

EBEX, a Balloon-Borne CMB Polarization Experiment

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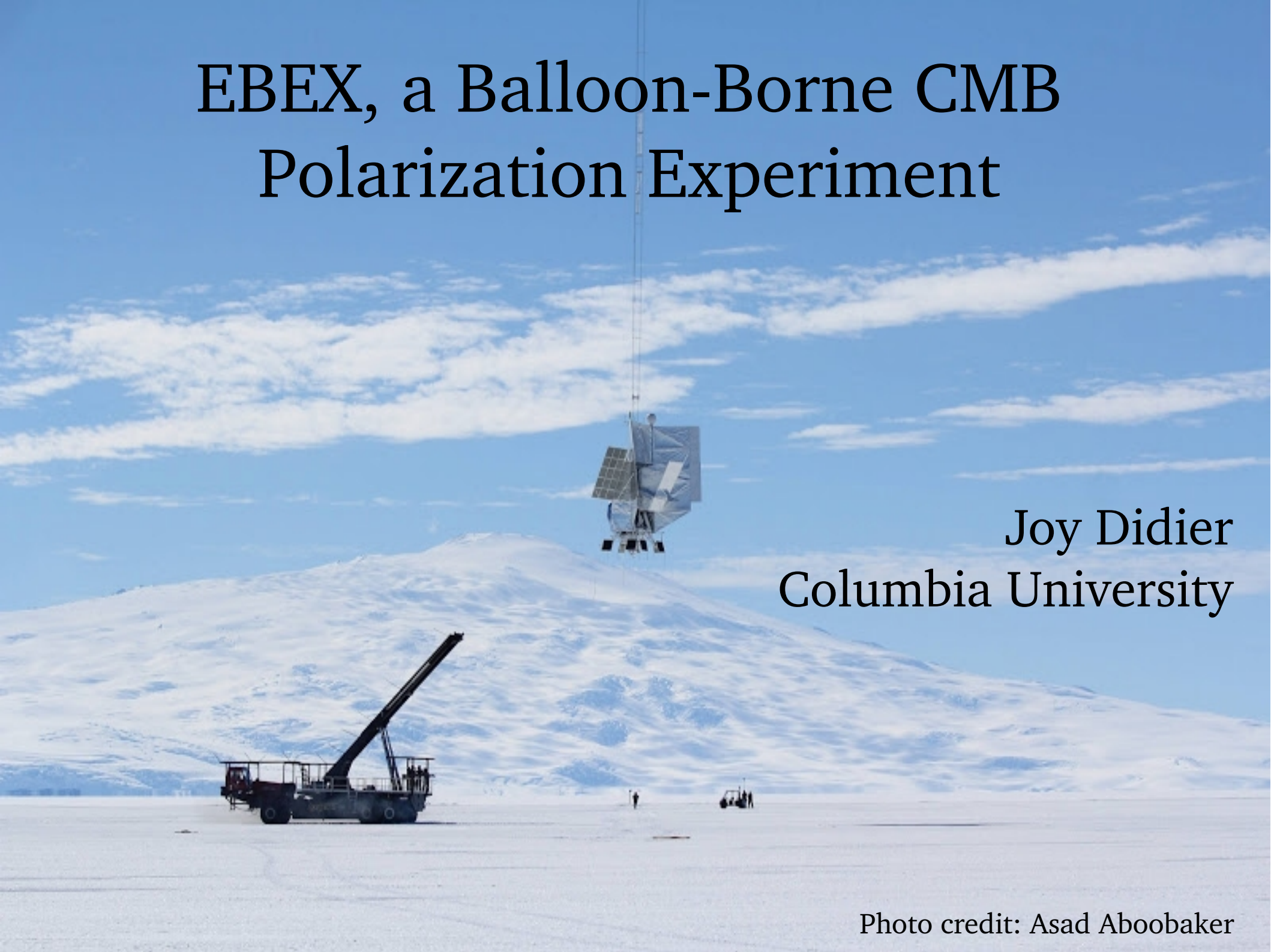
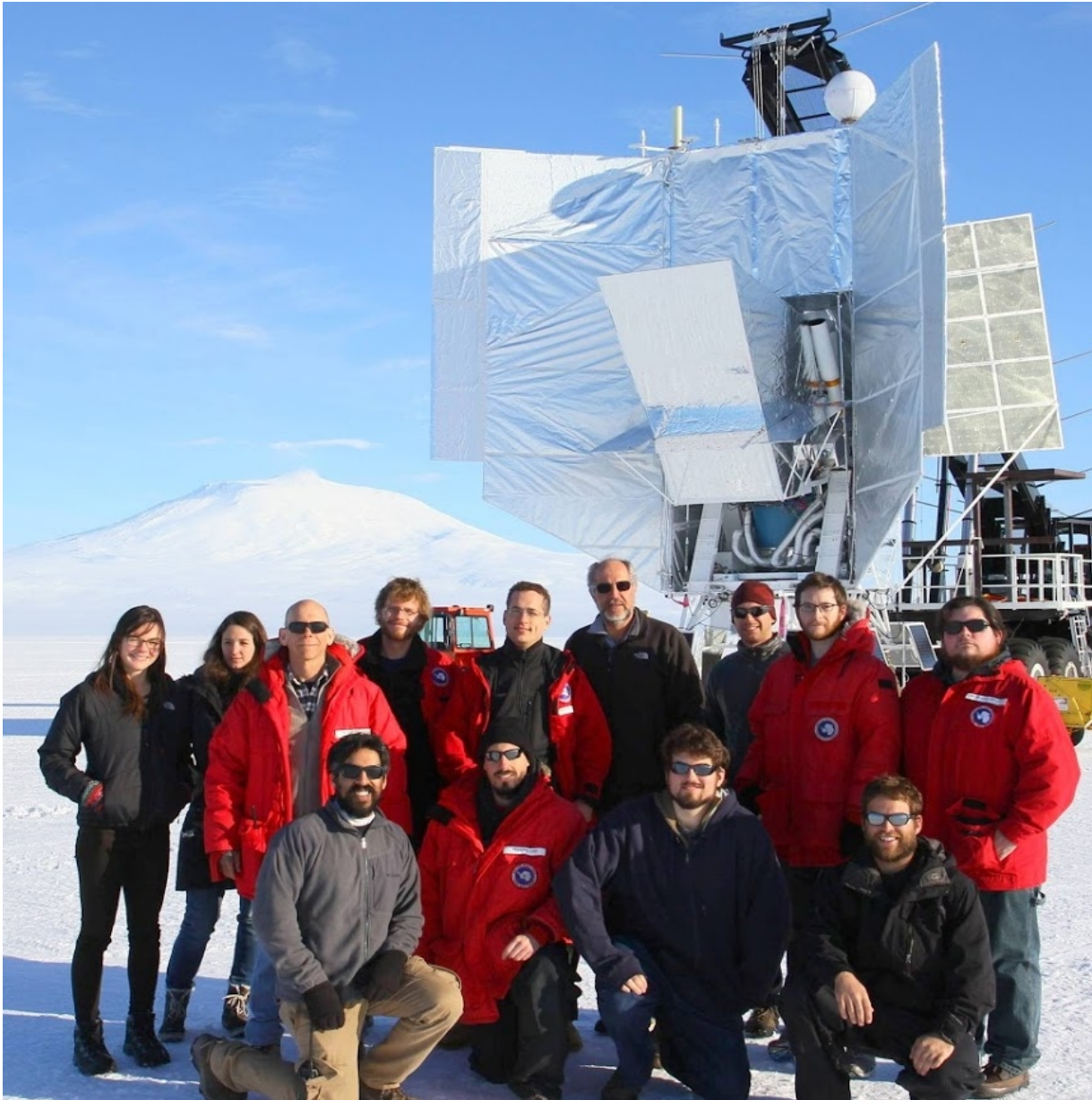


