Preflight Detector Characterization of BLAST-TNG

Sam Gordon (Adrian Sinclair)
LTD-18
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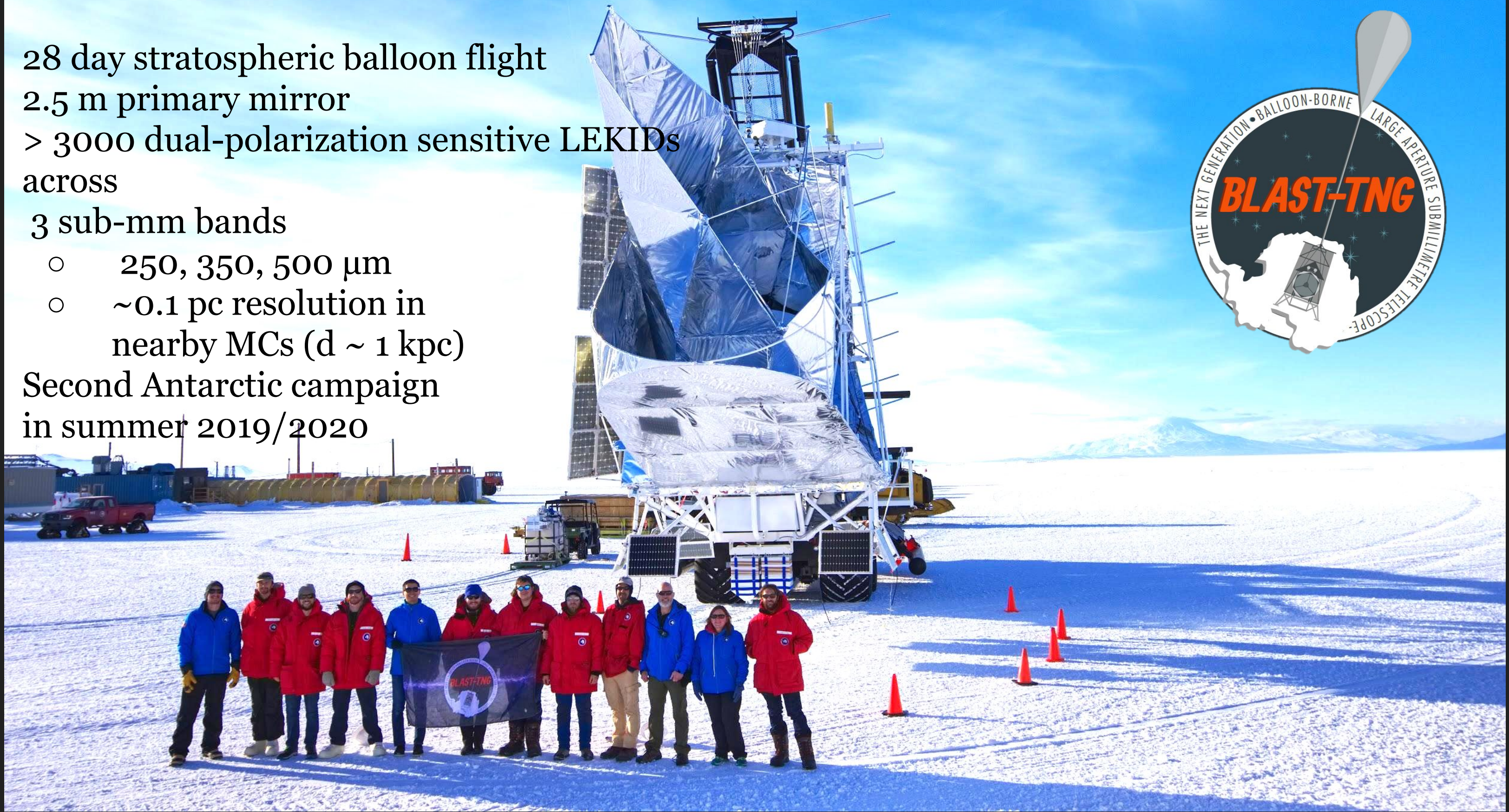
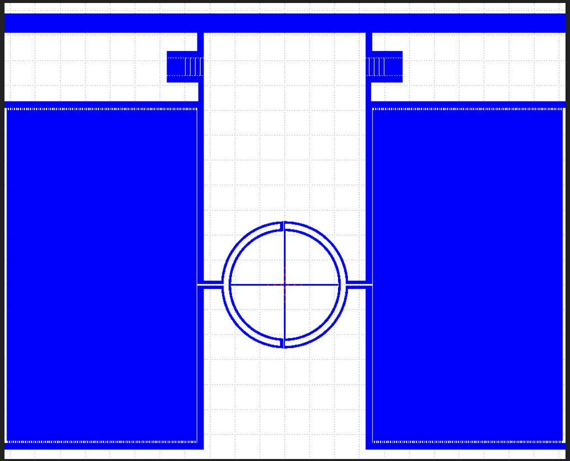
NIST
CARDIFF UNIVERSITY
ASU School of Earth and Space Exploration Arizona State University
Penn
Northwestern University

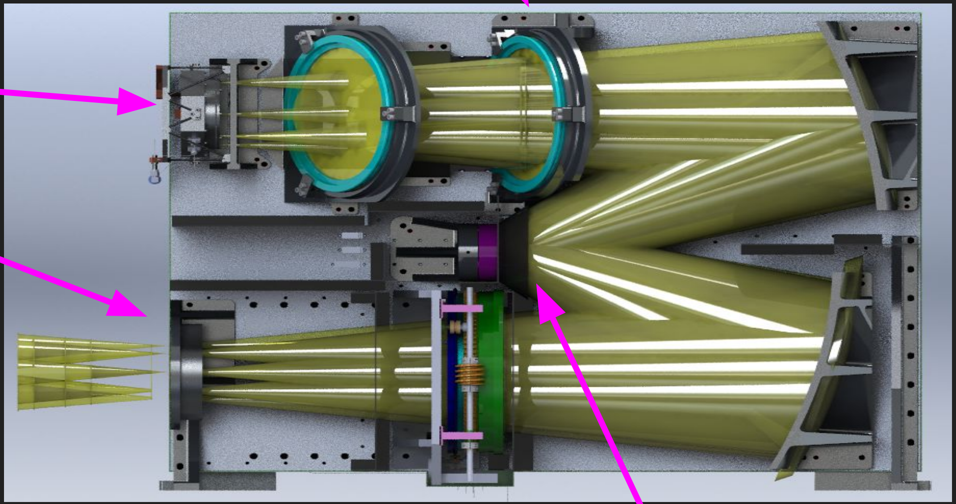
The Next-Generation
Balloon-Borne Large-Aperture Submillimeter Telescope

- 28 day stratospheric balloon flight
- 2.5 m primary mirror
- > 3000 dual-polarization sensitive LEKIDs across
  3 sub-mm bands
  - 250, 350, 500 µm
  - ~0.1 pc resolution in nearby MCs (d ~ 1 kpc)
- Second Antarctic campaign in summer 2019/2020

