EBEX (The E and B EXperiment)

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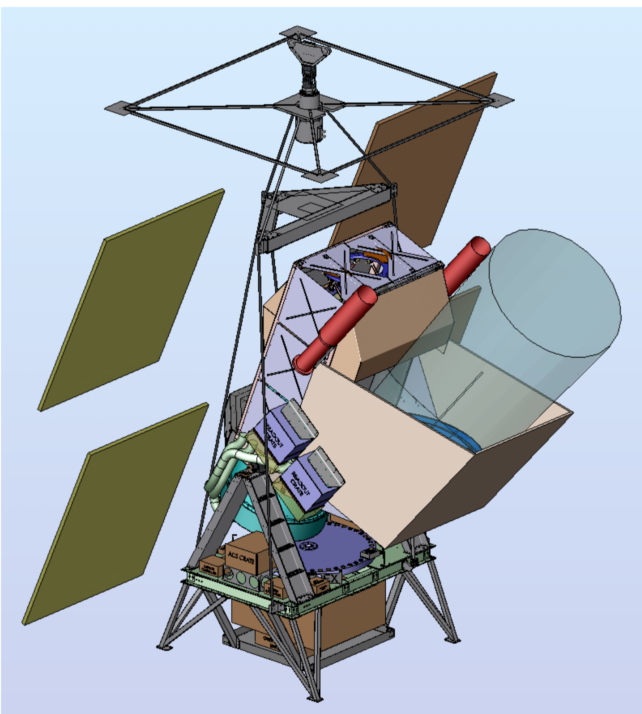