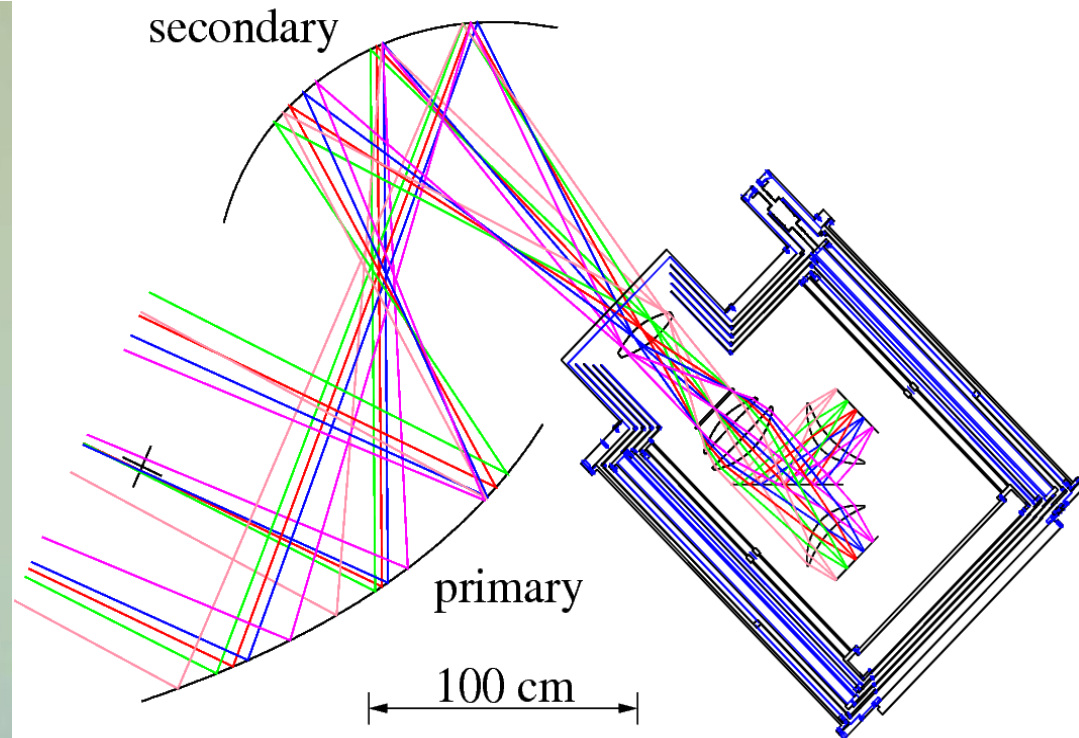
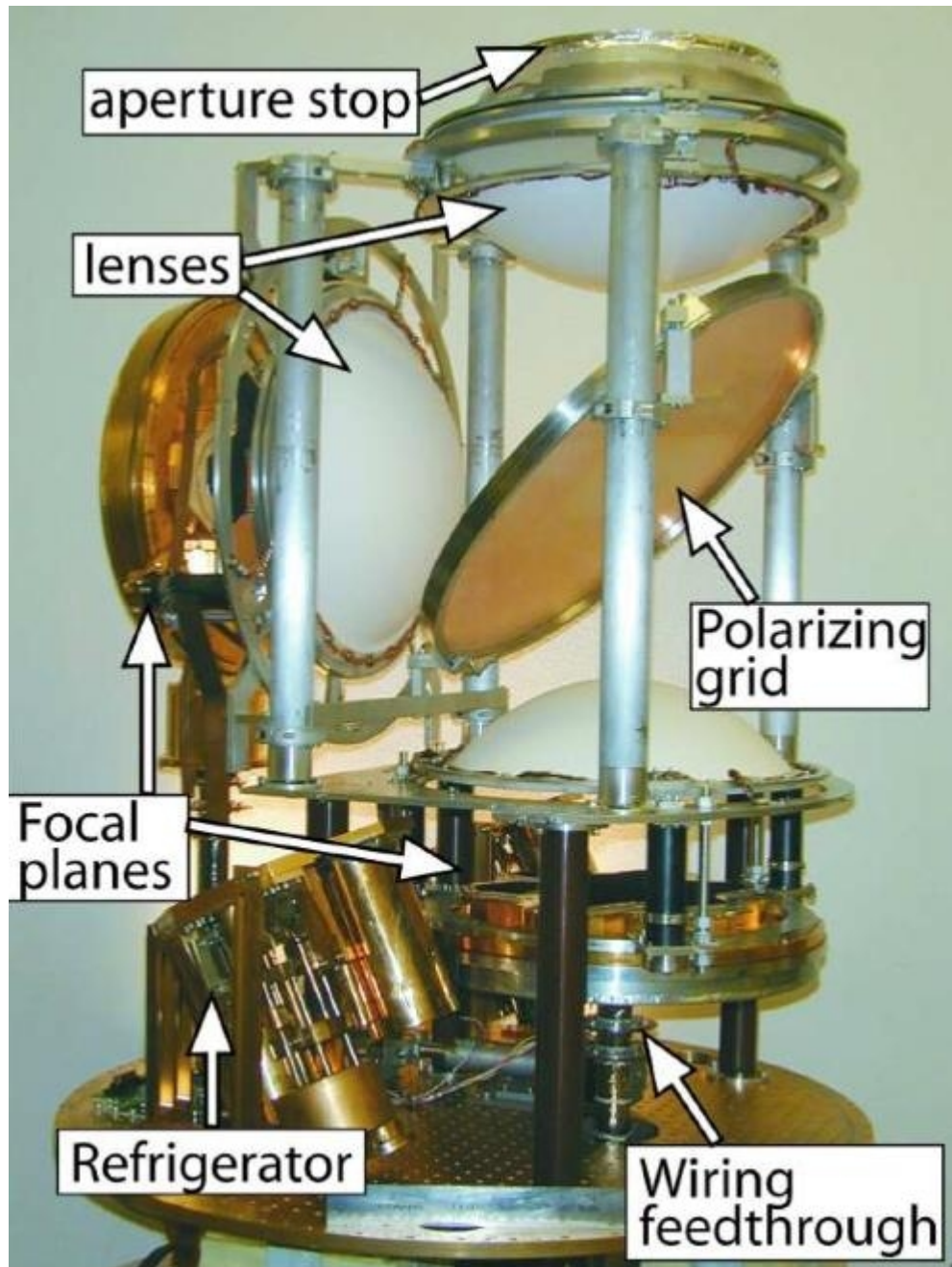
Photo credit: Asad Aboobaker

EBEX's Designed Science Goals



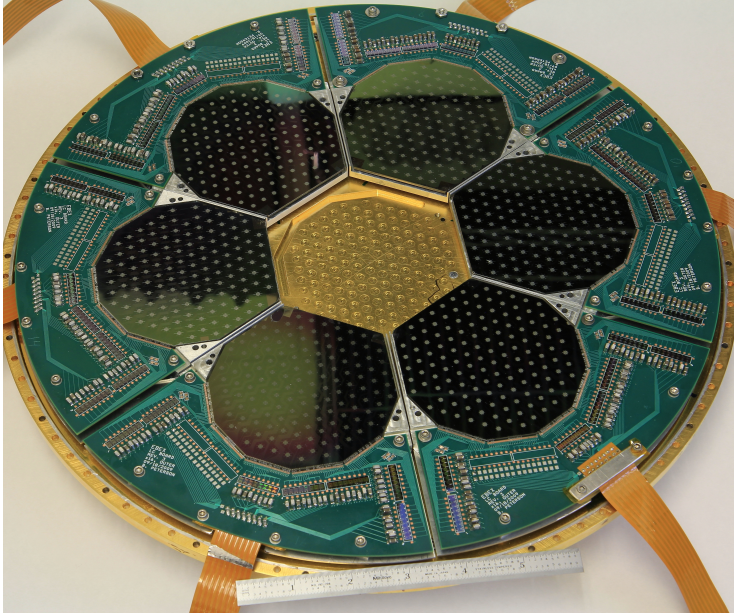
- Detect or put an upper limit on CMB polarization B-mode signal
- Detect lensing B-mode
- Determine properties of polarized dust foregrounds

