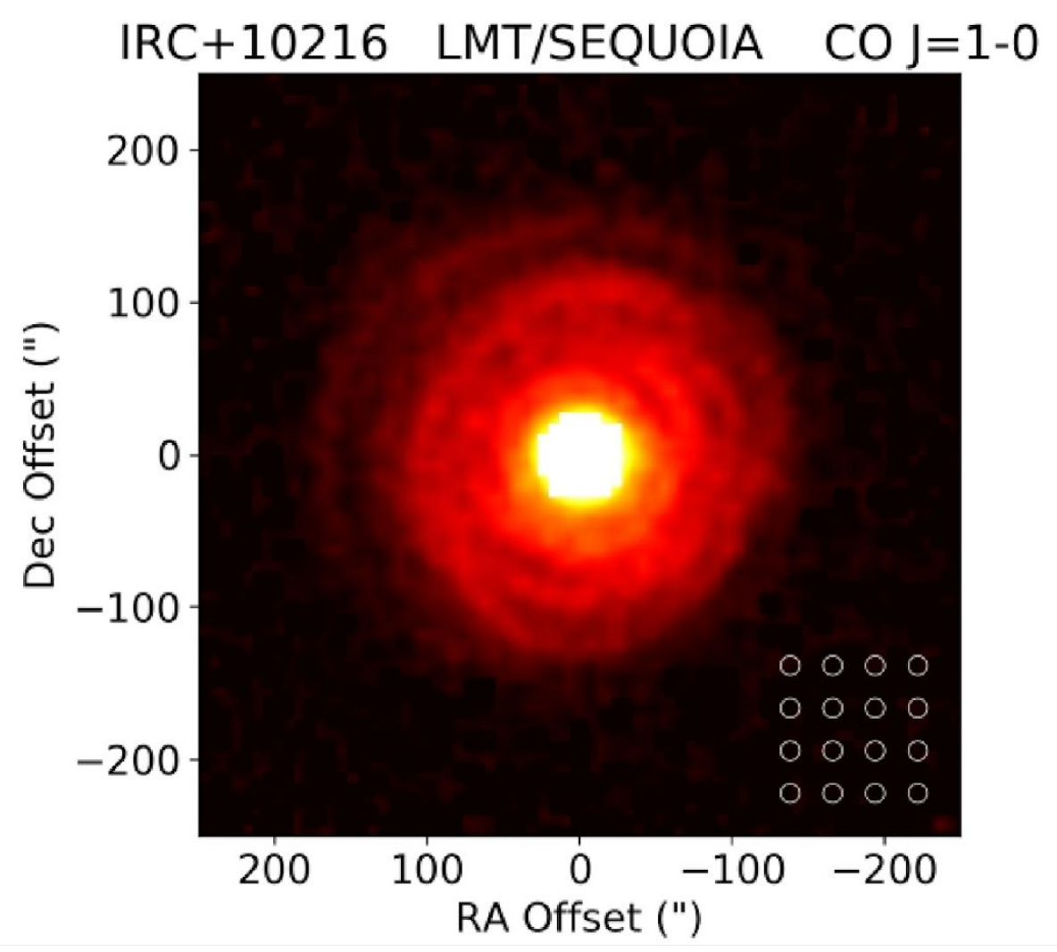
$$\sigma_{Allan}{}^2 = \frac{1}{2}(\langle d(t)^2 \rangle - \langle d(t) \rangle^2)$$