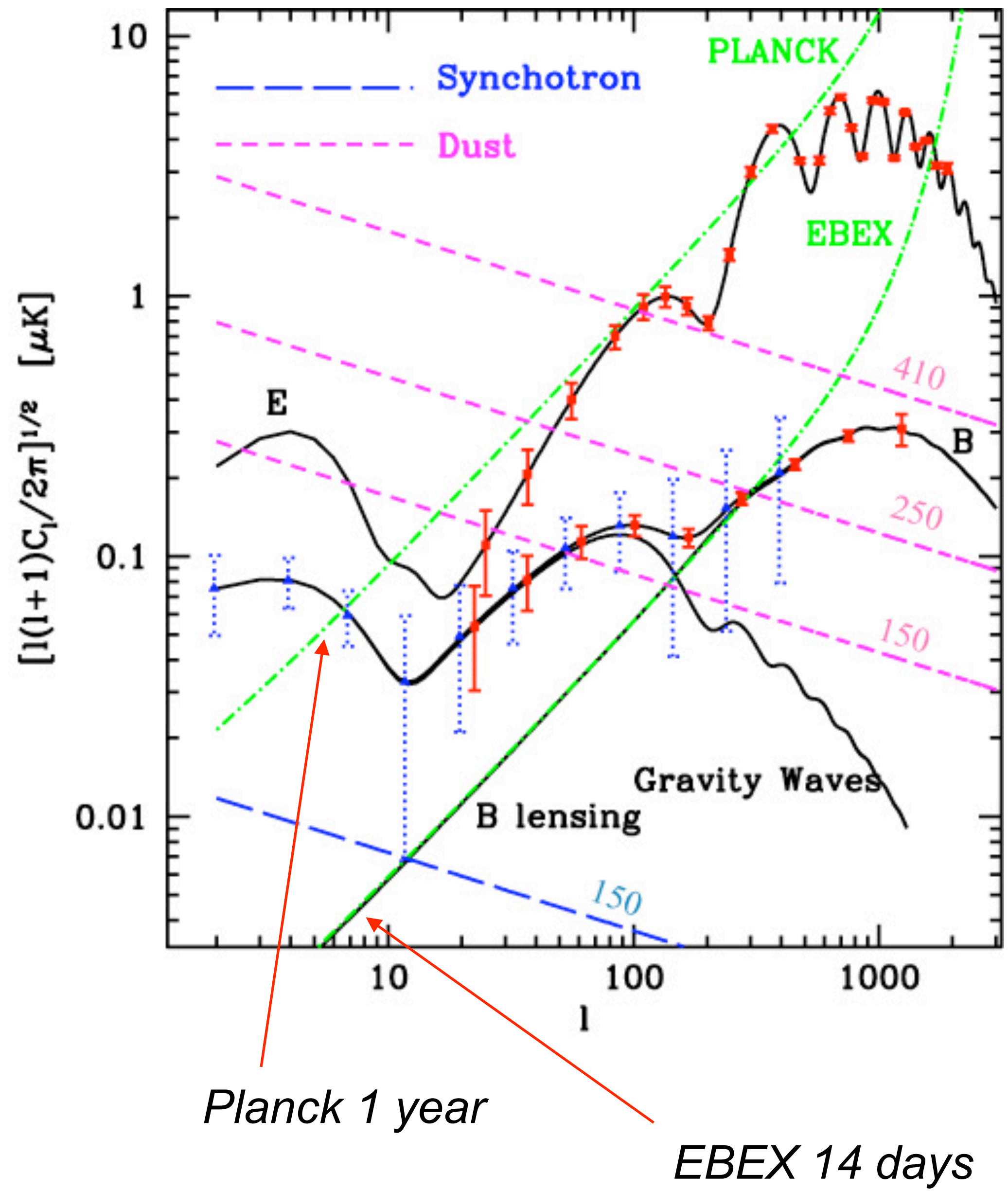
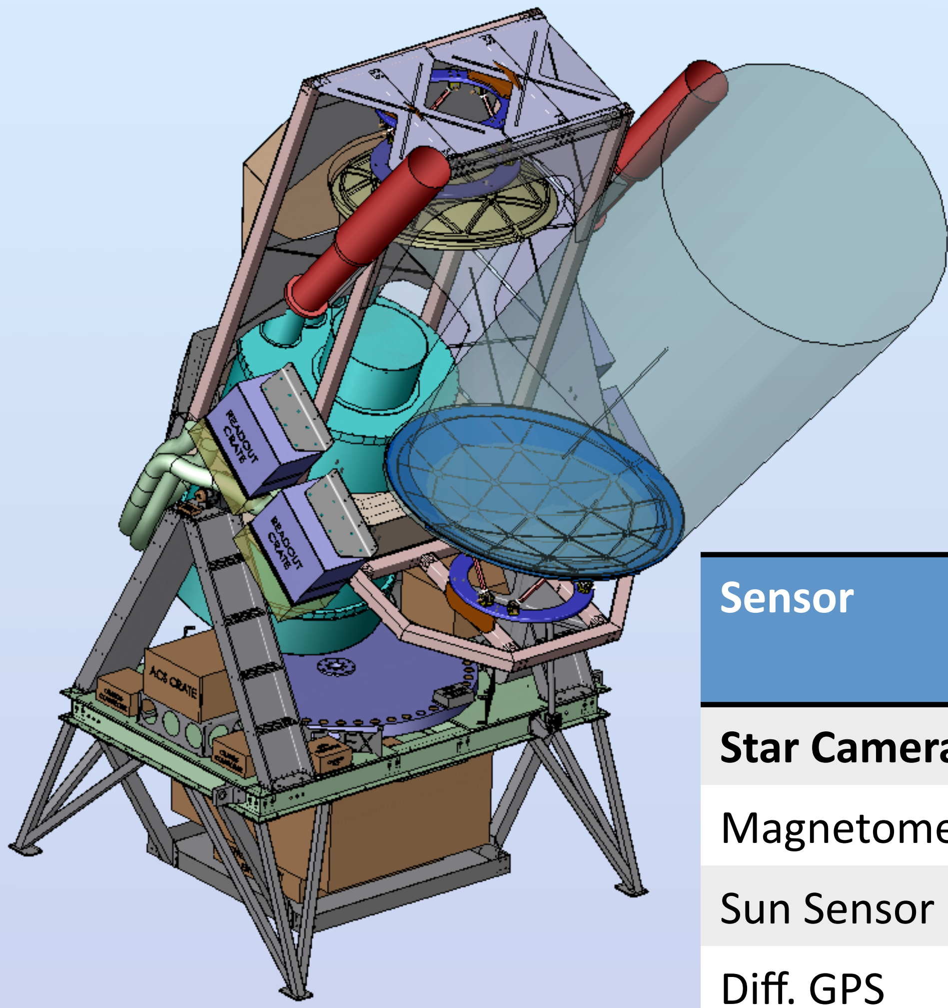
Science Goals

