Broad Spectrum Noise Sources for Calibration of BICEP/Keck CMB Experiments

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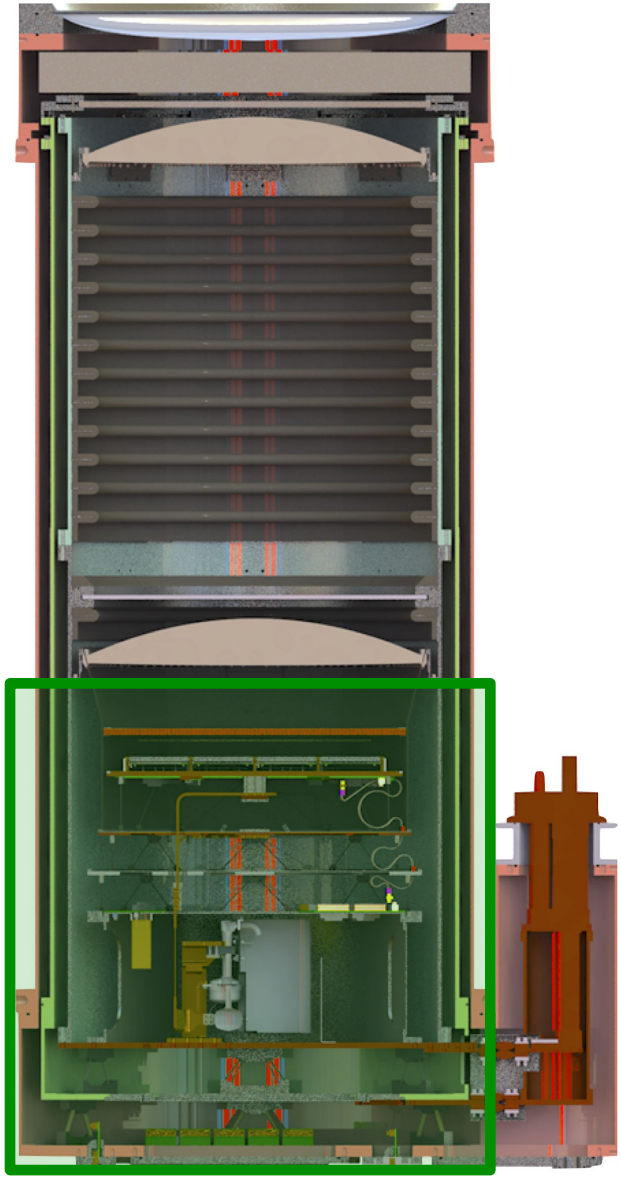
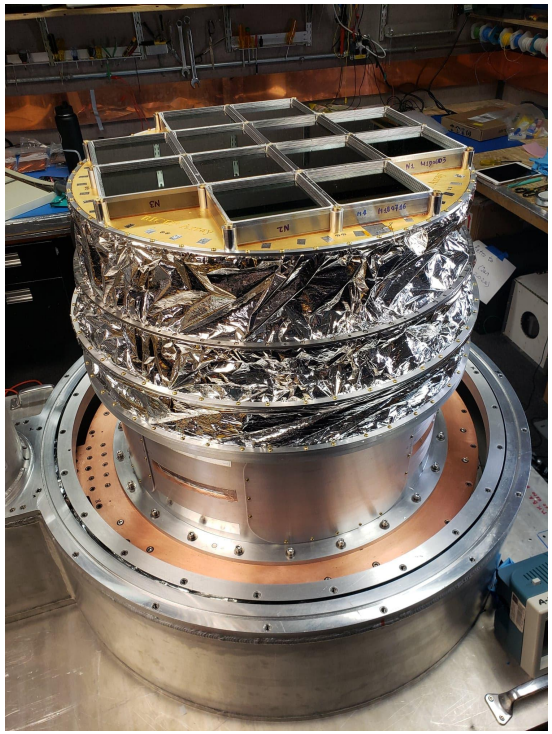
1-Min. Summary

- Motivation
  - Calibrators need high stable output with precise polarization and CMB spectral profile
  - Need higher signal than thermal sources
  - Gunn sources can produce standing waves
- Broad Spectrum Noise Source
  - Take low-frequency noise (Johnson noise) and amplify by ~70dB
  - Upconvert into desired frequency range
  - Quasi-thermal output with broad spectrum
- Performance
  - Capable of high power output (up to 10^11 Kelvin) that is extremely stable over our observing times
  - Relatively flat spectra
- Calibrations
  - Measurements of the far sidelobes (>20 deg) down to -70dB
  - Polarization angles and xpol response down to σ<0.1 deg and σ<0.003 respectively