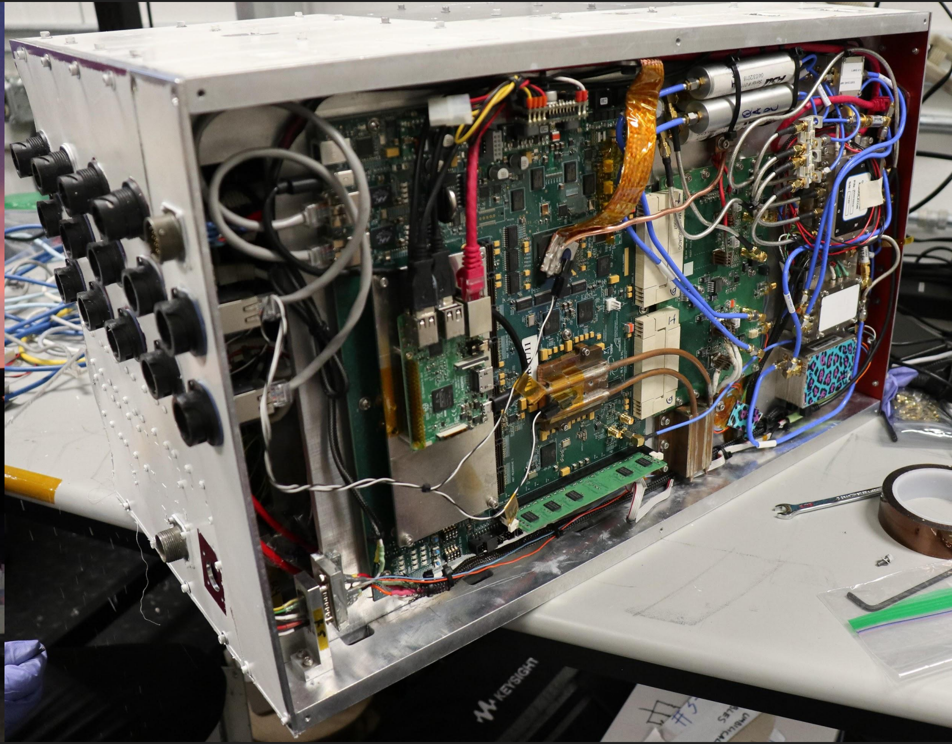


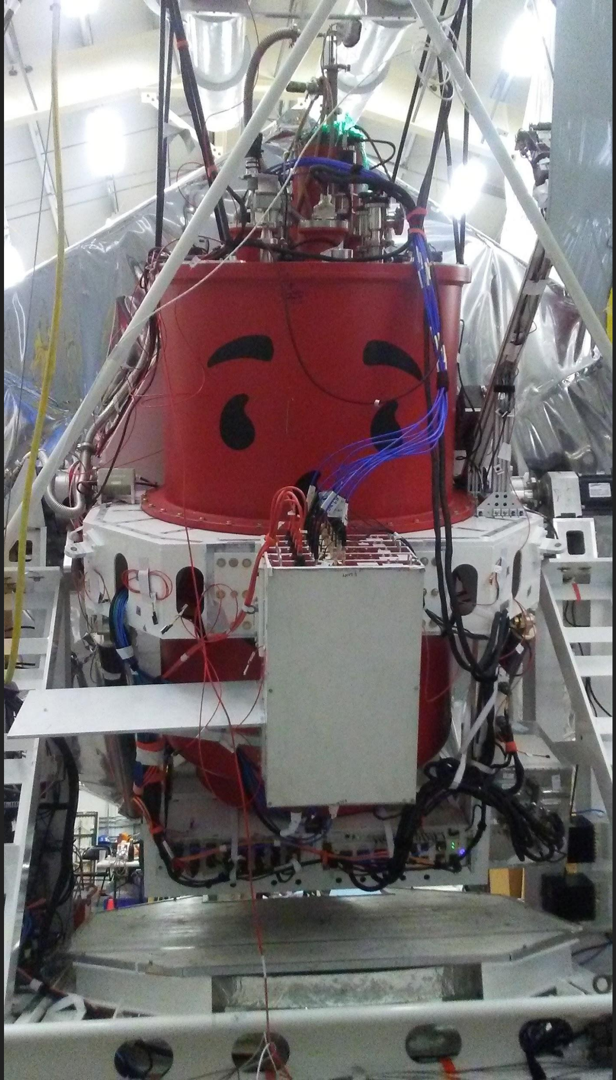
Focal Plane Arrays and Cold Optics

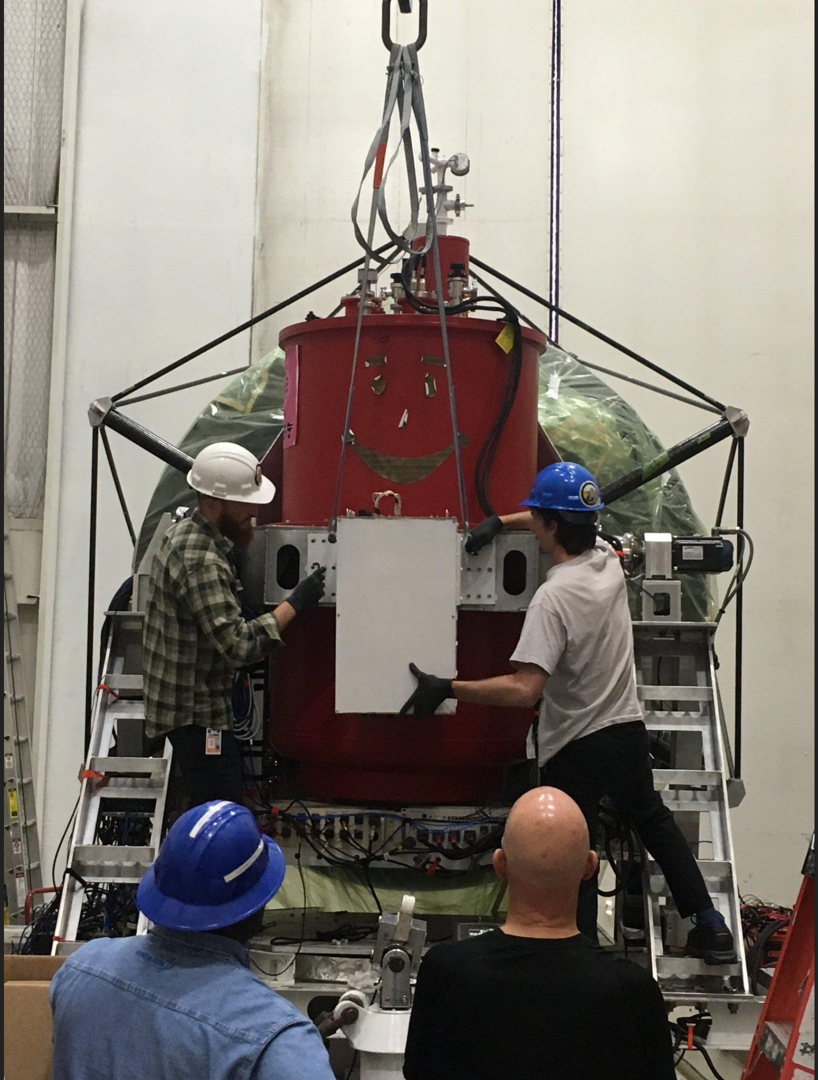




BLAST-TNG ‘ROACH2 MOTEL’ 5 slices = 5000 channels





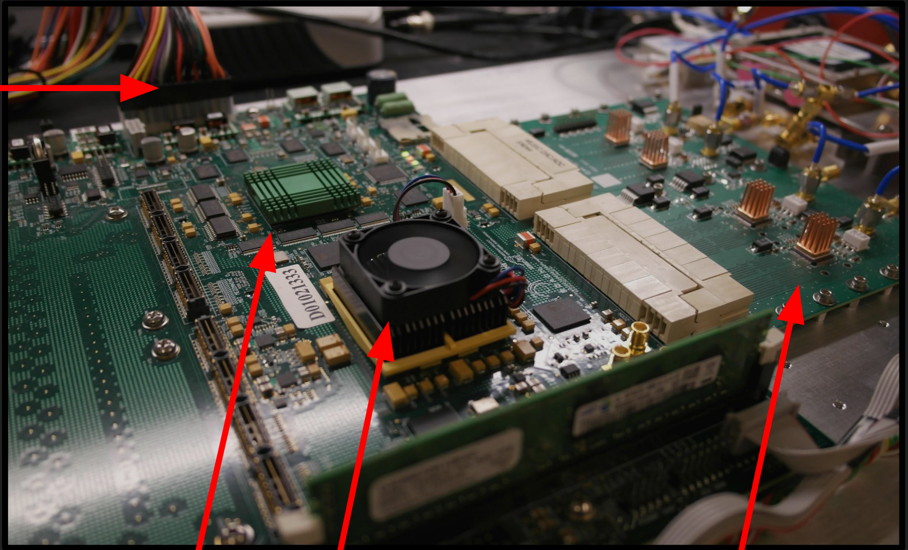


Key Readout System Requirements

Parameter	Requirement
RF bandwidth (MHz)	512
S_ϕ / chan (dBc/Hz)	$\lesssim$ -95
1/f f_c (Hz)	$\lesssim$ 0.5
Data rate (Hz)	200–500
Power dissipation (W)	$\lesssim$ 60
Time stamp precision (ms)	$\lesssim$ 1
DAC Tone Resolution (Hz)	$\leq$ 1000
Multiplexing Factor	$\gtrsim$ 500

Passively cool FPGA, PPC to < 80° C
Power/pixel ~ 60 mW

CASPER ROACH2



In-Flight Readout: Software Challenges

- *Channel - frequency mapping* (‘KID finding’)
    - Keep it consistent over different optical loadings, base temps
- *Resonant frequency tracking* (tone tracking)
    - How often will re-tunes be necessary?
    - Automatically check for retune condition during flight? (auto tune)
    - Schedule retunes on regular intervals (no automatic check)
    - What retune condition do we use (cal lamp? LO chop? Noise?)
- *Tone power calibration* - global (RF attenuators) and local (digital I/Q)
    - Required to ensure majority of channels stay photon-noise limited
    - Is auto-cal required?
    - Is there a safe window where tone powers can be left for entire flight?
- *Software/hardware interface limitations*
    - How many buttons do we need? Do they work reliably?
    - Can one of us just fly with the payload?