The Instrument: Receiver

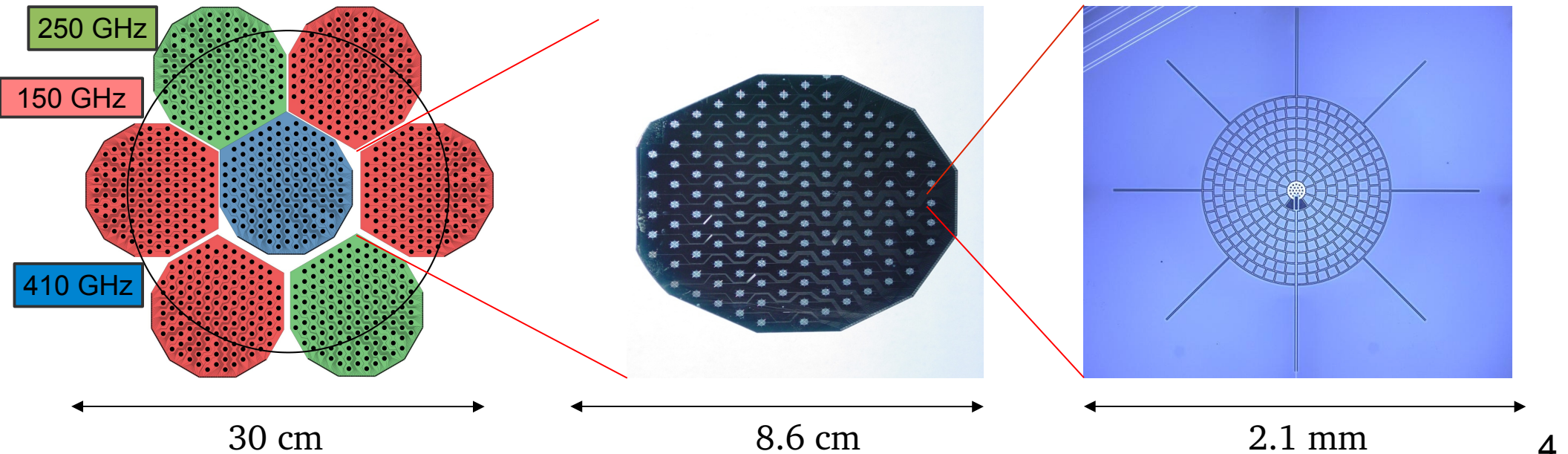


- 1.5 meter primary mirror
- 8' beam at all frequencies
- Two focal planes
- Achromatic half-wave plate continually rotating at 1.23 Hz on a Superconducting Magnetic Bearing
- Wire grid polarizer

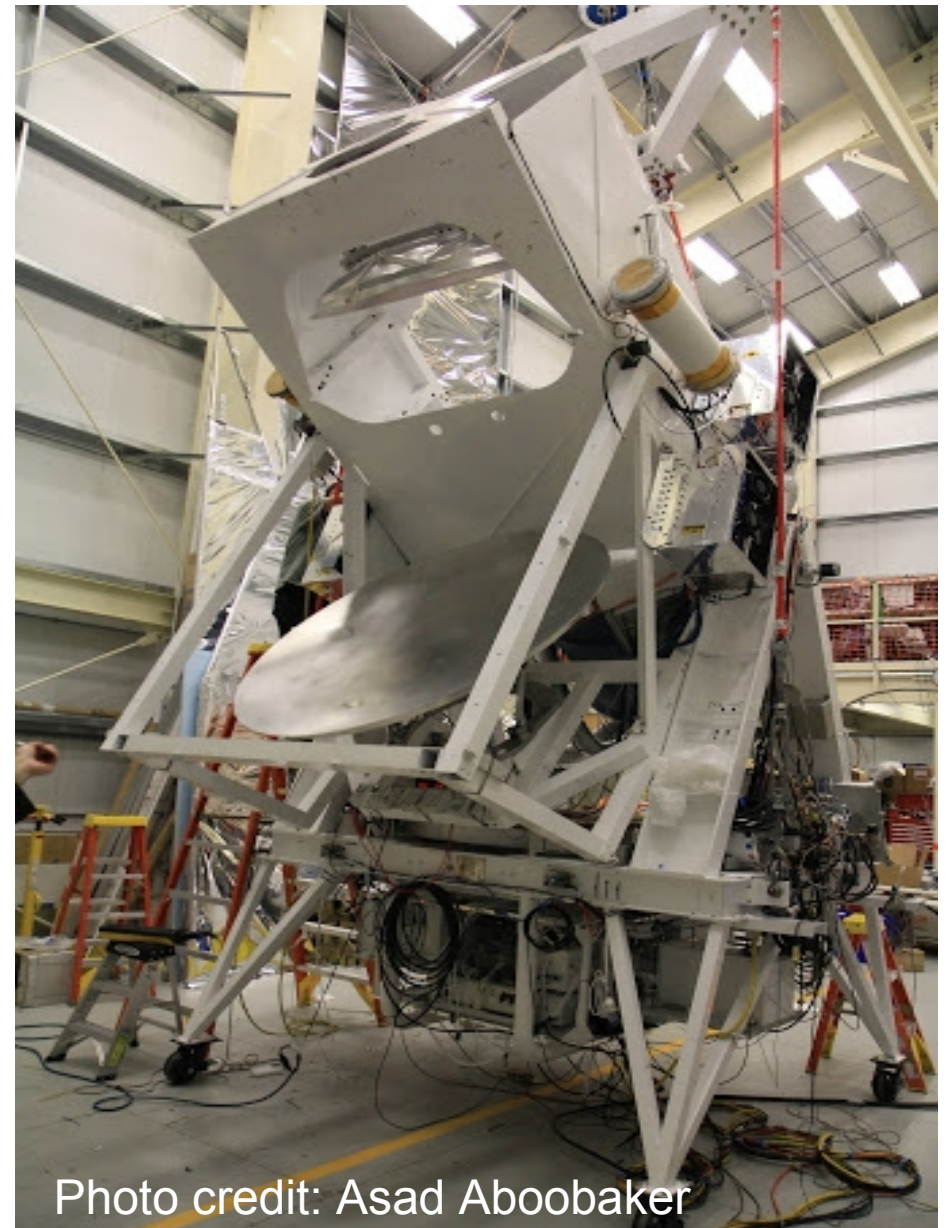
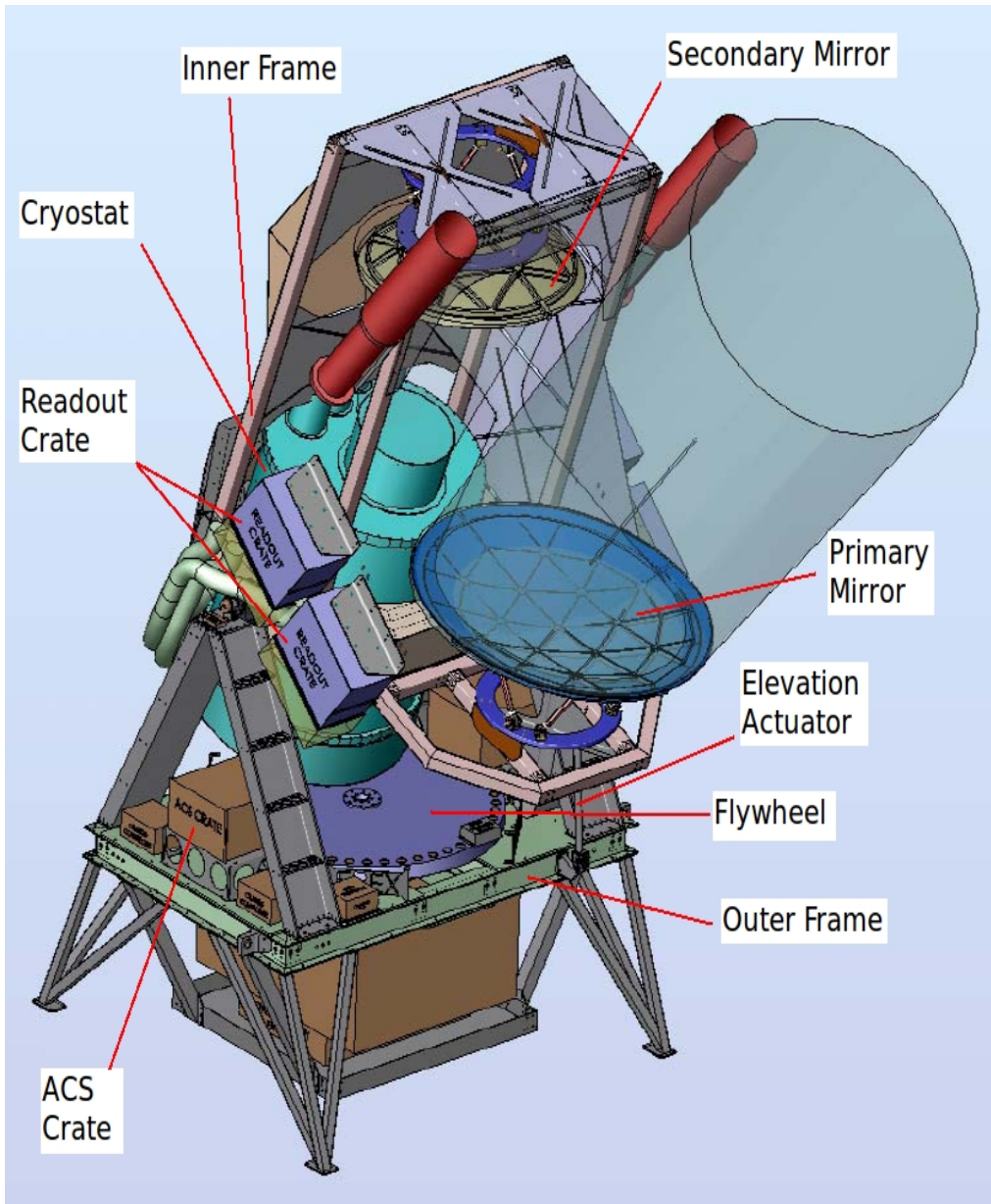
The Instrument: One of Two Focal Planes