BA1 instrumental highlights



Camera insert

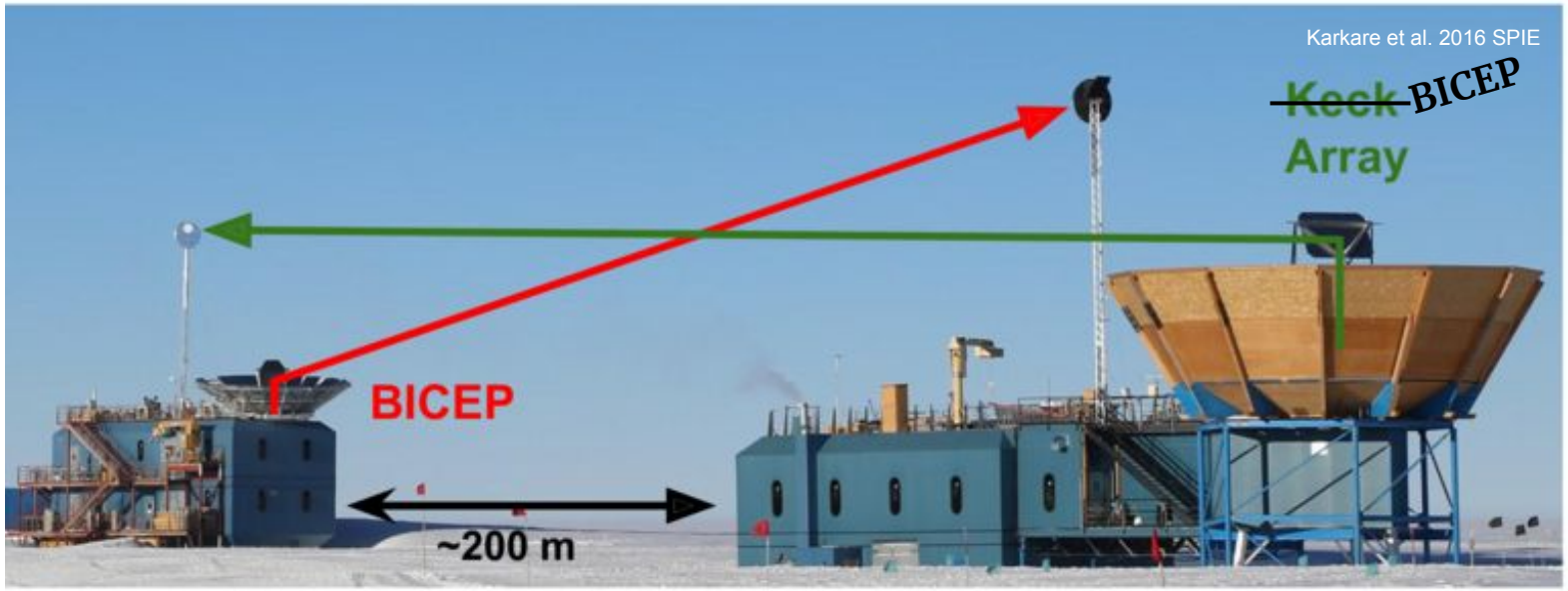


192/300 TES detectors at 30/40 GHz.

Integrated in 12 shielded modules, each with a low-pass mesh filters.

Time-Domain multiplexed readout.

Motivation: What Calibrations do we need?



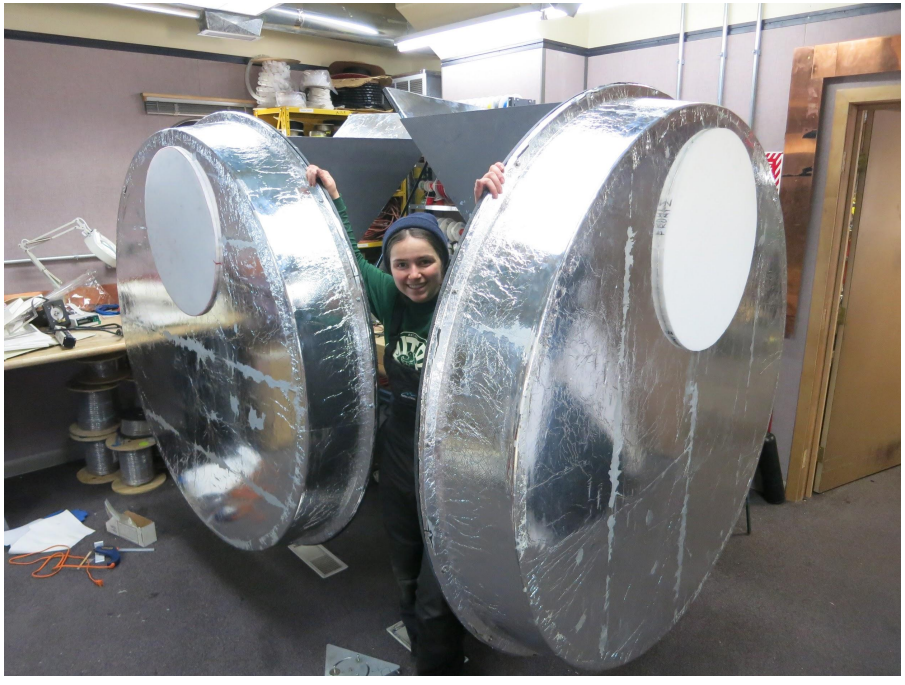
Calibrations

- Far field near- and far-sidelobe Mapping
- Polarization Calibration

Calibrator Requirements

- Stable output over observing times
  - σ < 1e-2 over O(24hrs) for FSL
  - σ < 1e-2 over O(1hr) for Pol Cal.
- High signal with tunable output power
- Thermal spectrum
- Highly/precisely polarized

Motivation: Source Alternatives



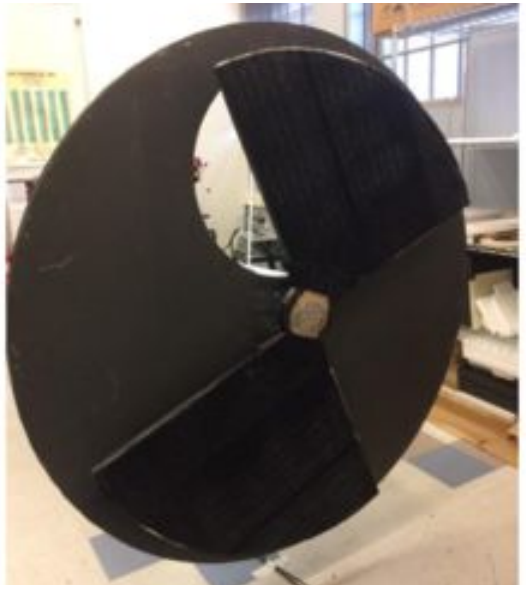
Thermal Sources

Pros:

- Approximate blackbody
- Easy to polarize

Cons:

- Physically Large
- Power based on ambient temperature
- Hard to precisely polarize



Motivation: Source Alternatives

Gunn Oscillators

Pros:

- Large signal
- Compact
- Easy to level output power
- Easy to polarize
- High chop rates

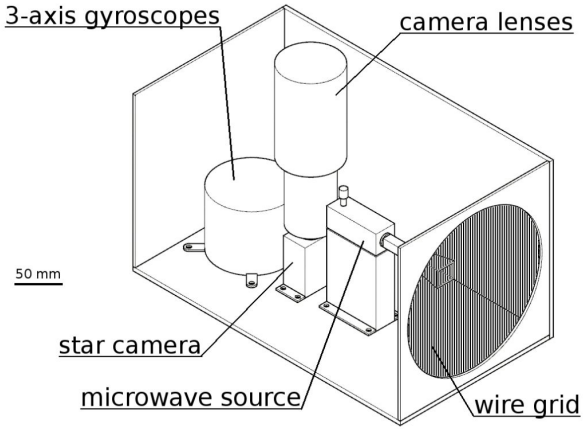
Cons:

- Monochromatic

POLARBEAR

Navaroli et al. 2018 SPIE

Federico et al. 2017 JAI

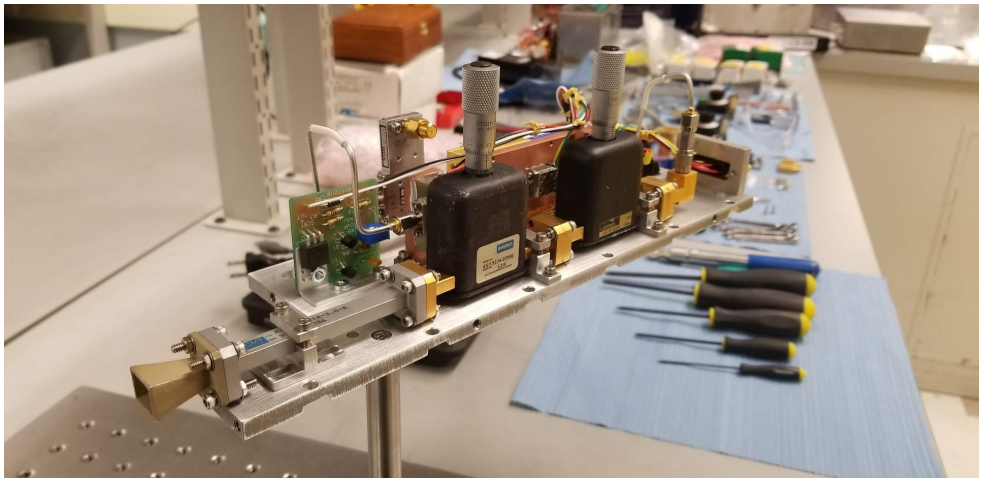


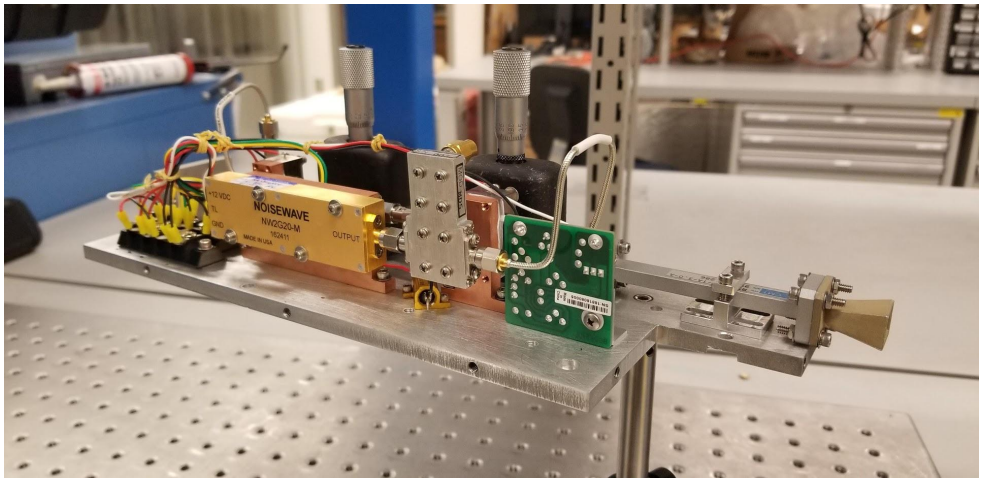
POLOCALC

Broad Spectrum Noise Source

Pros:

- Broad spectrum (quasi-thermal)
- High output (~90 GK_{RJ})
- 65 dB tunable attenuation
- Highly polarized (WG+wire grid)
- Electronically Chopped