	ROACH1 (SNOOKS)	ROACH2 (PIECES)	ROACH3 (MERLIN)	ROACH5 (RUBBLE)
IS_STREAMING	1	1	1	1
STATE	Streaming	Streaming	Streaming	Streaming
HAS_FIRMWARE	1	1	1	1
DATA_STREAM_ERROR	0	0	0	0
ALLOW_AUTO_TRNAROUND	1	1	1	1
ALLOW_CHOP_LO	1	1	1	1
CURRENT_N_TONES	260	524	622	486
N_CHANNELS	260	524	622	486
PREV_N_CHANNELS	252	393	625	385
HAS_VNA_TONES	0	0	0	0
HAS_TARG_TONES	1	1	1	1
POWER_PER_TONE [dBm]	-47.00	-47.00	-47.00	-47.00
SET_ATTEN_OUT [dB]	6	3	2	3
READ_ATTEN_OUT [dB]	6	3	2	3
SET_ATTEN_IN [dB]	17	20	21	20
READ_ATTEN_IN [dB]	17	20	21	20
ADC_RMS_I [mV]	142.58	106.80	97.86	100.05
ADC_RMS_Q [mV]	142.70	107.59	102.82	107.10
LO_CENTER_FREQ_MHZ	540.000	827.000	850.000	828.000
LO_FREQ_READ_MHZ	540.000	827.000	850.000	828.000
DOING_FULL_LOOP	0	0	0	0
DOING_FIND_KIDS_LOOP	0	0	0	0
DOING_TURNAROUND_LOOP	0	0	0	0
IS_WRITING	0	0	0	0
IS_SWEEPING	0	0	0	0
IS_FINDING_KIDS	0	0	0	0
TONE_FINDING_ERROR	0	0	0	0
FPGA_CLOCK_FREQ_MHZ	257.75	257.47	257.28	257.45
HAS_QDR_CAL	1	1	1	1
QDR_CAL_FAIL	0	0	0	0
HAS_VNA_SWEEP	1	1	1	1
HAS_TARG_SWEEP	1	1	1	1
HAS_REF_PARAMS	1	1	1	1
SWEEP_FAIL	0	0	0	0
FIRMWARE_UPLOAD_FAIL	0	0	0	0
KATCP_CONNECT_ERROR	0	0	0	0
PI_ERROR_COUNT	0	0	0	0
PI_REBOOT	0	0	0	0
LAST_DF_RESPONSE [Hz]	0.00	0.00	0.00	0.00
DF_RETUNE_THRESH	100000	100000	100000	100000
N_OUT_OF_RANGE_THRESH	300	300	300	300
N_OUTOFRANGE	0	0	0	0
IS_CHOPPING_LO	0	0	0	0
HAS_LAMP_CONTROL	0	0	0	1
WAITING_FOR_LAMP	0	0	0	0
FULL_LOOP_FAIL	0	0	0	0
TURN_AROUND_LOOP_FAIL	0	0	0	0
EXT_REF	1	1	1	1
IS_COMPRESSING	0	0	0	0
PI_TEMP	34.8	34.8	36.4	34.3