- Detect or set upper bound on inflation B-mode
- Measure lensing B-mode
- Understand Polarized Dust
- Improve estimation of cosmological parameters



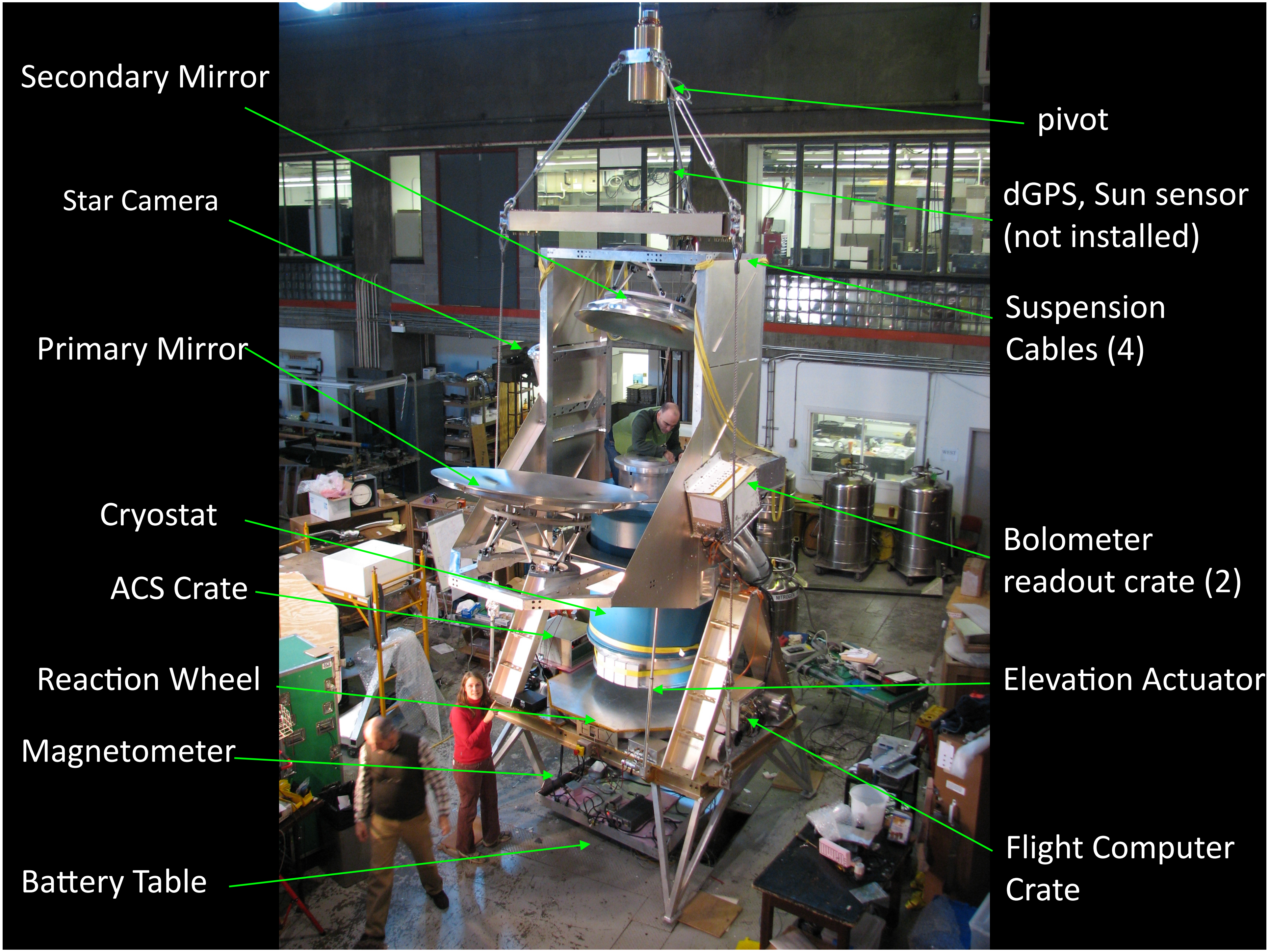


Attitude Control System



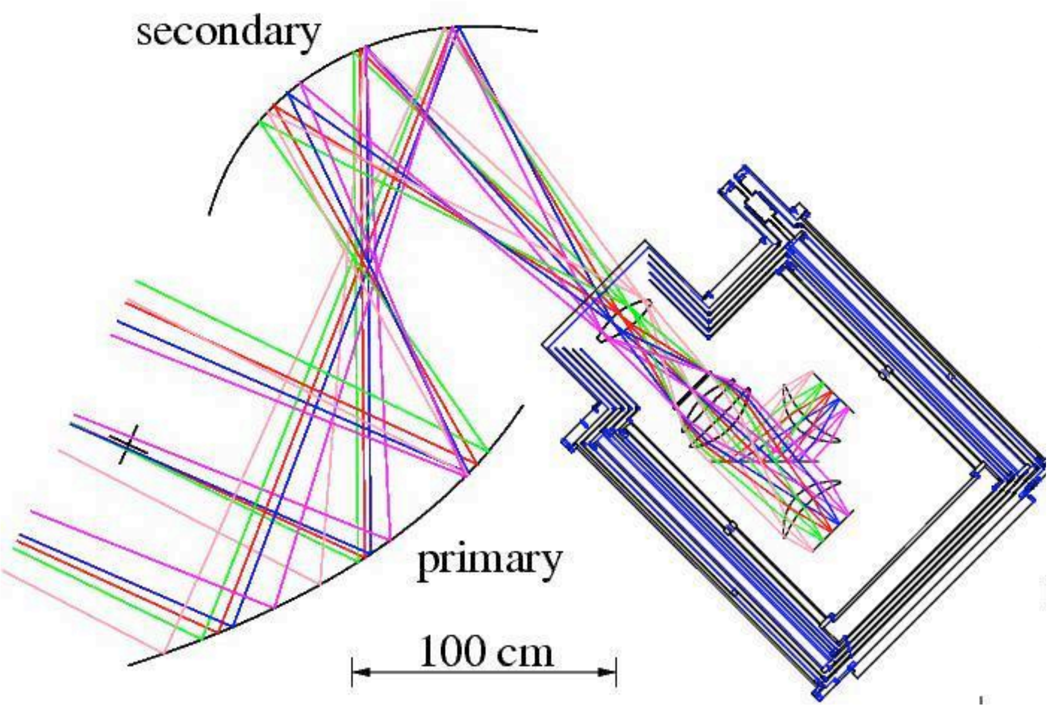
- Cable Suspension (as in BLAST)
- Control – Flywheel, Pivot, Elevation Actuator