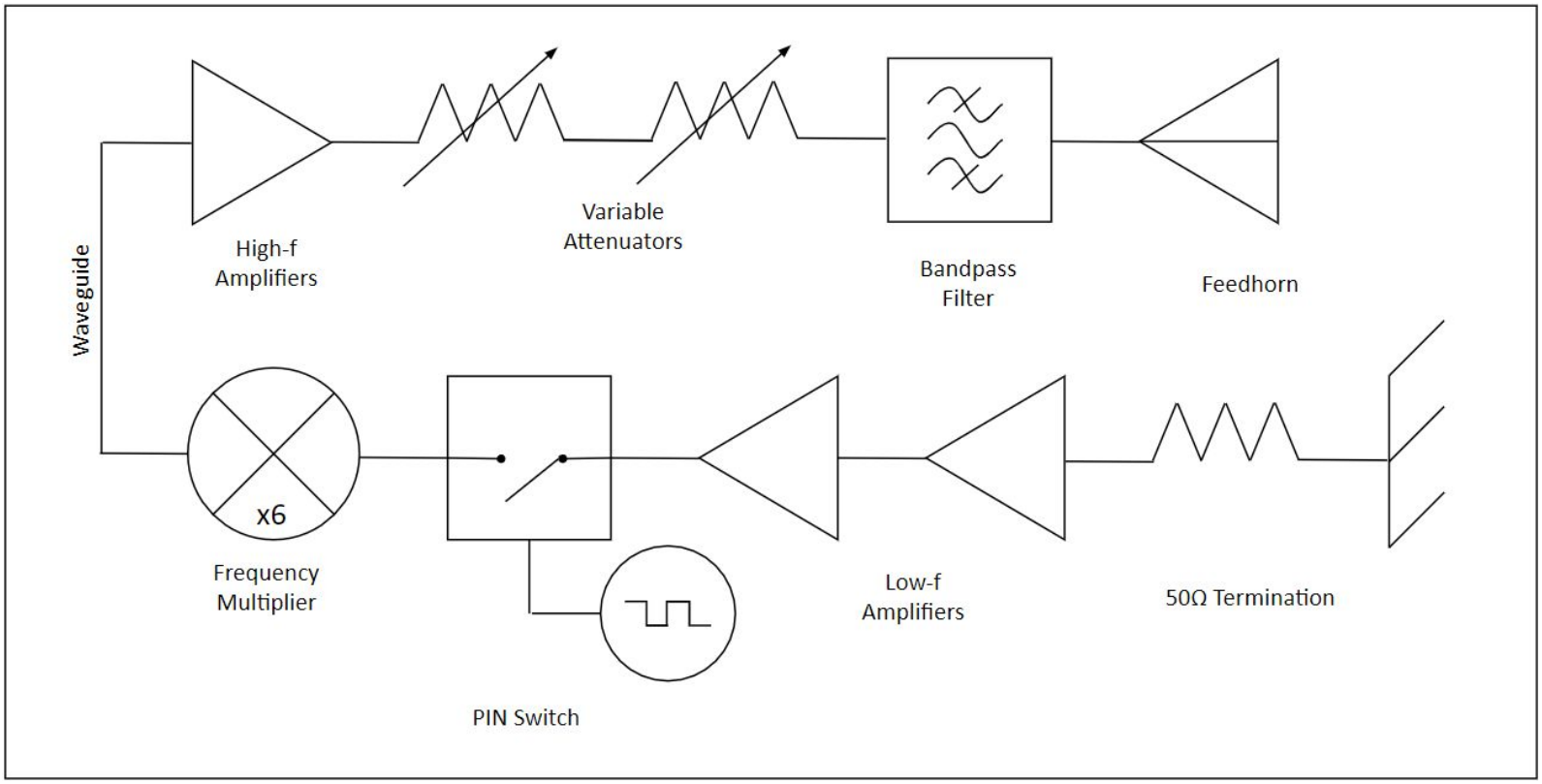




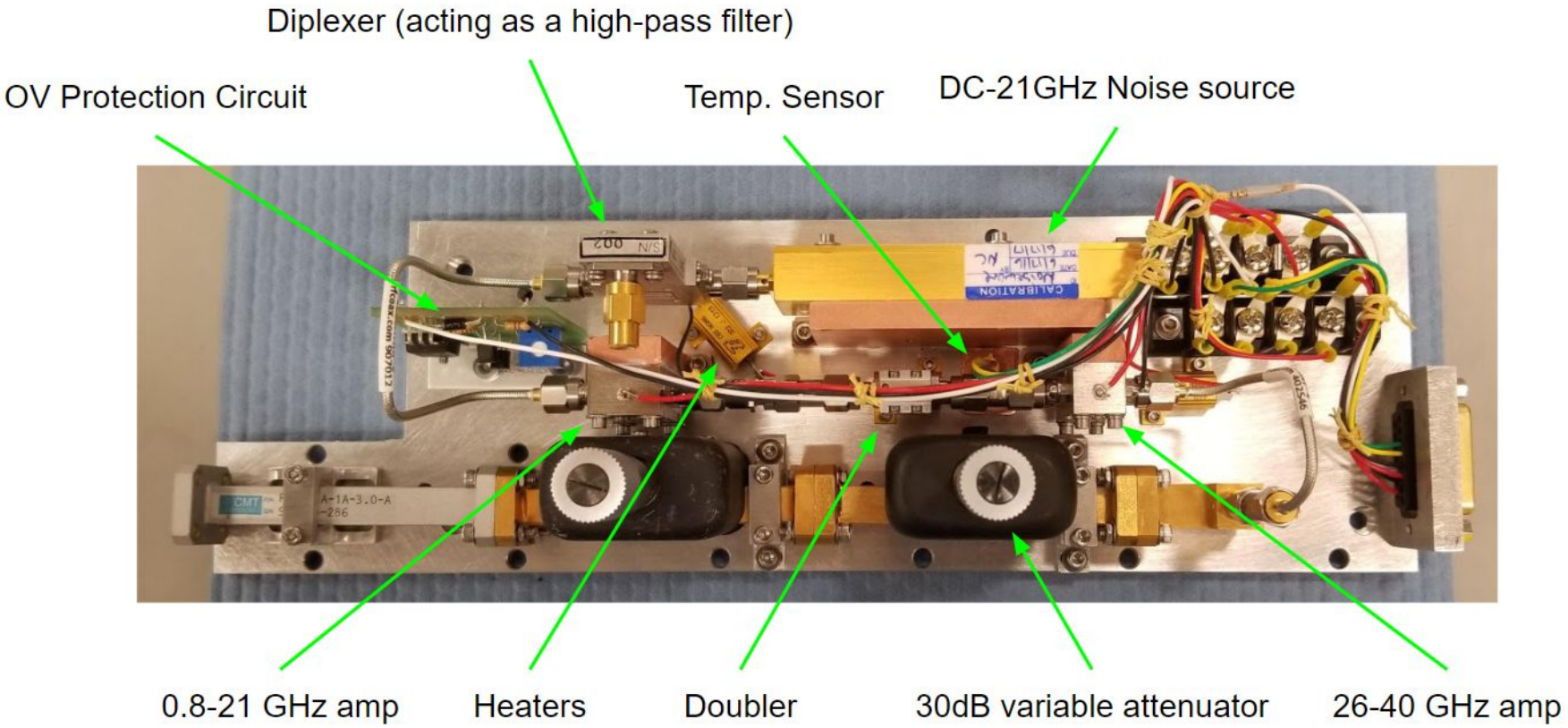
Cons

- More complex than thermal / Gunn sources
- More expensive (but only slightly)

Broad Spectrum Noise Source



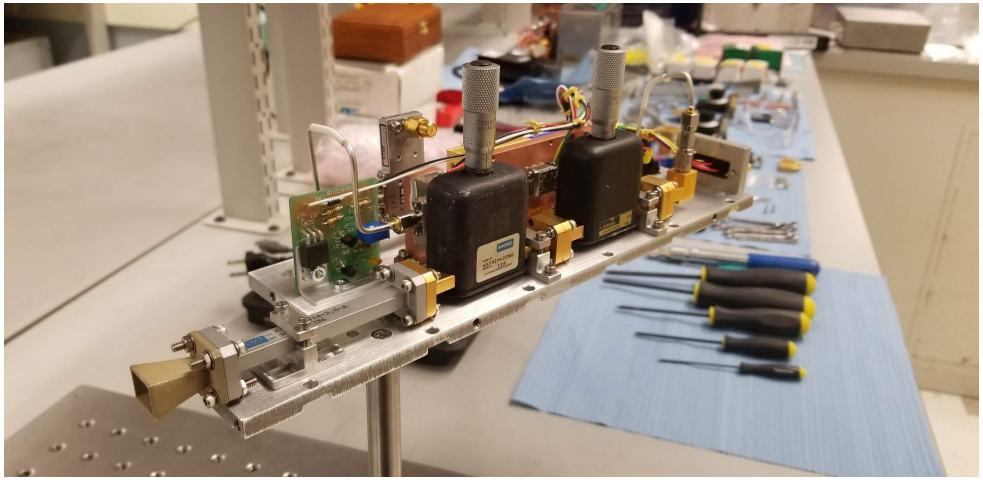
30/40 GHz BSNS



Broad Spectrum Noise Source

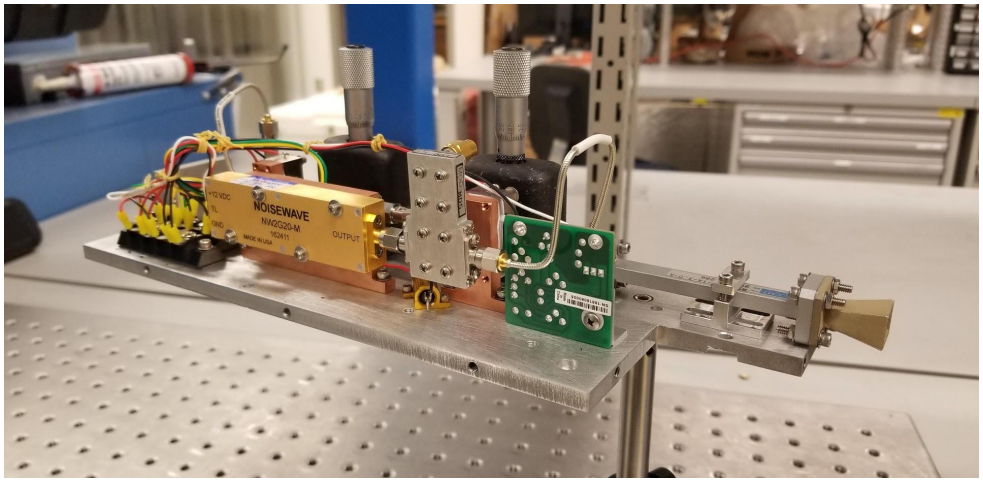
Why start with low frequency?