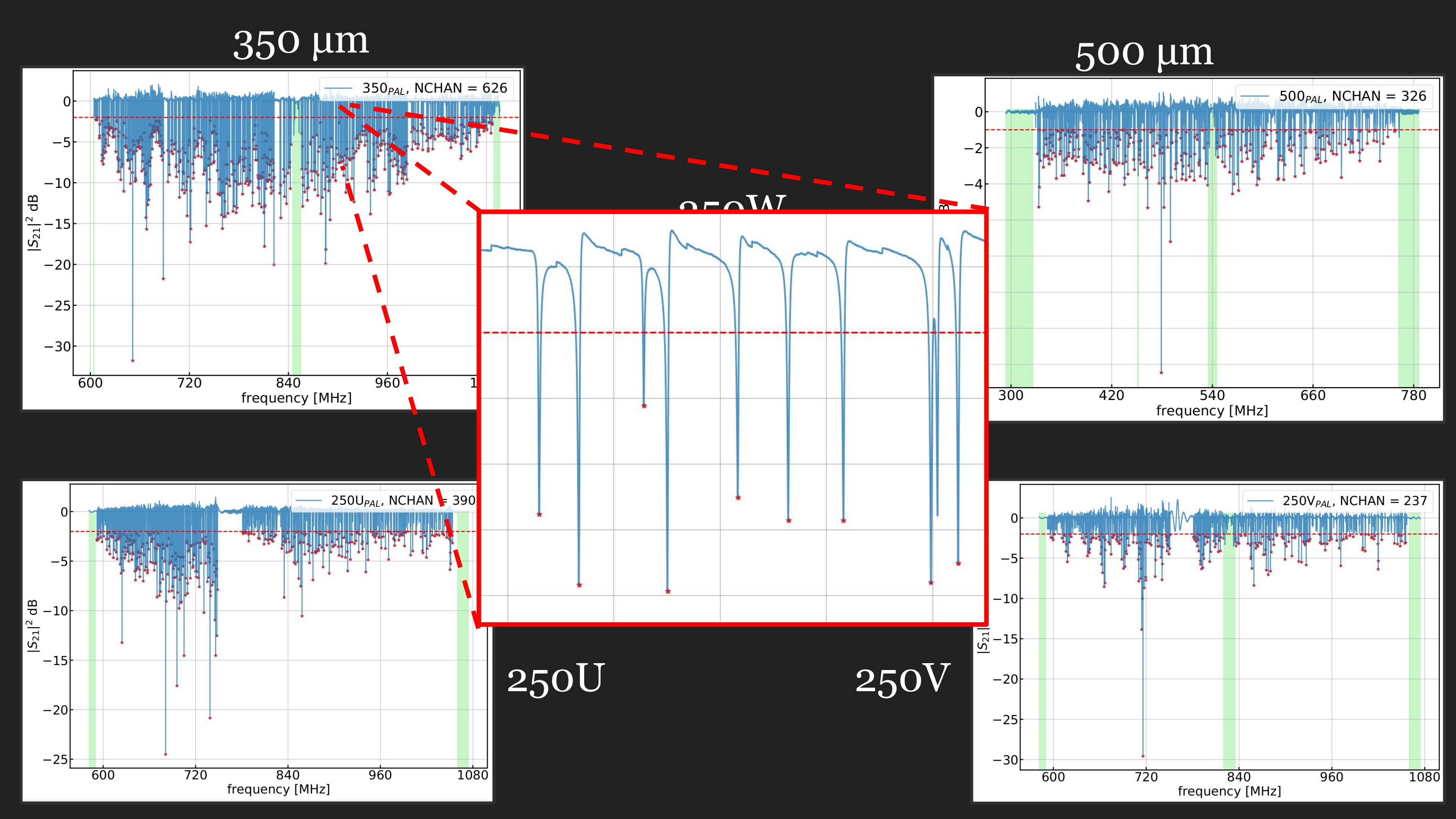
TEMPERATURES	
R1 FPGA	20.33
R2 FPGA	24.90
R3 FPGA	19.98
R4 FPGA	16.79
R5 FPGA	22.04
R1 PPC	19.49
R2 PPC	25.49
R3 PPC	24.34
R4 PPC	25.17
R5 PPC	21.47

FLIGHT COMPUTERS	
FC1_CMD_COUNT	257
FC2_CMD_COUNT	257
FC_IN_CHARGE	1

CRYO STATUS	
TR_HE3_FRIDGE	0.314276
350 ARRAY TEMP	0.323442
250 LNA	ON
350 LNA	ON
500 LNA	ON
CAL LAMP	-0.0474713
FRIDGE_CYCLE_STATE	0
POT VALVE	CLOSED
ROACH_LAMP_NOW	0
ROACH_ENABLE_CAL_PULSE	1

POINTING	
ELEVATION	44.8938
AZIMUTH	184.627
SHUTTER	CLOSED
RA	18.8178
DEC	-56.9892

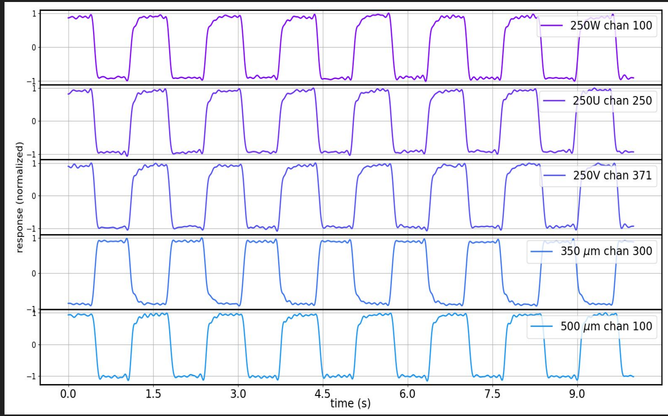
TIMING	
R1_PPS_COUNT	4842
R2_PPS_COUNT	4842
R3_PPS_COUNT	4842
R5_PPS_COUNT	4842
R1_PACKET_COUNT	2.35817e+06
R2_PACKET_COUNT	2.35831e+06
R3_PACKET_COUNT	2.35844e+06
R5_PACKET_COUNT	2.35813e+06
R1_UTC_TIME	668577531
R2_UTC_TIME	668577528
R3_UTC_TIME	668577518
R4_UTC_TIME	668577539

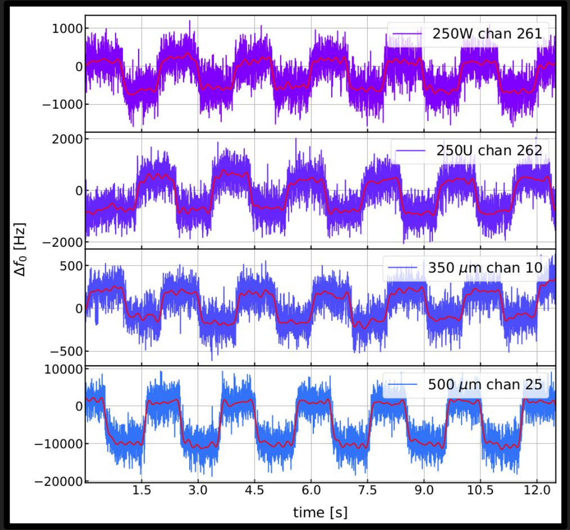

350 µm
500 µm
250U
250V
350PAL, NCHAN = 626
500PAL, NCHAN = 326
250UPAL, NCHAN = 390
250VPAL, NCHAN = 237
|S21|2 dB
frequency [MHz]

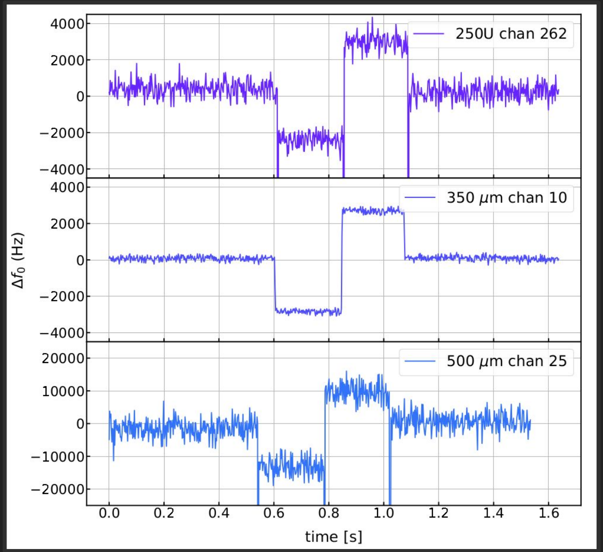
Timestreams - real-time conversion from *I*/*Q* to df with IQ gradient method

Cal lamp chops (every full loop)

LO chops (azimuth turnarounds)