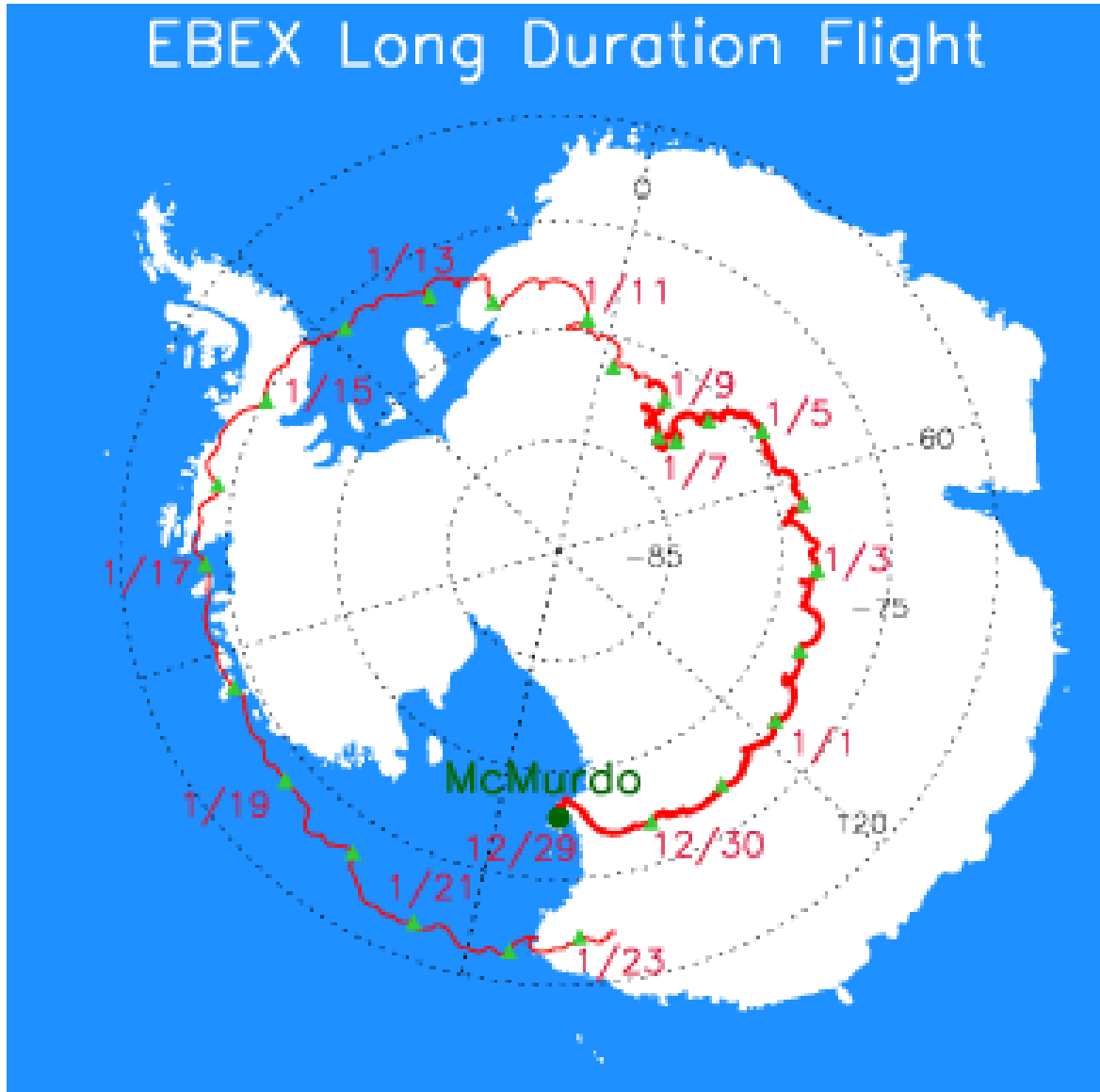
- Focal plane maintained at 0.27 K
- 3 frequency bands: 150, 250 and 410 GHz
- > 1000 TES bolometers
- Digital frequency domain multiplexed SQUID readout



The Instrument: Gondola



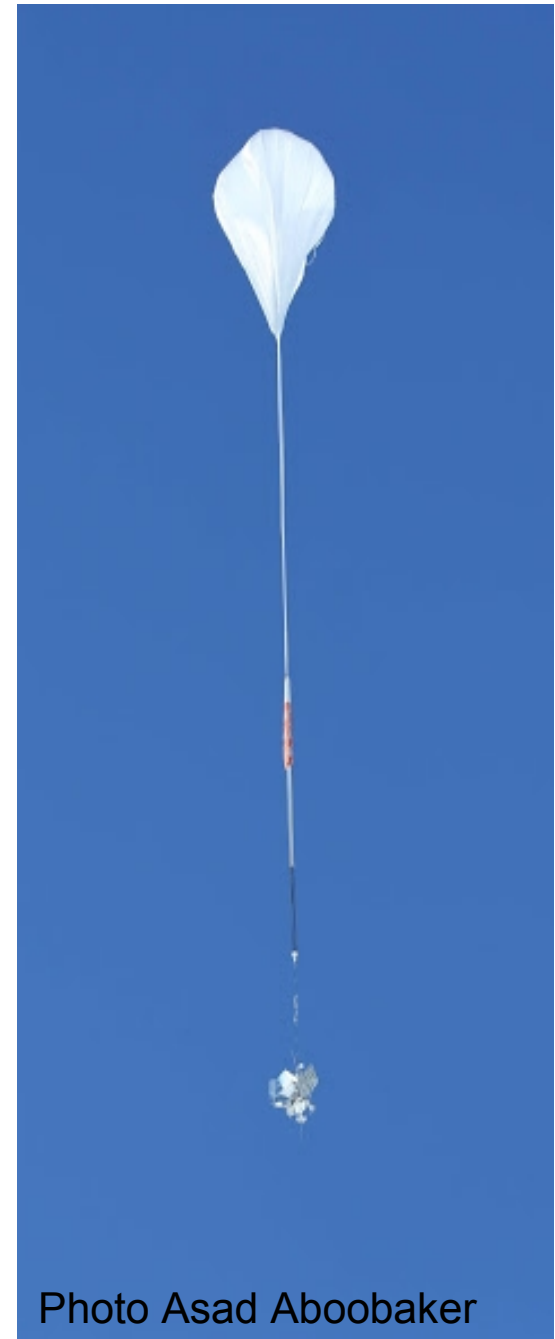
The Flight: Overview



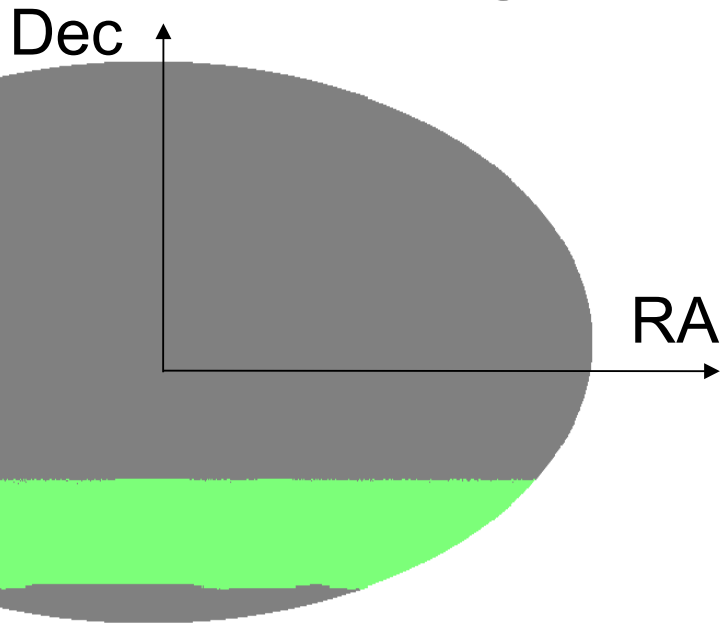
- Launch on 2012-12-29 from McMurdo station
- 11 days of observations as predicted
- Float altitude \sim 35 km = 115,000 feet
- 1.3 TB of data recovered
- Electronics, mirrors, pointing sensors recovered
- Data analysis ongoing ₆