- Cheaper
- Higher stability
- Easier to chop

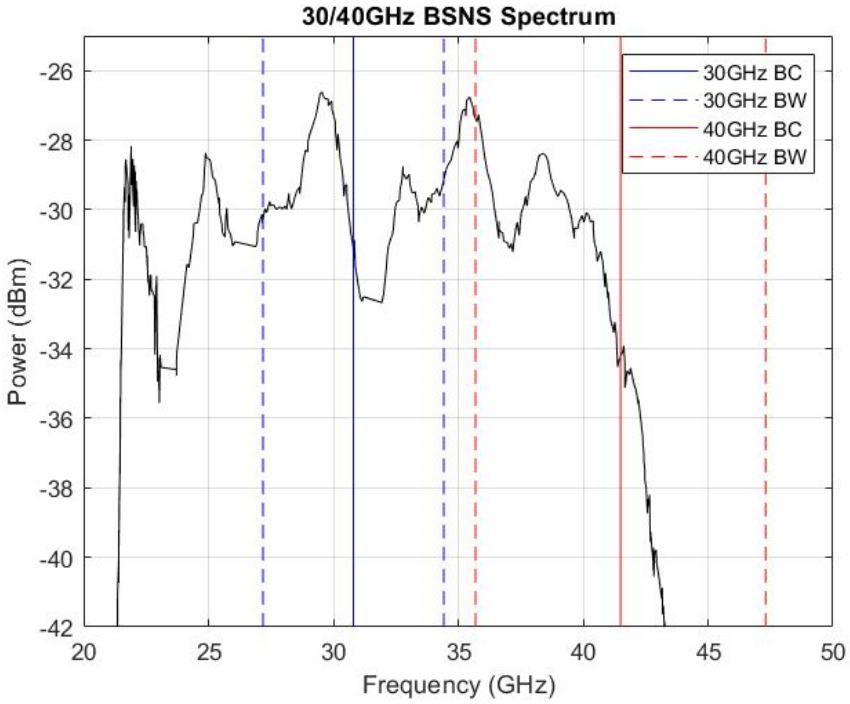


Possible downsides

- Coherence time?



Spectral Performance



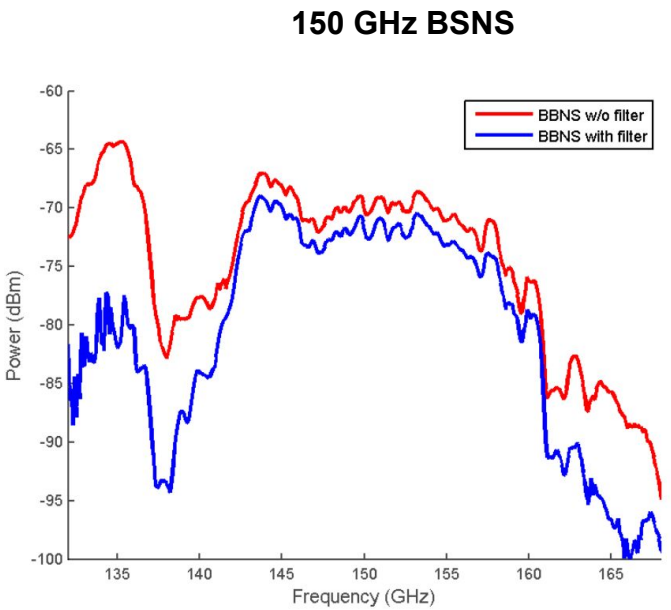
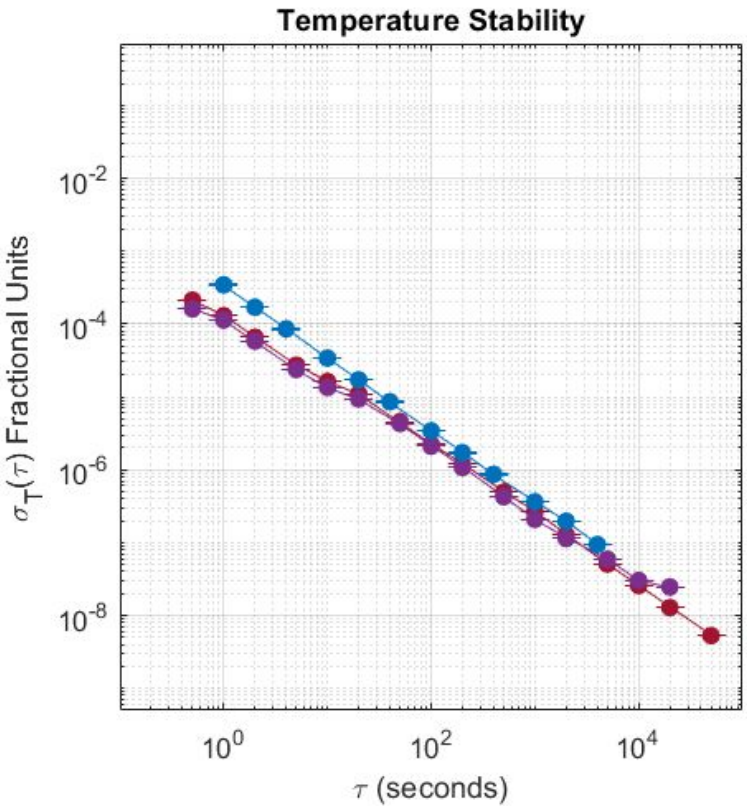
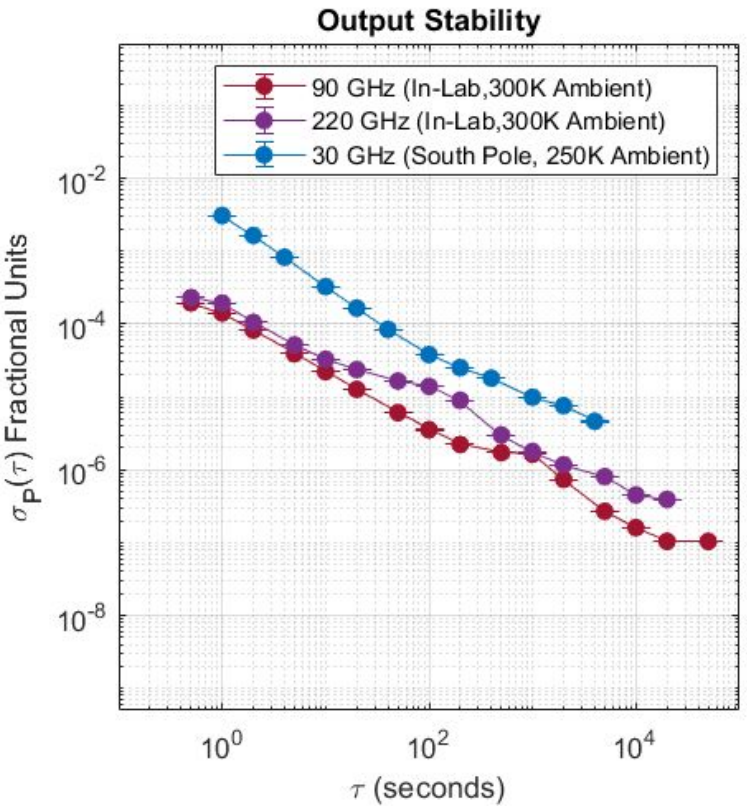