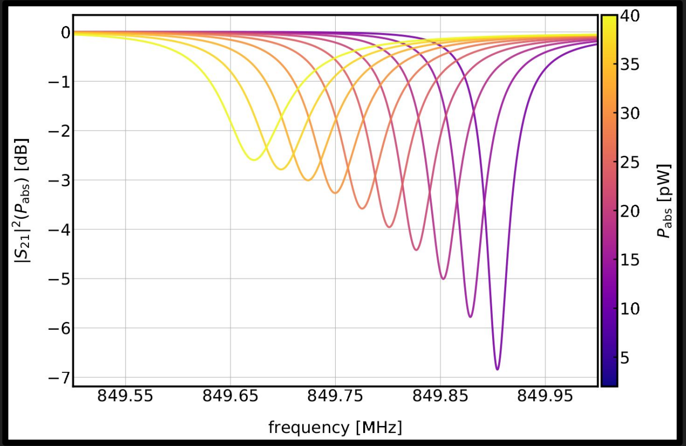
Filtered timestreams with NDF
30 Hz

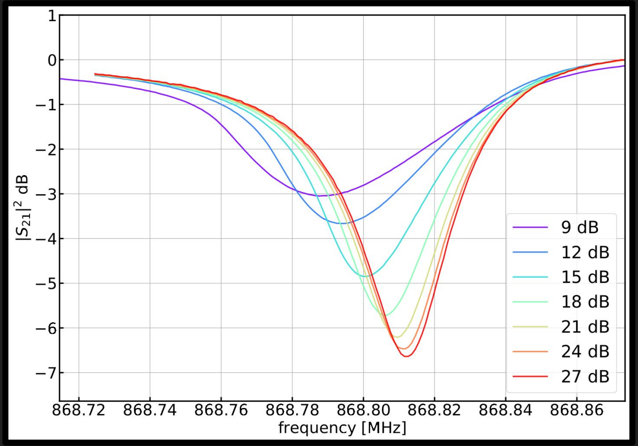
No NDF (single channels, ice)
244 Hz

Optical and Temperature Responsivities

Verified using LEKID software model which estimates:

- Quality factors (Q_r , Q_c , Q_i)
- Frequency response to dT and dP_{abs}: df/dT, df/dP
- Quasiparticle number densities
- Sensitivity/Noise-equivalent power
- Photon-noise
- Detector-noise
- Amplifier-noise



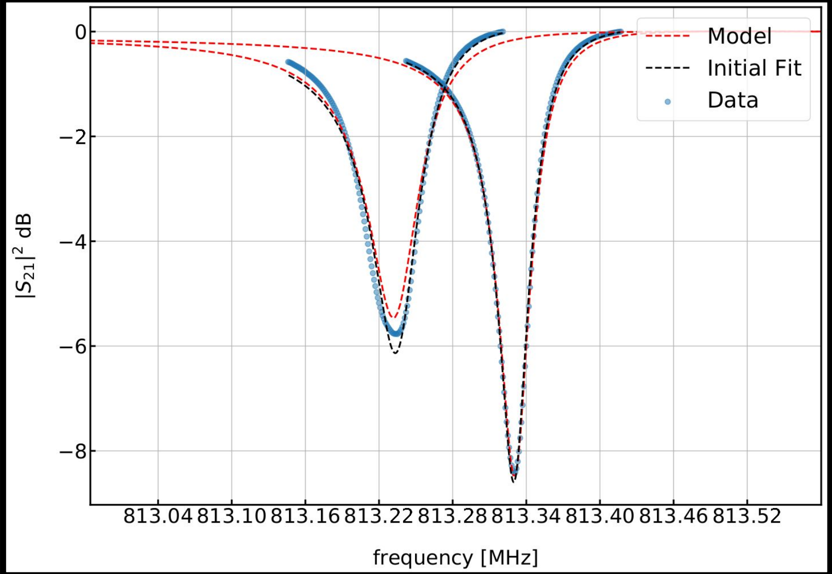


Instrumental optical efficiency estimated to be ~ 30%

Pre-flight characterization in Palestine - readout power not optimized → sensitivities are upper limits

	250 µm	350 µm	500 µm
$\mathrm{NEP}_{freq,prop}{}^{1}\mathrm{W}/\sqrt{\mathrm{Hz}}$	6.5×10^{-17}	5.5×10^{-17}	4.7×10^{-17}
$\mathrm{NEP}_{phot,prop}{}^{2}\mathrm{W}/\sqrt{\mathrm{Hz}}$	17×10^{-17}	12×10^{-17}	8.7×10^{-17}
$\mathrm{NEP}_{freq,Pal}\ \mathrm{W}/\sqrt{\mathrm{Hz}}$	35×10^{-17}	35×10^{-17}	10.0×10^{-17}
$\mathrm{NEFD}_{Pal}\ \frac{MJy\sqrt{s}}{sr}$	0.13	0.12	0.034
σ_{map} mJy/beam per detector	68.75	96.25	39.28
σ_{map} mJy/beam	2.17	3.77	2.27
I_{min} MJy/sr	78.16	49.46	10.19

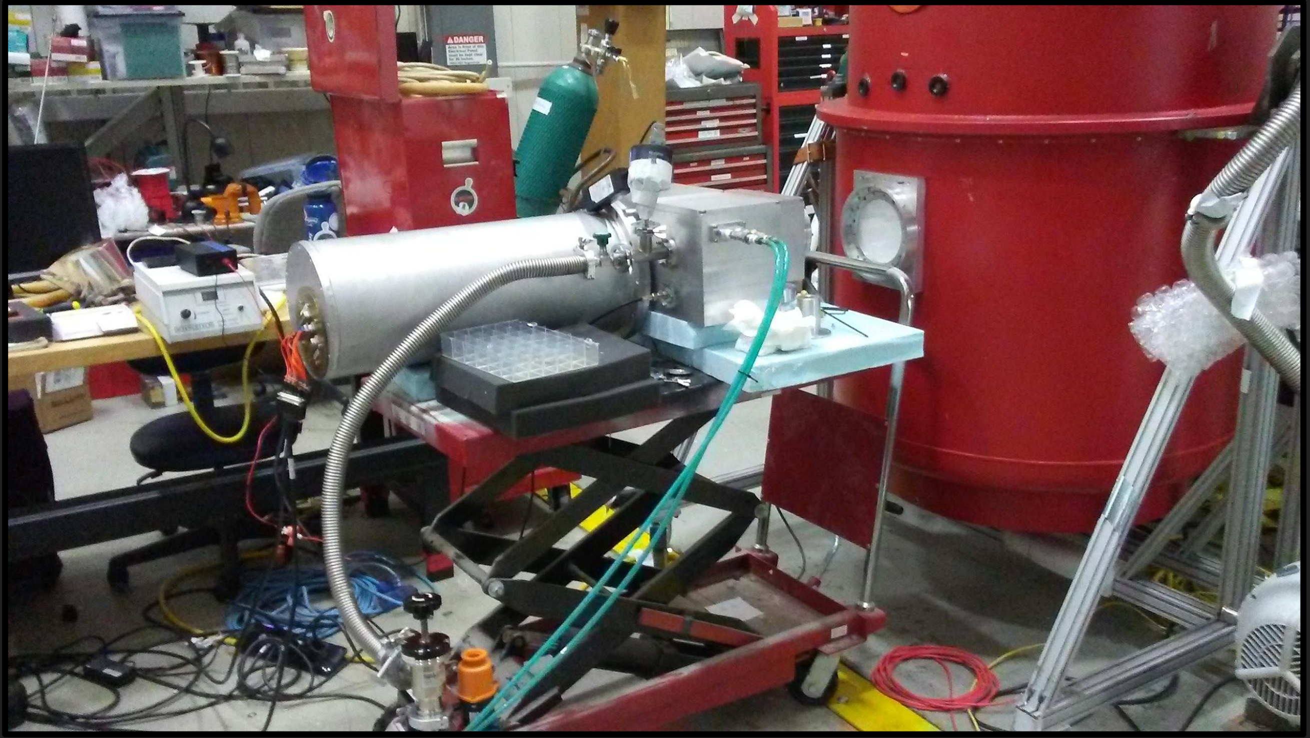
[1] Values from the original BLAST-TNG proposal.