The Flight: Success

- First use on a **science** balloon flight:
 - Monolithic array of about a thousand bolometers
 - TES bolometers
 - 16x frequency multiplexing
 - SQUID amplifiers
- Successful operation of AHWP and SMB with $\sim 1,000,000$ rotations
- Successfully tuned in flight
- Successful operation of star cameras, gyros and other pointing sensors
- Successful in flight telemetry and data storage

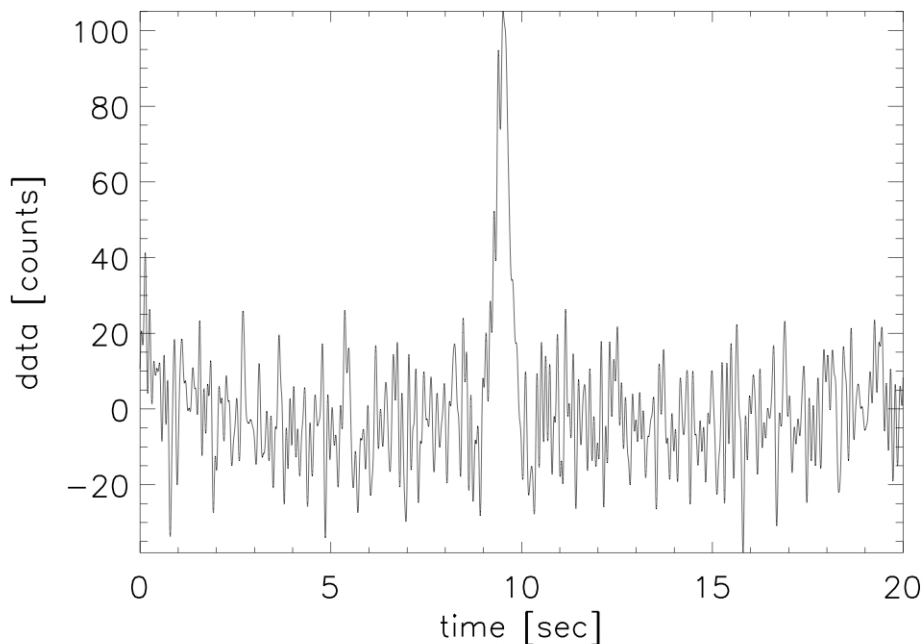


The Flight: Observations



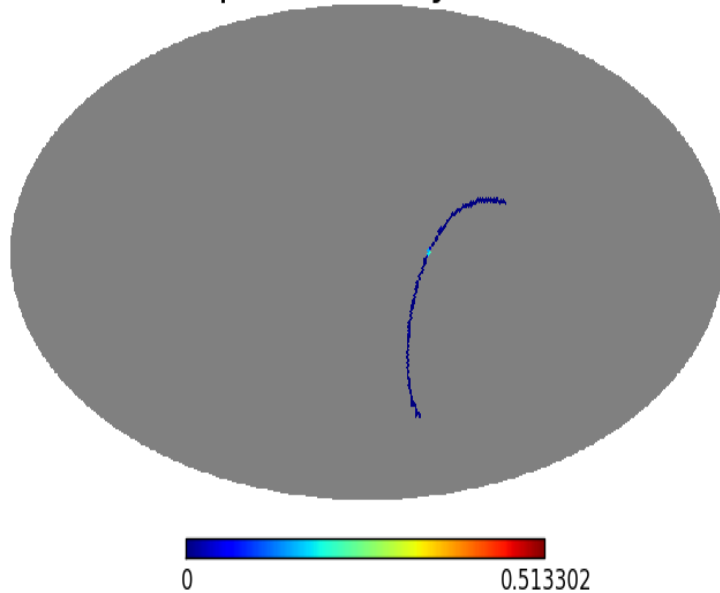
- Observed 6000 square degrees of sky
- Calibrated on RCW38
- Observed galaxy crossing real-time
- Elevation sky dips measure optical loading vs atmospheric depth

Drift removed filtered data

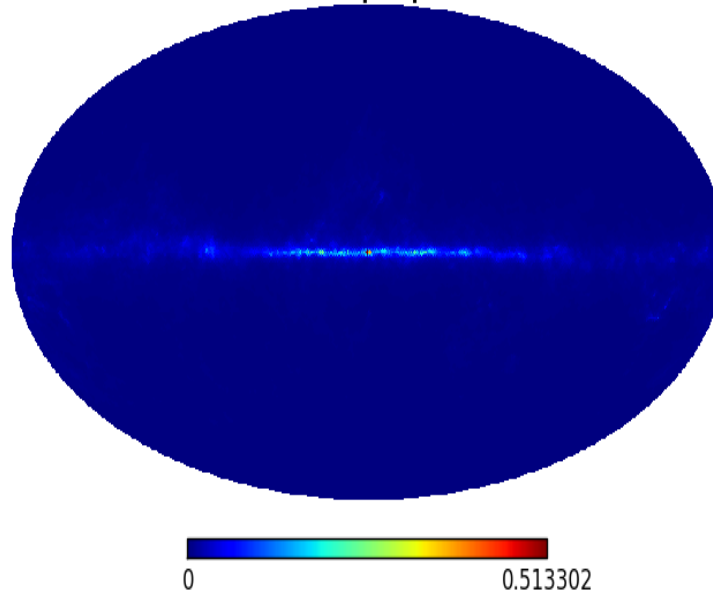


Example Calibration

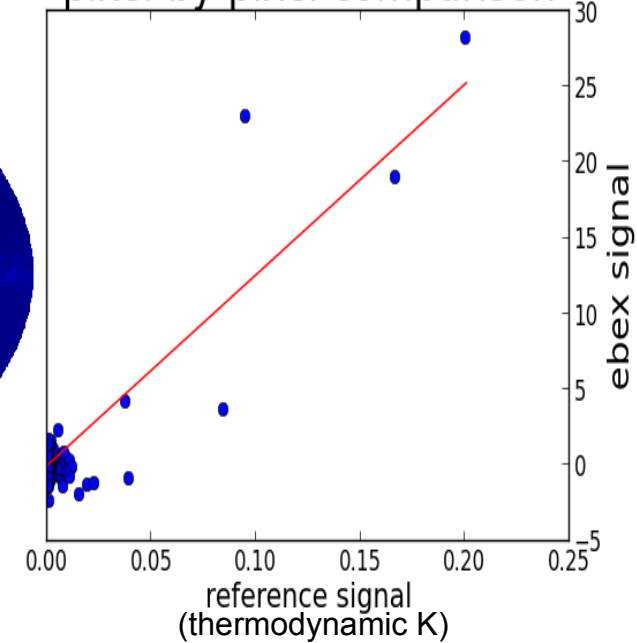
ebex map (scaled by calibration)