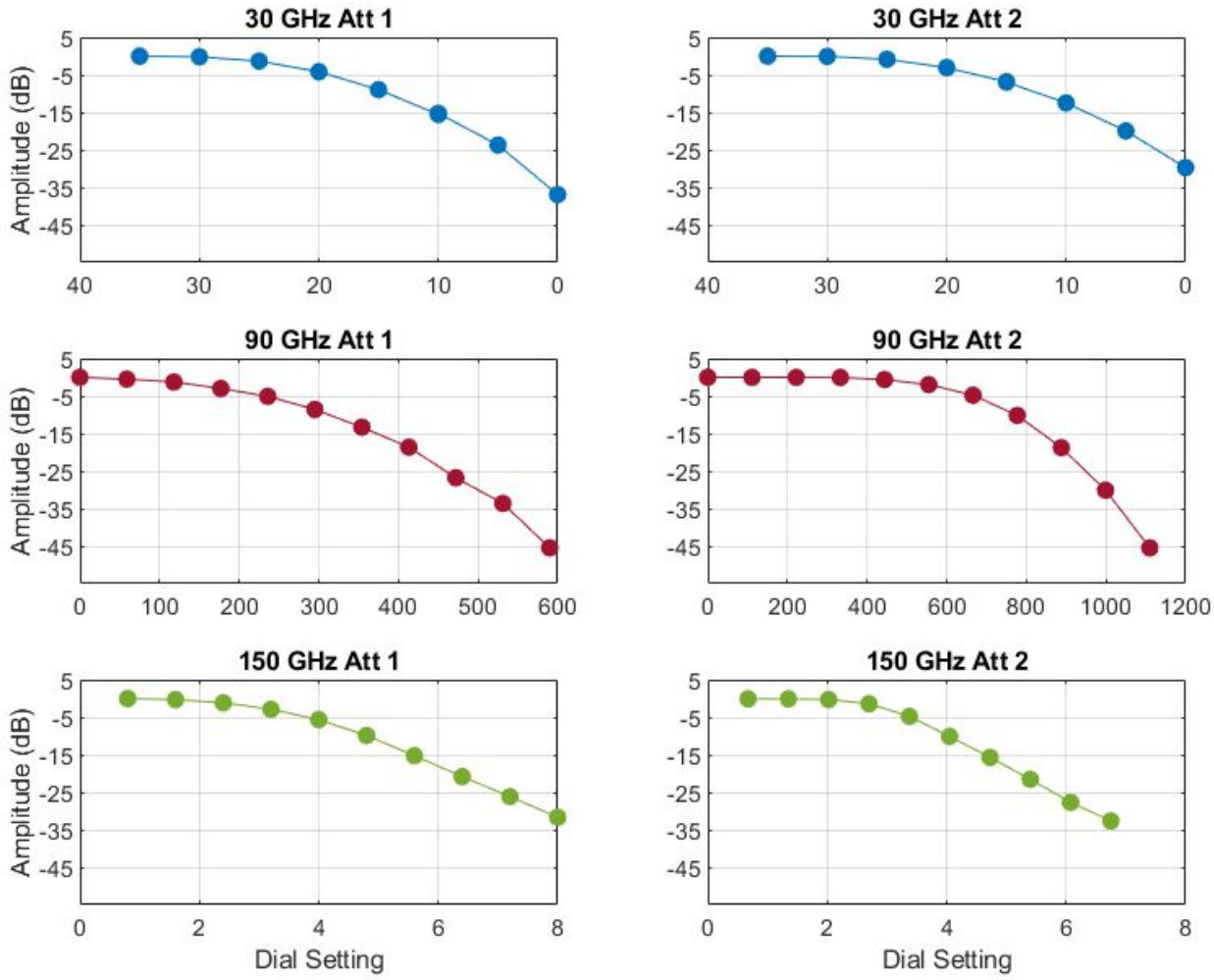
Figure 6: Calibrated spectrum for the broadband noise source with and without the 140-160 GHz filter.