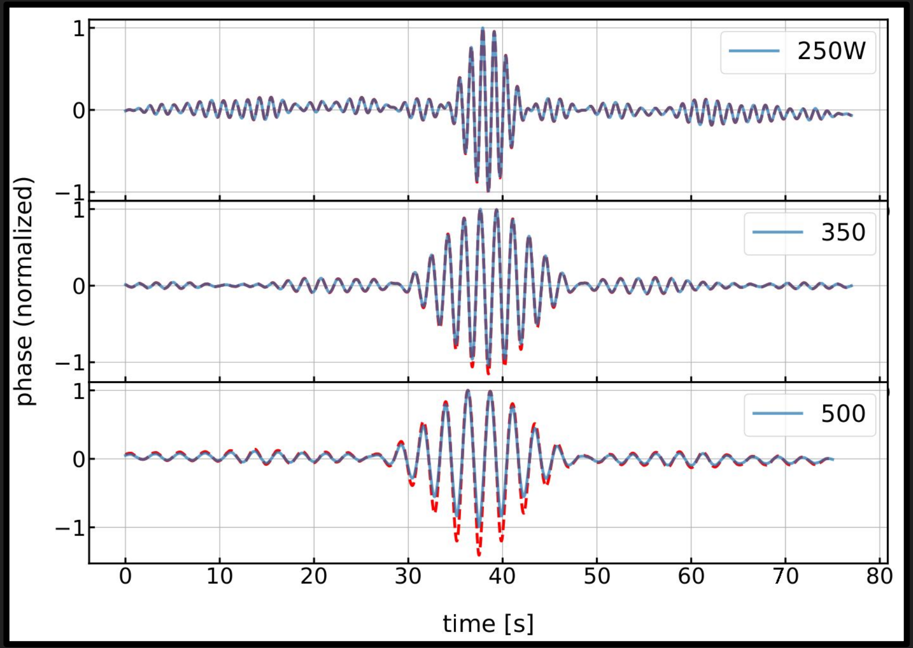
Band	$R_P\ (df/f_0)/\mathrm{pW}$	$R_T\ (df/f_0)/\mathrm{mK}$
250 µm	1.7×10^{-5}	9.15×10^{-7}
350 µm	5.2×10^{-6}	1.51×10^{-6}
500 µm	1.6×10^{-4}	3.91×10^{-6}