reference map: planck2013

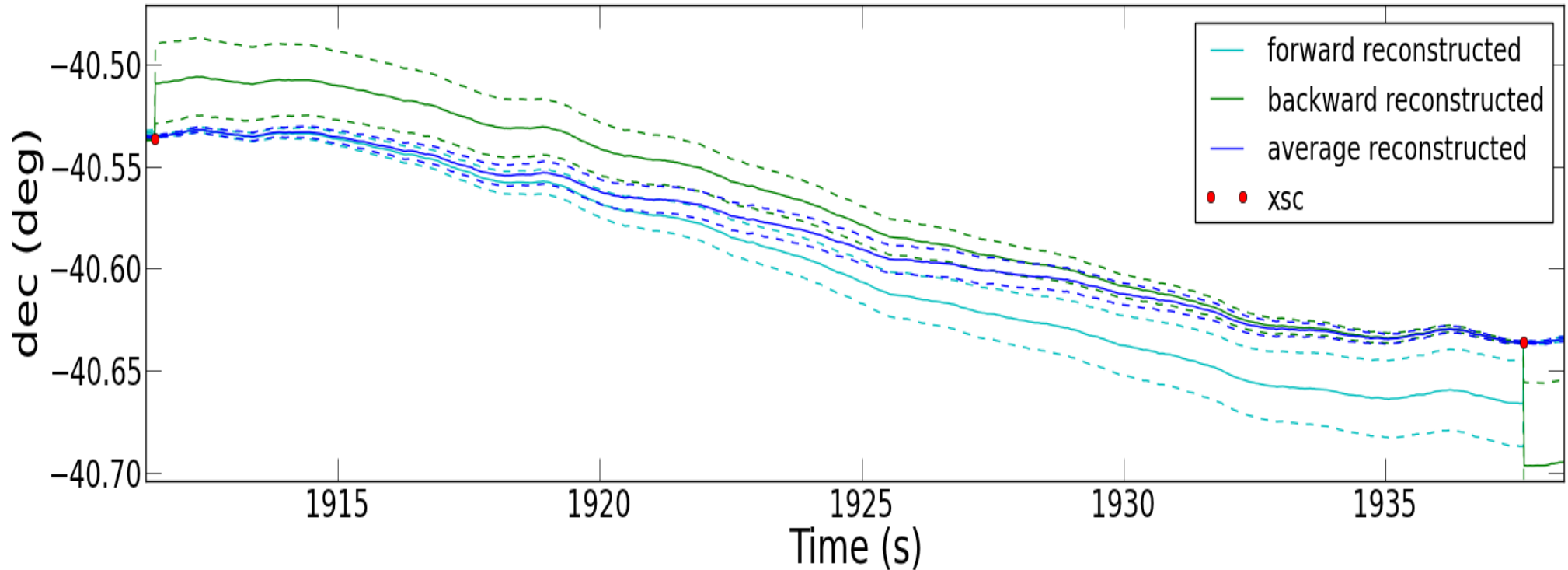


pixel-by-pixel comparison



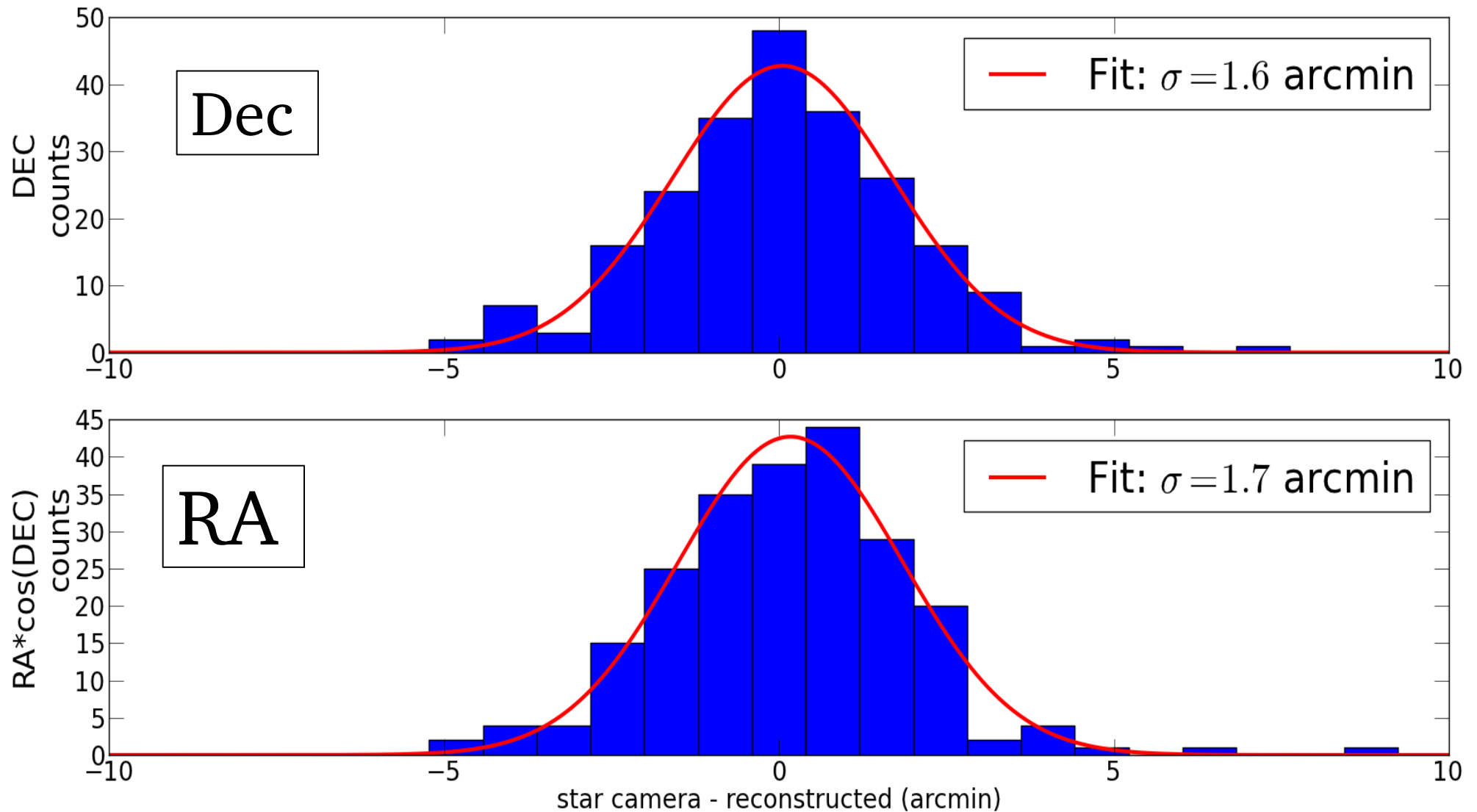
- 3 minutes of data from a single 250 GHz detector crossing the galactic plane
- HWP not rotating for plotted data
- Plot uses real-time pointing attitude (accuracy ~ 1 deg)
- In the process of removing HWP template and reconstructing better pointing