Output Stability





Attenuation Range

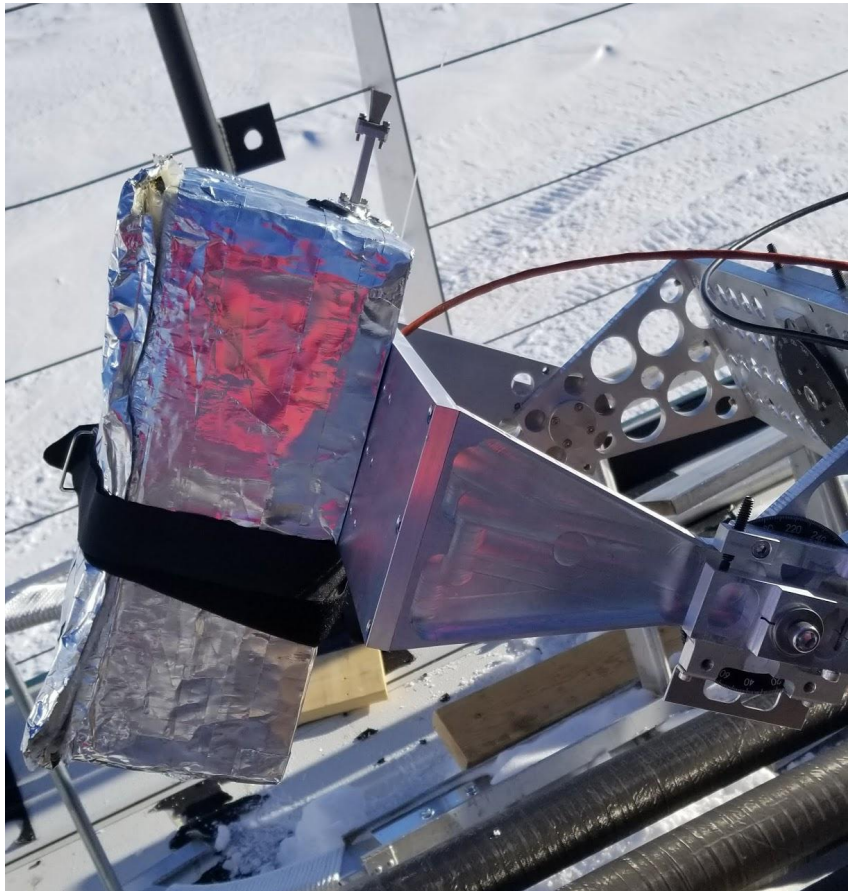


Source Comparison

Source (GHz)	Output (dBm)	Bandpass (GHz)	Output (dBK_{RJ})	Flatness (dB)	Atten. Range (dB)
30/40	13	16	110	~6	65
90	2.3	13*	100*	1*	95
150	-0.7	20	95	~10	70
220	-40	36*	60*	4*	60*

*Based on design specifications

Far Sidelobe Mapping



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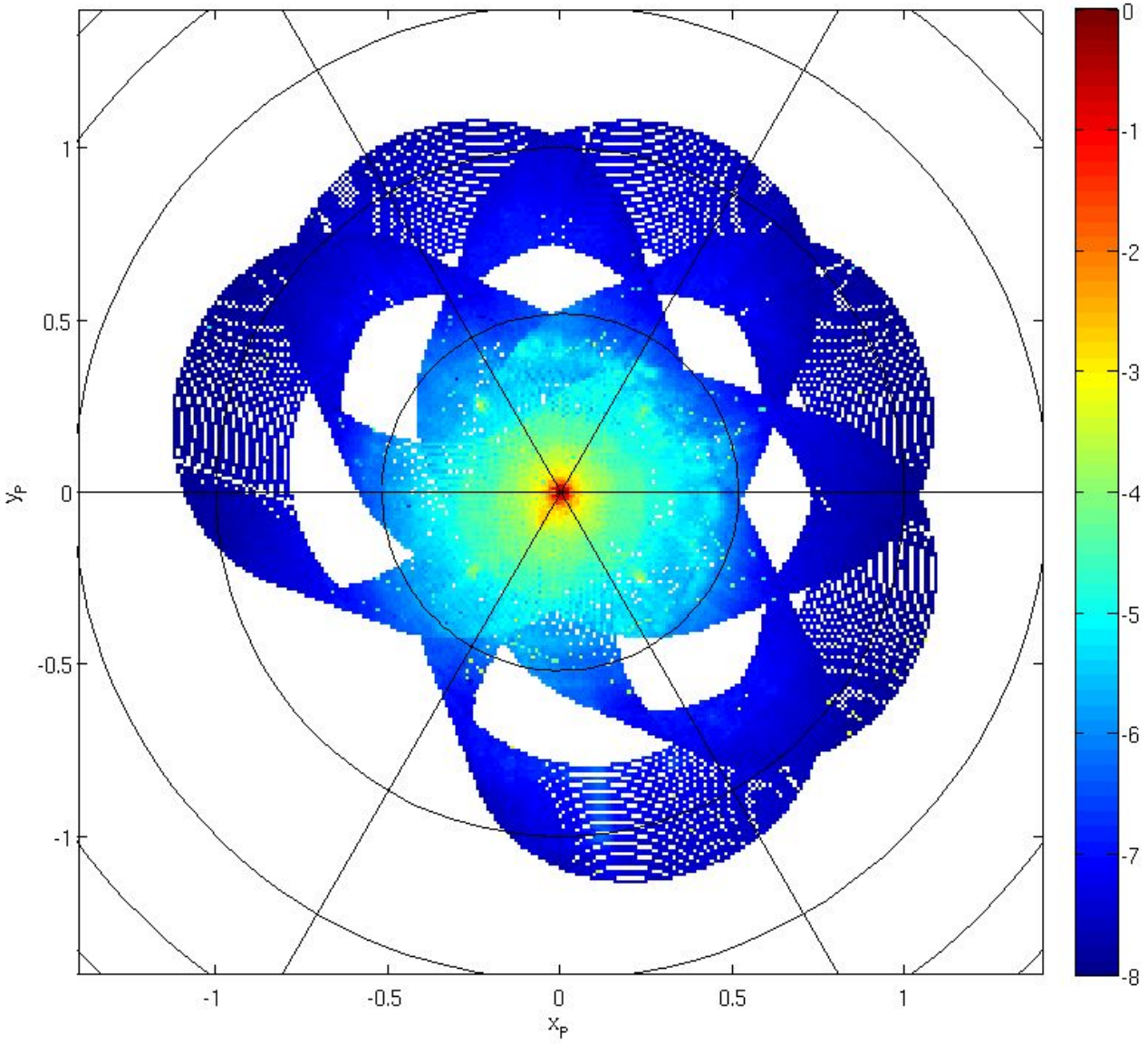