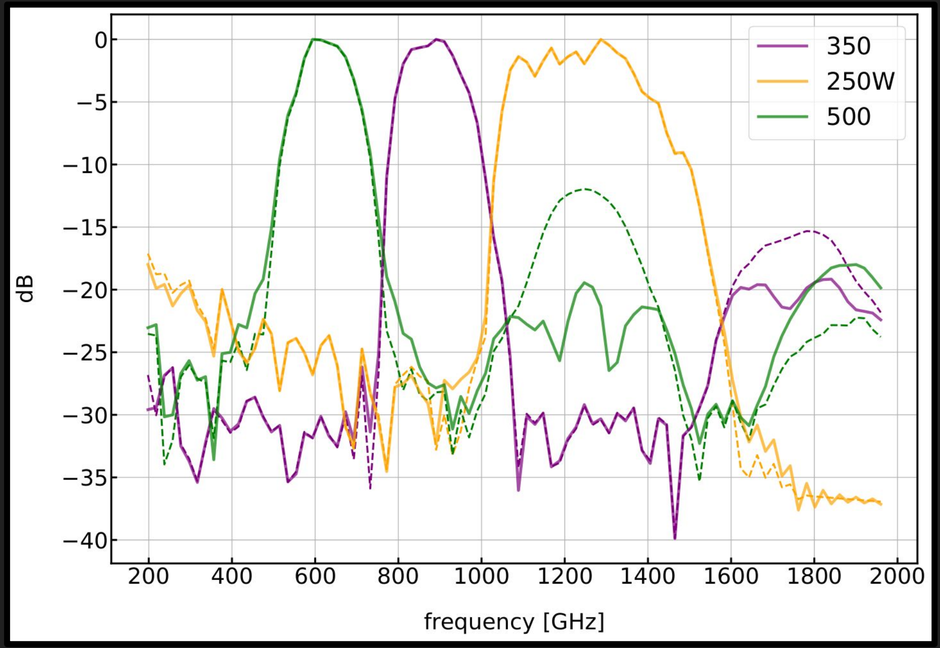
Avg values provided by NIST

Optical Passband Measurement

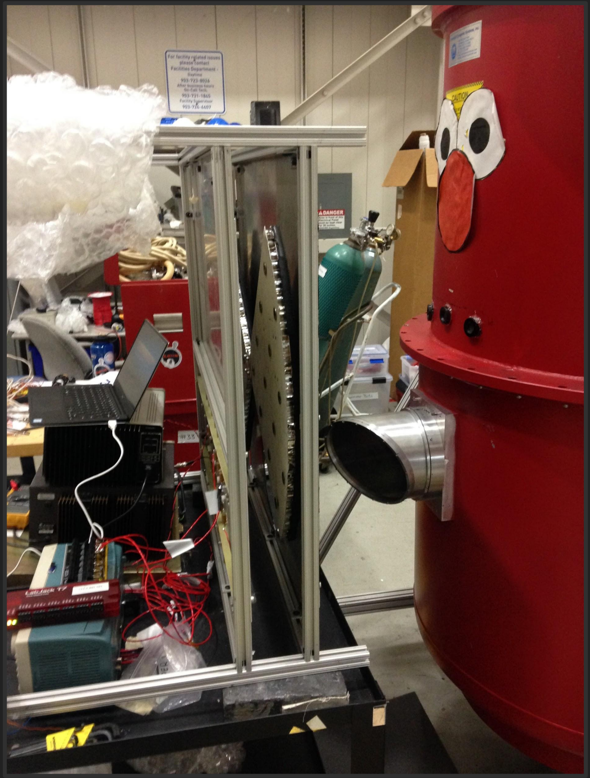


Optical Passband Measurement

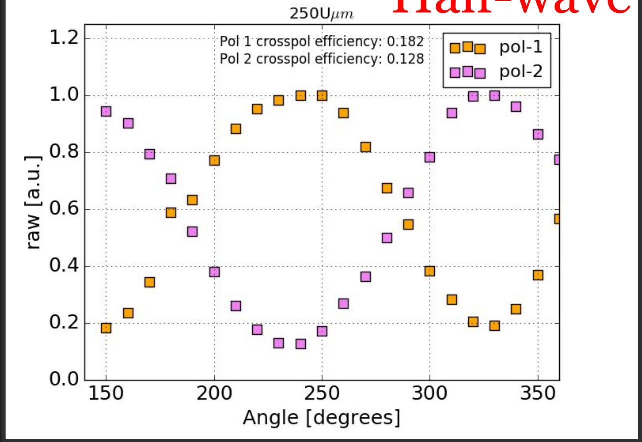


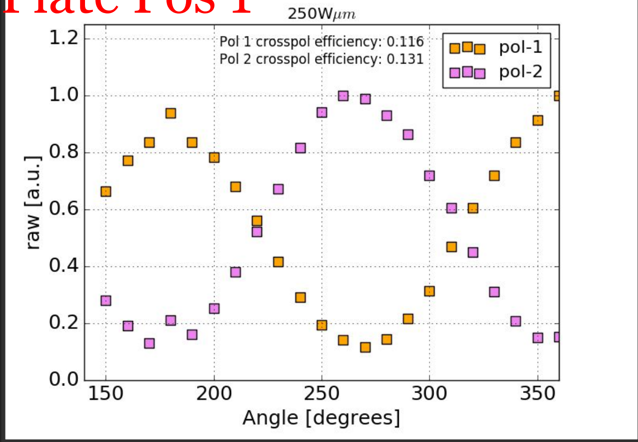


Polarization Efficiency Measurements

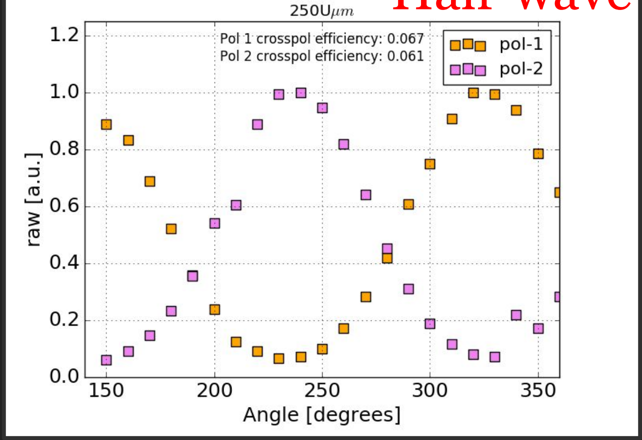


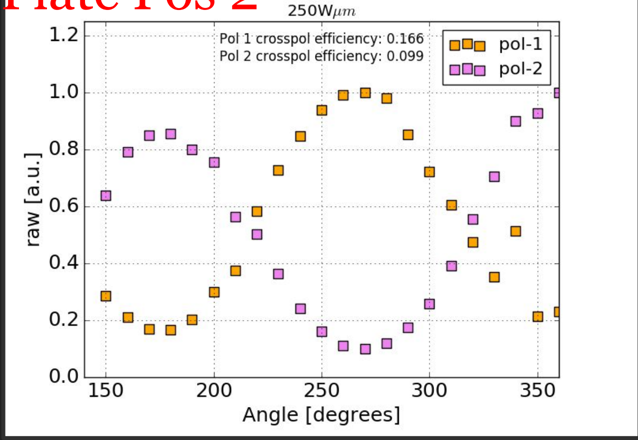
Half-wave Plate Pos 1



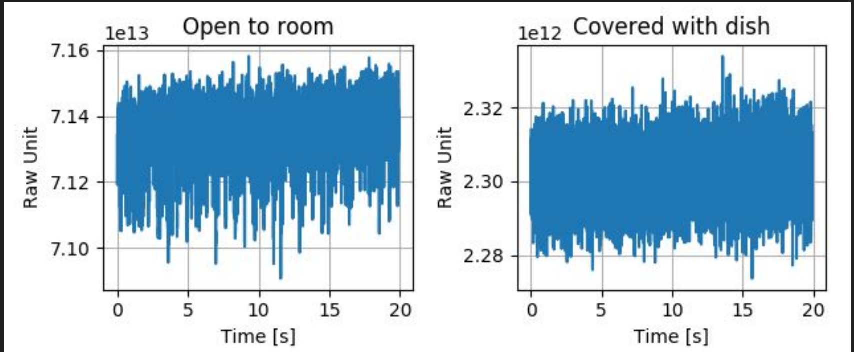


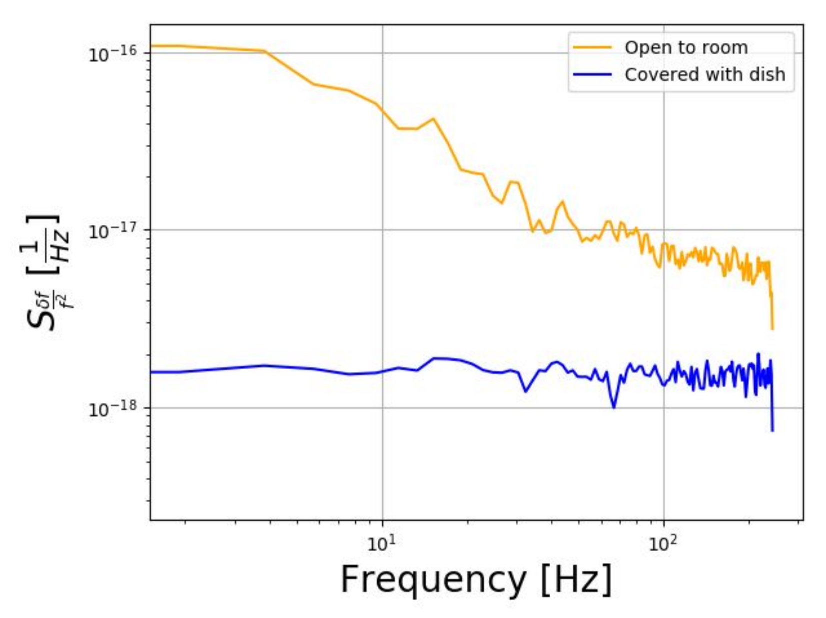
Half-wave Plate Pos 2

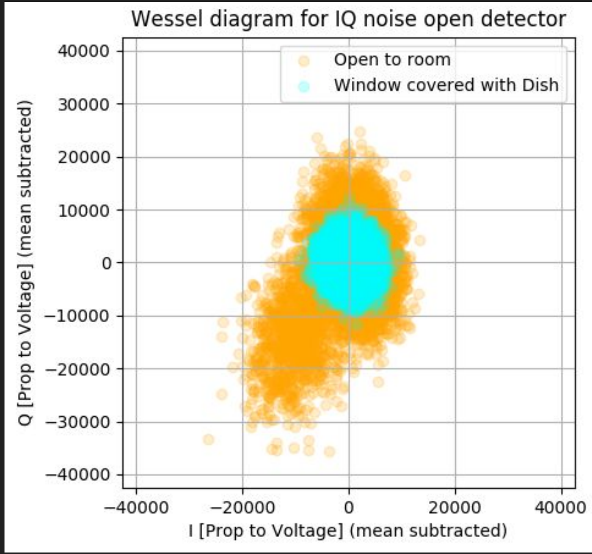




Optical tests in Antarctica - without NDF





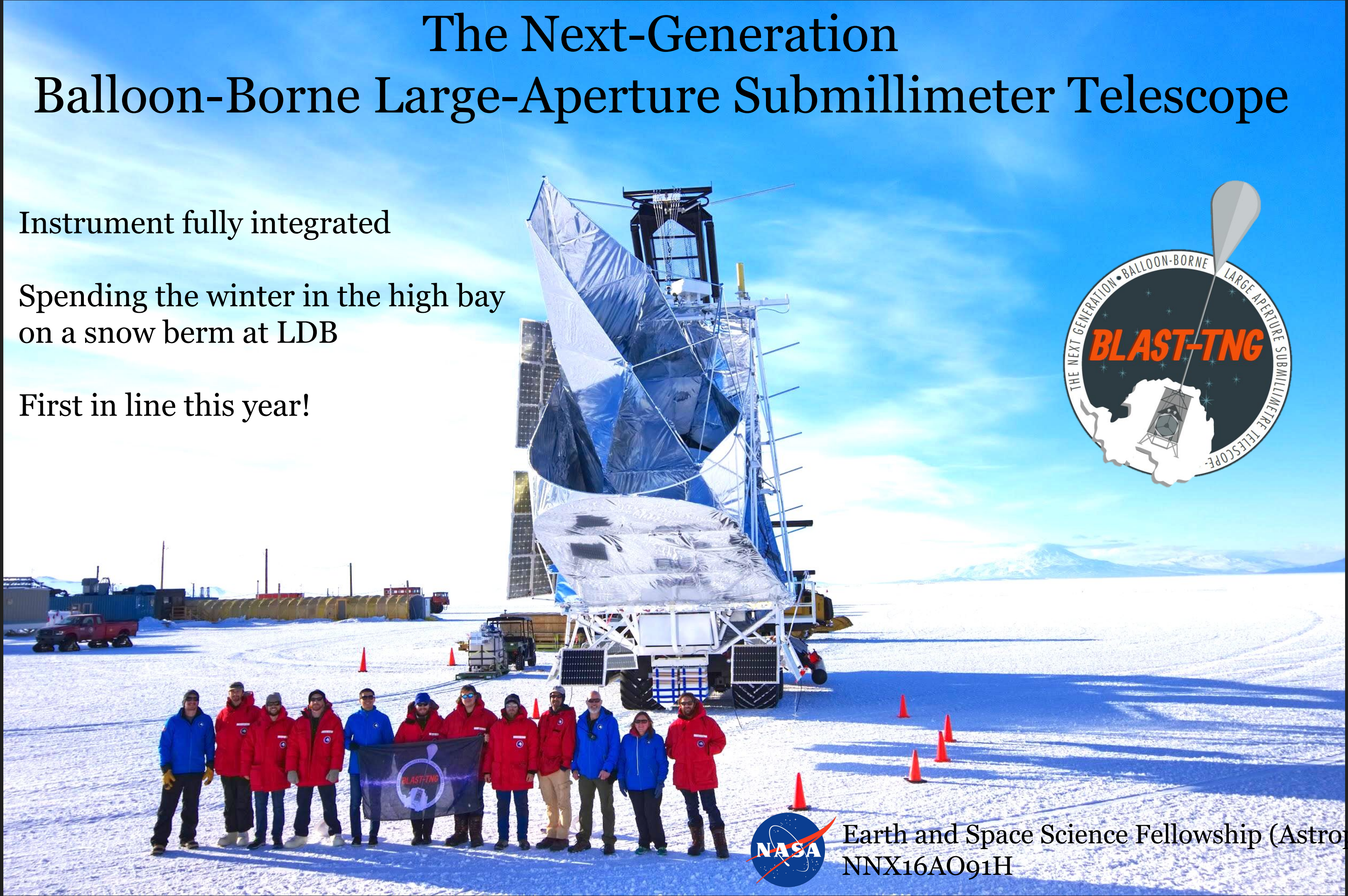


Tone powers are optimized over Palestine tests

Discovered WiFi pick up in cryostat