Pointing Reconstruction: Theory



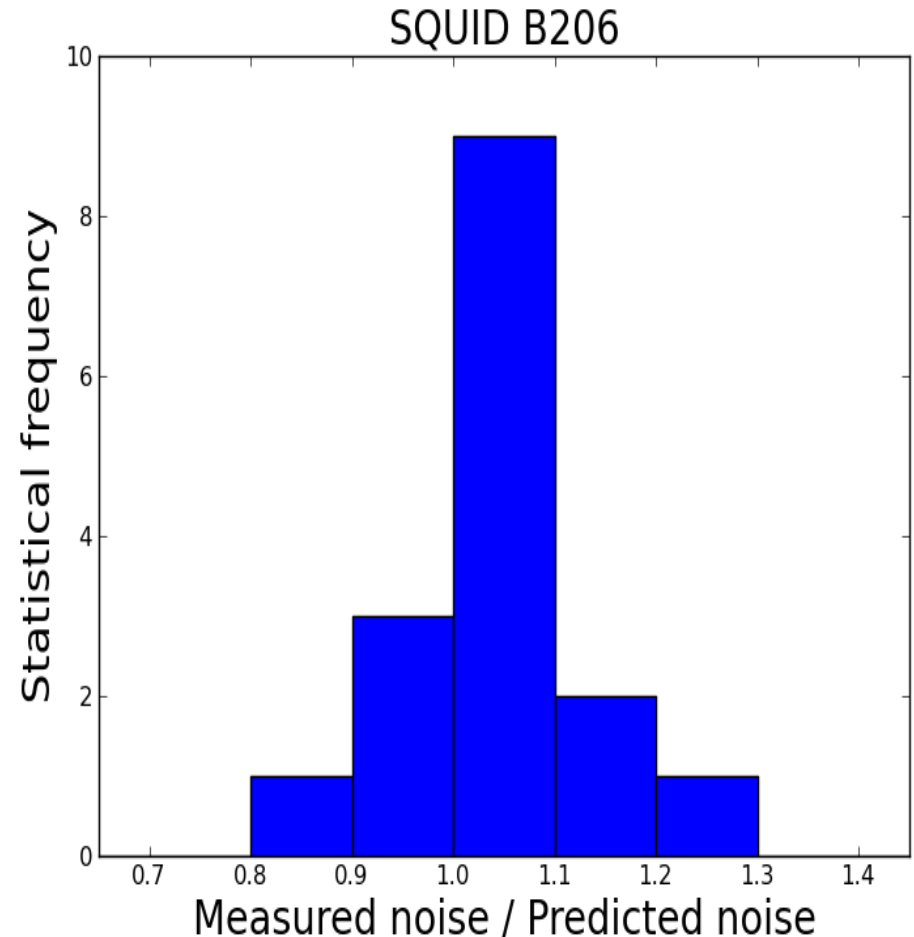
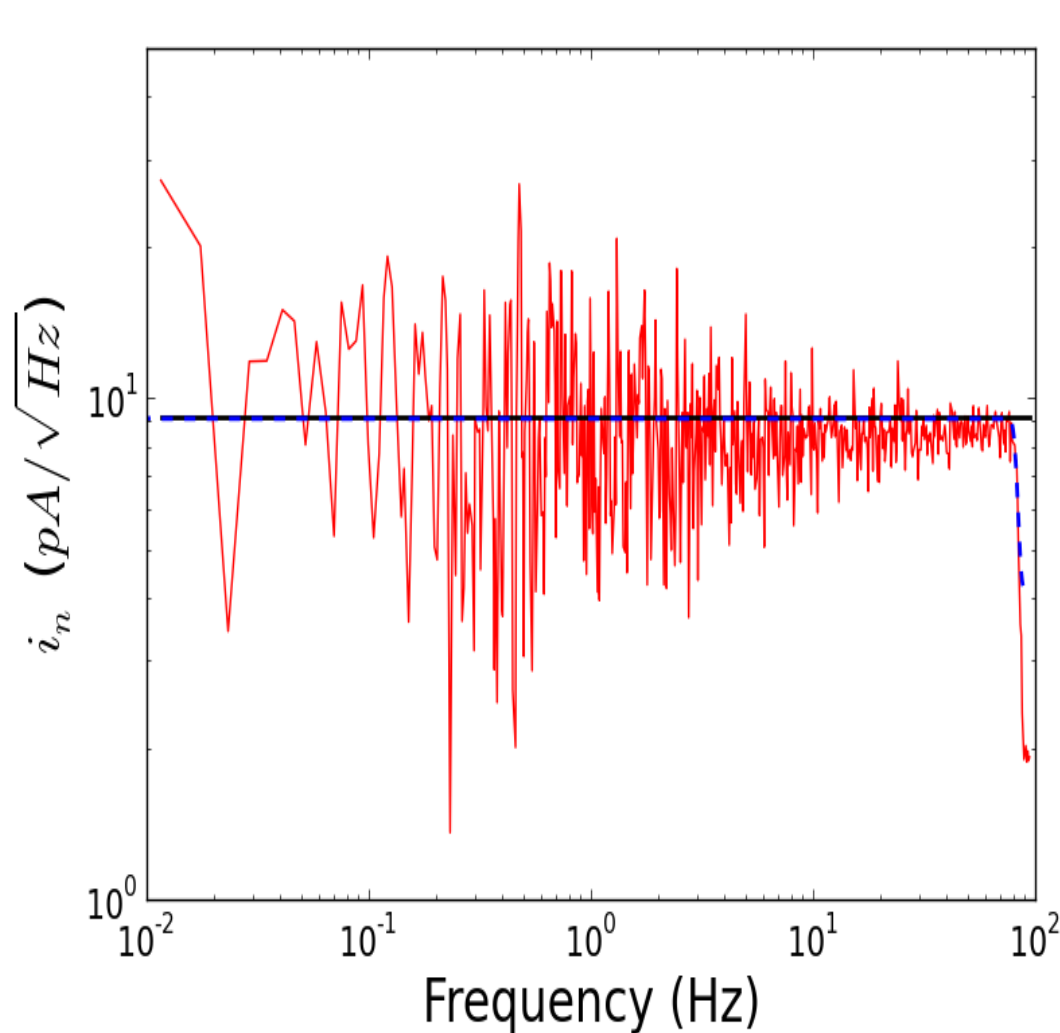
- Gyroscopes integrated between star camera readings
- Integration forwards and backwards in time, biggest error mid-throw
- Real-time pointing accuracy ~ 1 degree
- Theoretical reconstructed pointing accuracy $\sim 13''$ mid-throw.

Pointing Reconstruction: Preliminary Results



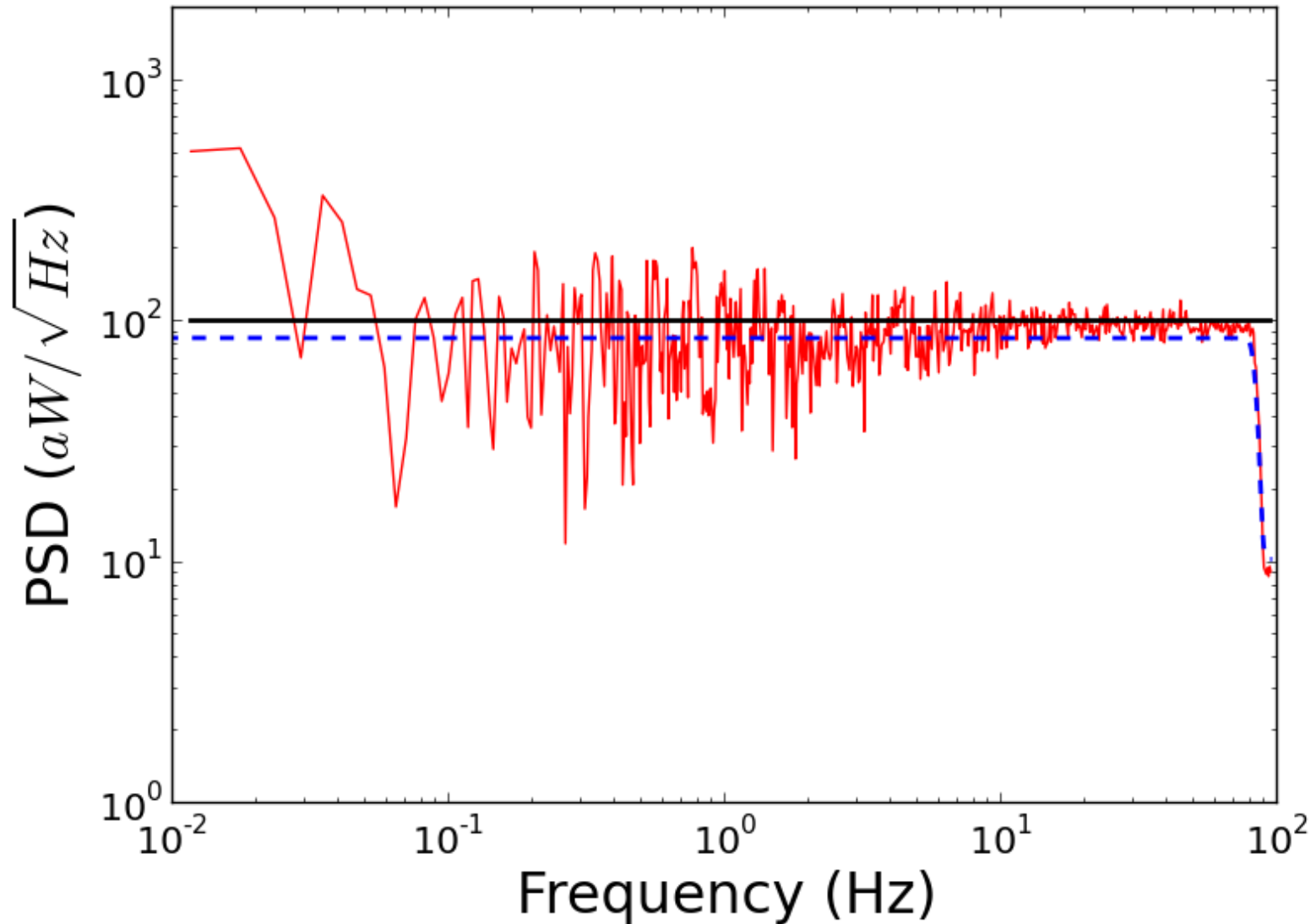
- Preliminary pointing reconstruction on a subset of ~ 15 hours of data
- Error mid-throw ~ 0.8 arcminutes
- Analysis ongoing to further refine pointing