Credit: Eric Yang, Stanford University

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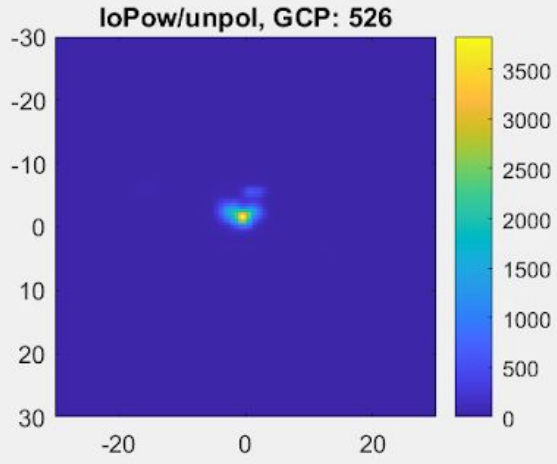
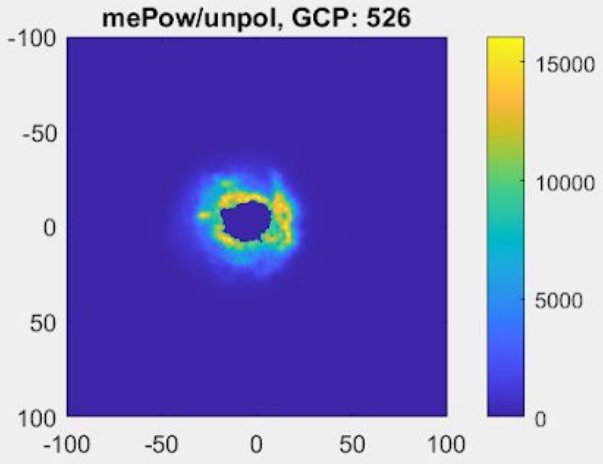
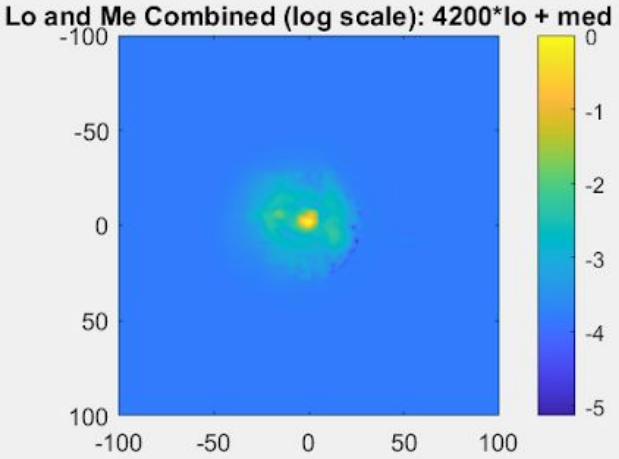
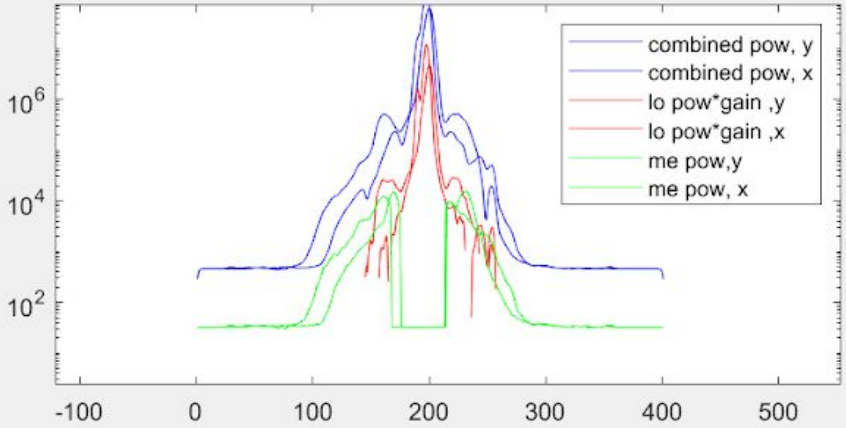




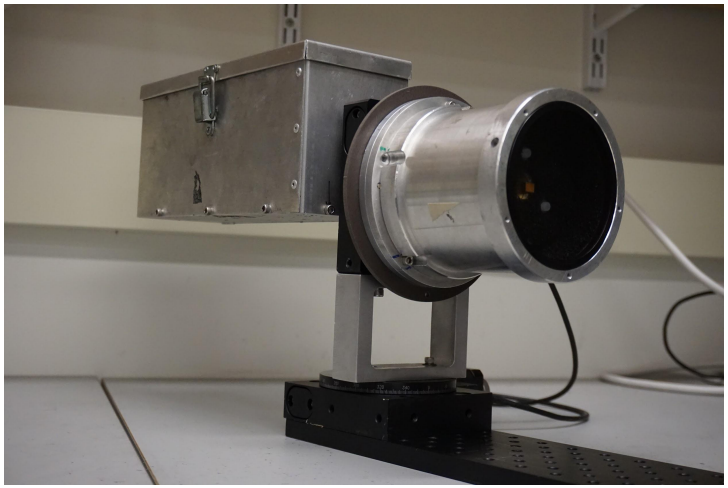




Credit: E. Schoen & R. Basu Thakur, CIT

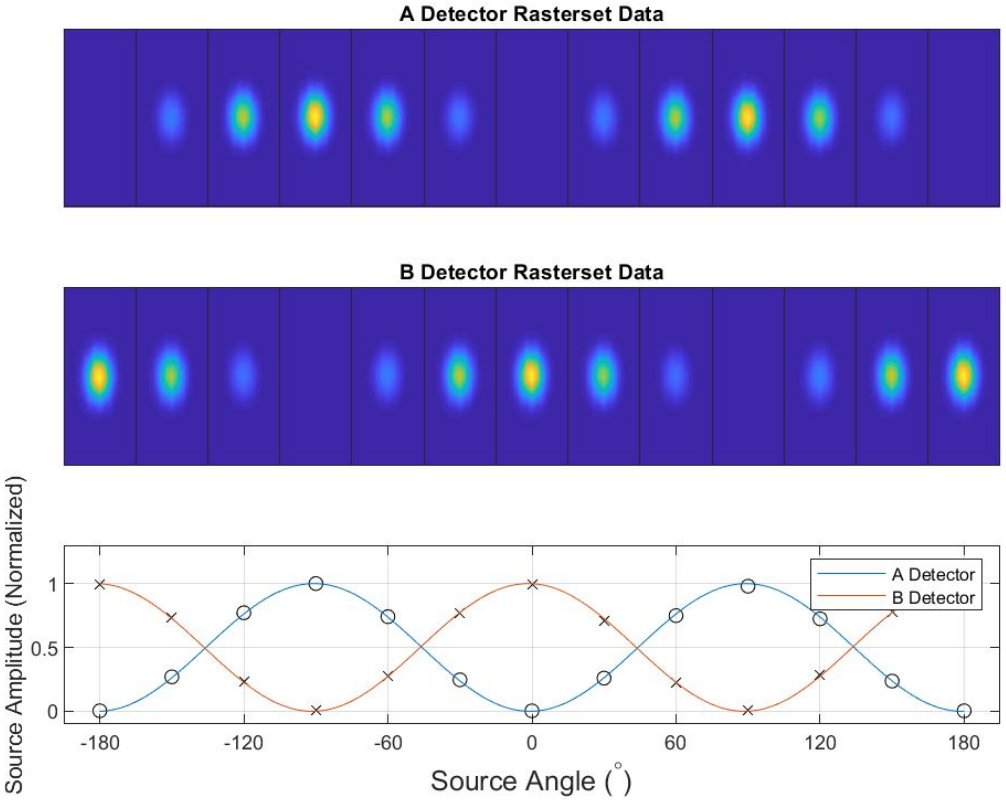
Polarization Calibration

- Polarizing Grid
  - xpol response <0.03% @ 150 GHz
- Precision Rotation Stage
  - Angle repeatability < 0.01°



- Measured pol angles σ<0.1°

- Measures xpol resp. σ<0.003



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