Planning a couple of days of ground tests pre-flight

The Next-Generation Balloon-Borne Large-Aperture Submillimeter Telescope



Instrument fully integrated

Spending the winter in the high bay on a snow berm at LDB

First in line this year!

NASA Earth and Space Science Fellowship (Astrophysics)
NNX16AO91H

Next steps for BLAST-TNG type readout systems:

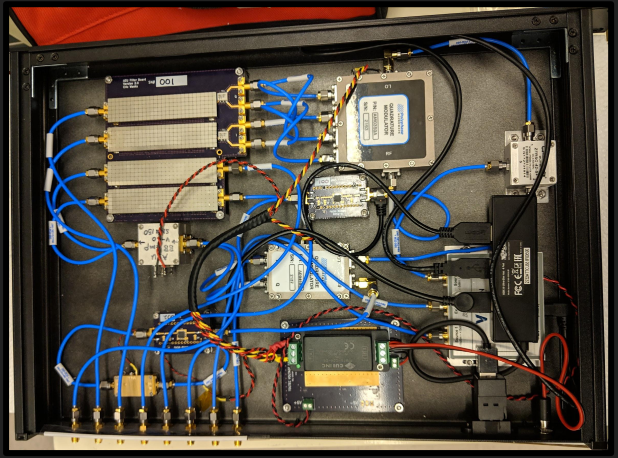


Image: Phil Mauskopf

IF single board integration = SWAP-c reduction

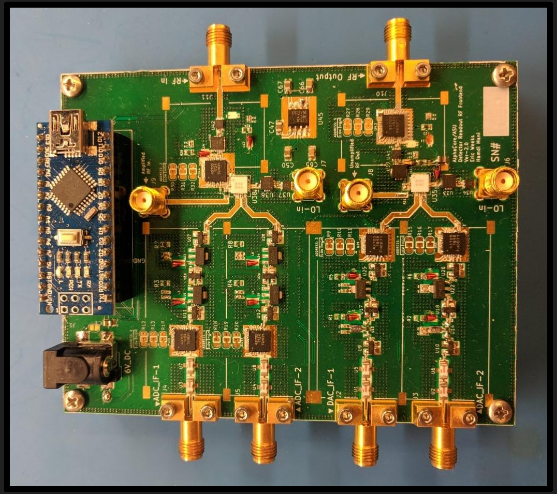
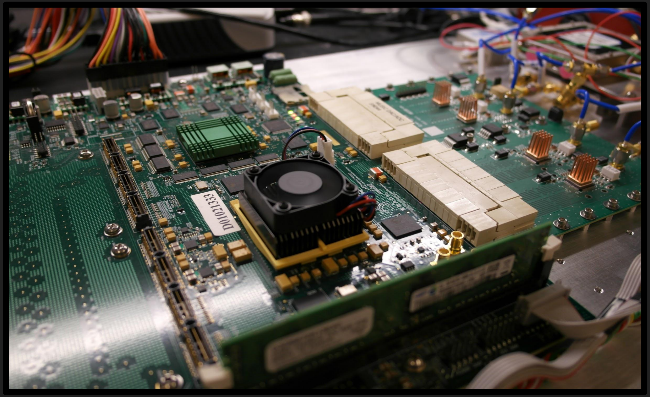
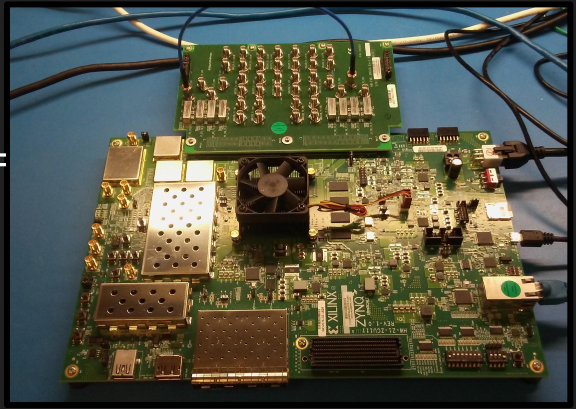


Image: Eric Weeks



Xilinx RF System on a Chip (RFSoC) = 8X Bandwidth, ⅓ power dissipation



Thanks!

Earth and Space Science Fellowship (Astrophysics) NNX16AO91H