Example Study of In-flight Noise: Dark SQUID



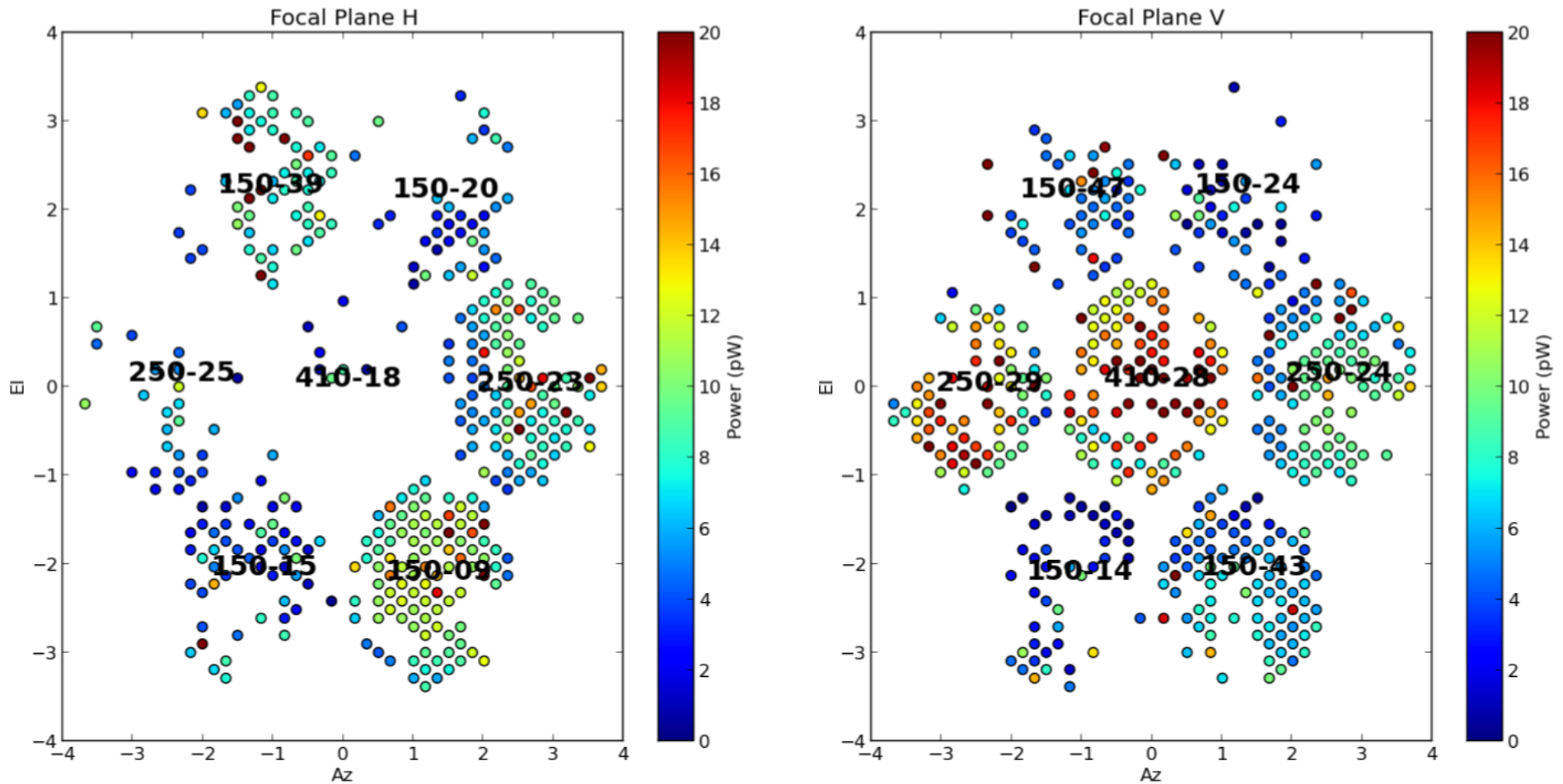
- Blue: expected SQUID noise
- Red: In flight SQUID noise (@ 915 kHz)

Example Study of In-flight TES Noise:



- Red: preliminary noise power spectrum of a 150 GHz detector
- Dashed blue: predicted noise

Example Bolometer Tuning



- First tuning after ascent
- 823 live detectors shown
- Another 209 possibly working (analysis in progress)

EBEX Summary

- EBEX's first science flight in January 2013
- 6000 square degrees of sky observed during 11 days with over 1000 TES bolometers
- First (and only) use of TES bolometers on a balloon platform
- First implementation of fmux system + first (and only) use of x16 fmuxing
- Data recovered, analysis is underway
- Plan to re-fly the EBEX receiver with upgraded focal plane array (EBEX6k)

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Collaboration

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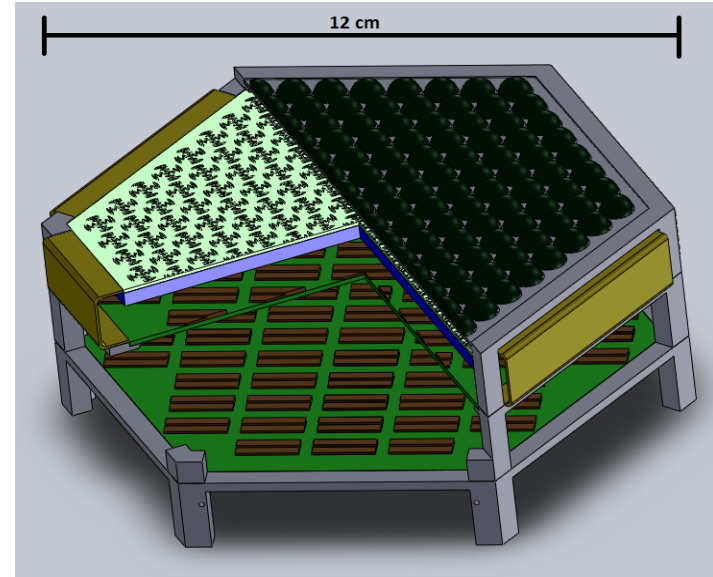
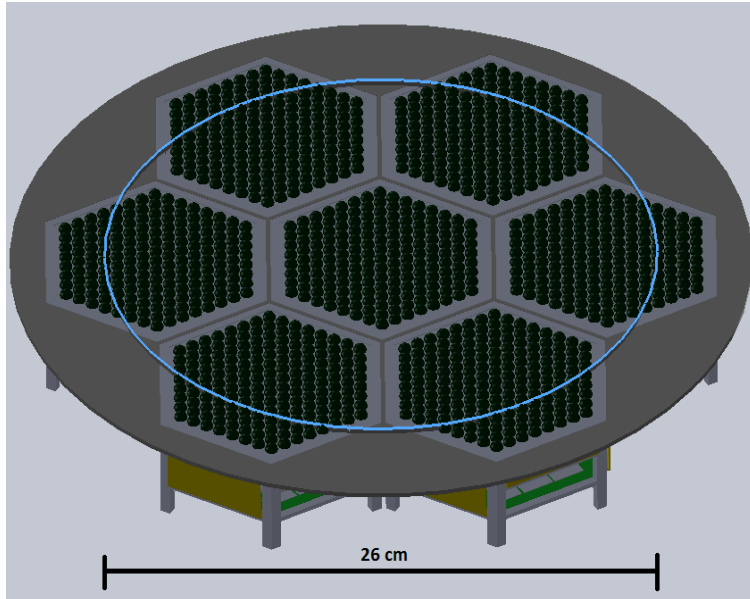
Lorne Levinson

Ilan Sagiv



Extra material

EBEX 6k



- Re-fly EBEX with upgraded focal plane
- Lens-coupled sinuous antenna multichroic pixel (SAMP)
- 1008 multichroic pixels for a total of 6048 TES detectors
- Bands at 90, 150, 250 GHz
- 2 sigma upper limit on the tensor to scalar ratio of $r \leq 0.007$
- x64 digital frequency multiplexing