$$\sim \tau^{-1} + \tau^{\alpha-1}$$

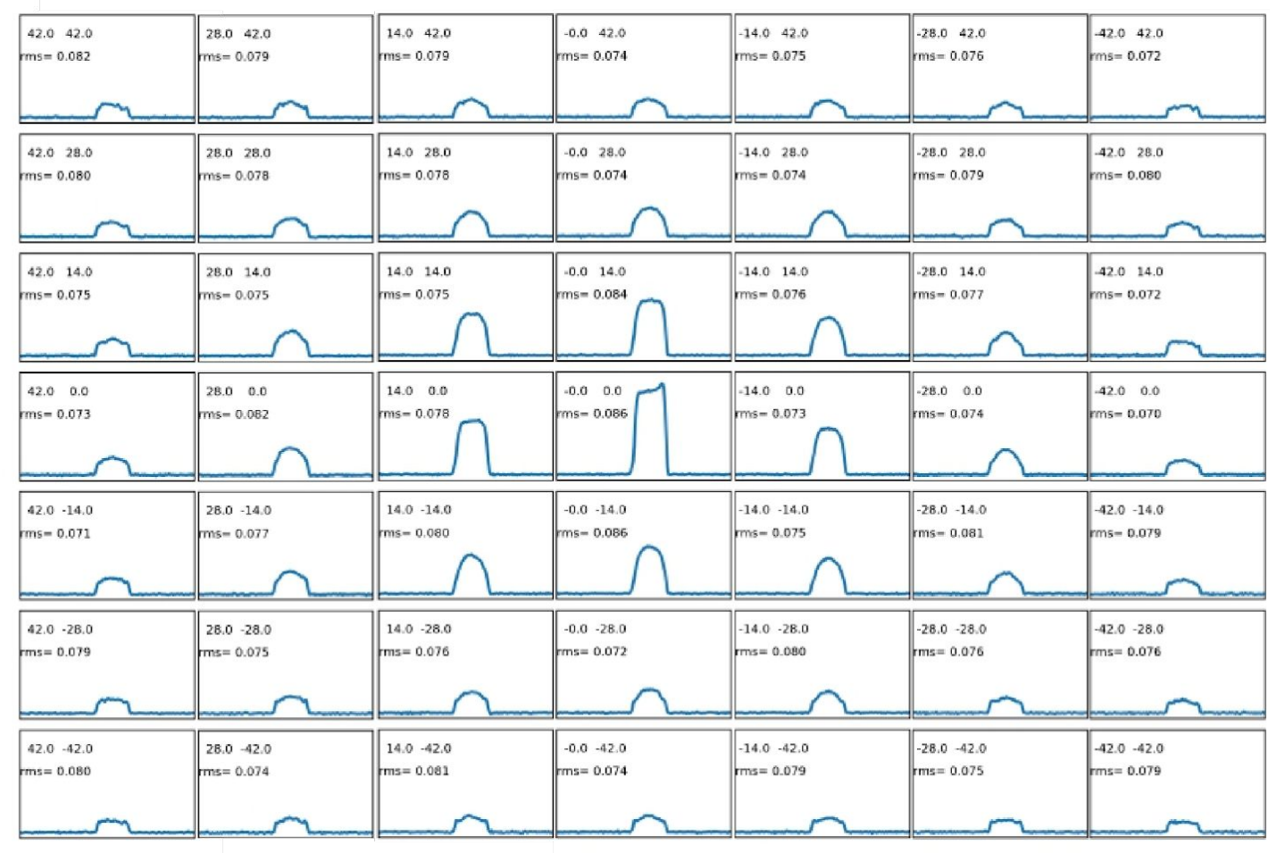
- Where $\alpha \gtrsim 2$ for drift noise
- *T* is then the turnover time of $\sigma_{Allan}{}^2(\tau)$. For $\tau > T$, the signal-to-noise worsens [3]



With 1000's of samples of contiguous 50 ms integrations on a noise source, we show the system is stable for integration $\tau \lesssim 100$s



Result of averaging 4 SEQUOIA On-The-Fly Maps of CO J=1-0 line in the region around the carbon star IRC+10216. The **top** panel shows an image of the emission near the line center. The envelope around the star shows evidence of multiple shells. The footprint of the SEQUOIA array is shown in the lower right corner. The **bottom** panel shows the spectra in the inner part of the image on a 14" grid (P. Schloerb, private communication)



References

1. Patel, NA et al. (2014). "Characterizing the Performance of a High-Speed ADC for the SMA Digital Backend". In: Journal of Astronomical Instrumentation 3.01, p. 1450001.
2. Narayanan, G., Snell, R., and Bemis, A. (2012). "Molecular outflows identified in the FCRAO CO survey of the Taurus Molecular Cloud". In: Monthly Notices of the Royal Astronomical Society 425.4, pp. 2641–2667.
3. Schieder, R. and C. Kramer (2001). "Optimization of heterodyne observations using Allan variance measurements". In: Astronomy & Astrophysics 373.2, p. 746.

Acknowledgements

This research was funded in part by the National Science Foundation and Consejo Nacional de Ciencia y Tecnología (CoNaCyT)

CASPER
XILINX
MATLAB SIMULINK
python