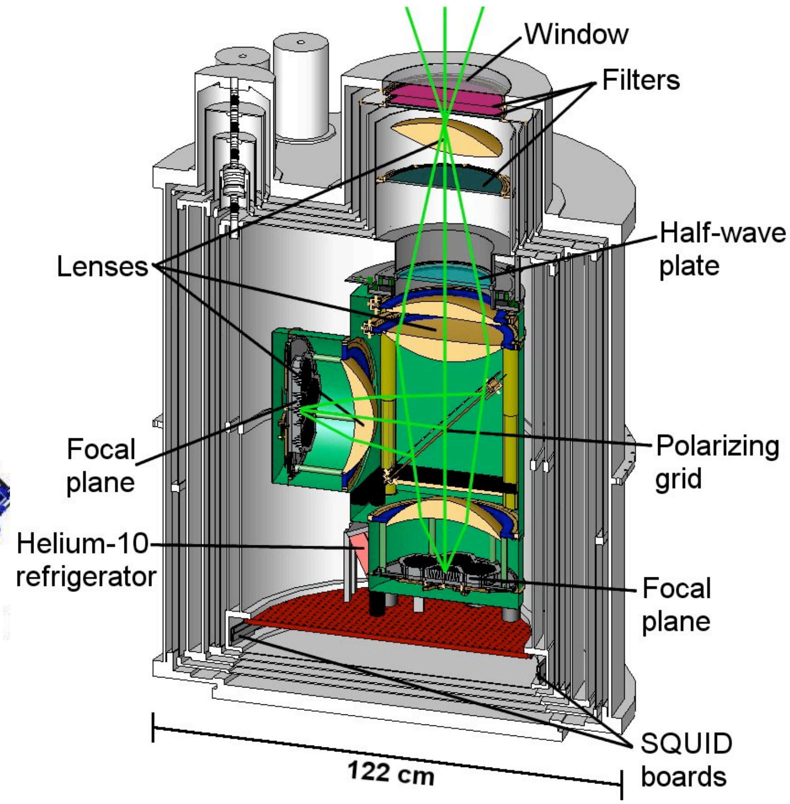
Sensor	Relative/ Absolute	Predicted Accuracy
Star Camera (2)	Absolute	5" (Az,El), 3' (roll)
Magnetometer	Absolute	~ 0.5-4^{o} (Earth field model)
Sun Sensor	Absolute	~1^{o}
Diff. GPS	Absolute	6' (AZ), 12' (pitch, roll)
Tiltometer	Absolute	1'
Gyros (6)	Relative	11" max over scan
Rotary Encoder	Relative	20"


Secondary Mirror
Star Camera
Primary Mirror
Cryostat
ACS Crate
Reaction Wheel
Magnetometer
Battery Table
pivot
dGPS, Sun sensor
(not installed)
Suspension
Cables (4)
Bolometer
readout crate (2)
Elevation Actuator
Flight Computer
Crate

Optics

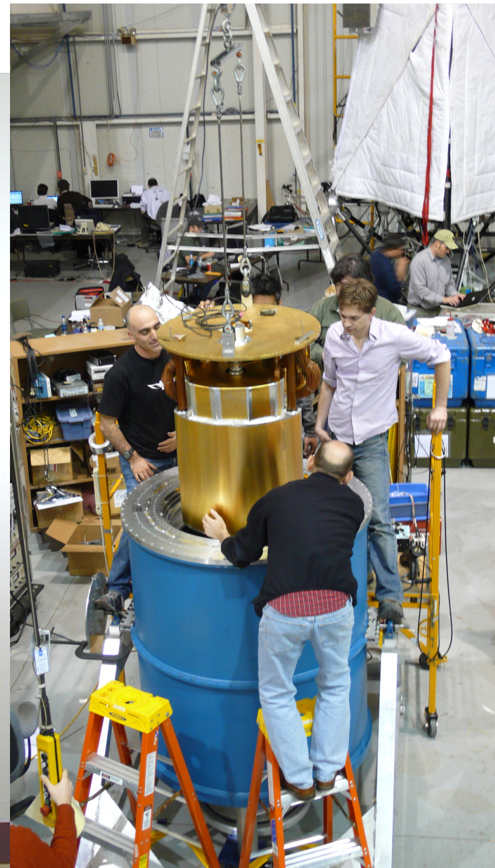
- 1.5 m Aperture Gregorian Dragone telescope (Archeops primary)
- Cold aperture stop for sidelobe control
- Achromatic Half Wave Plate for polarization modulation
- Polarizing Grid for simultaneous detection of both orthogonal states

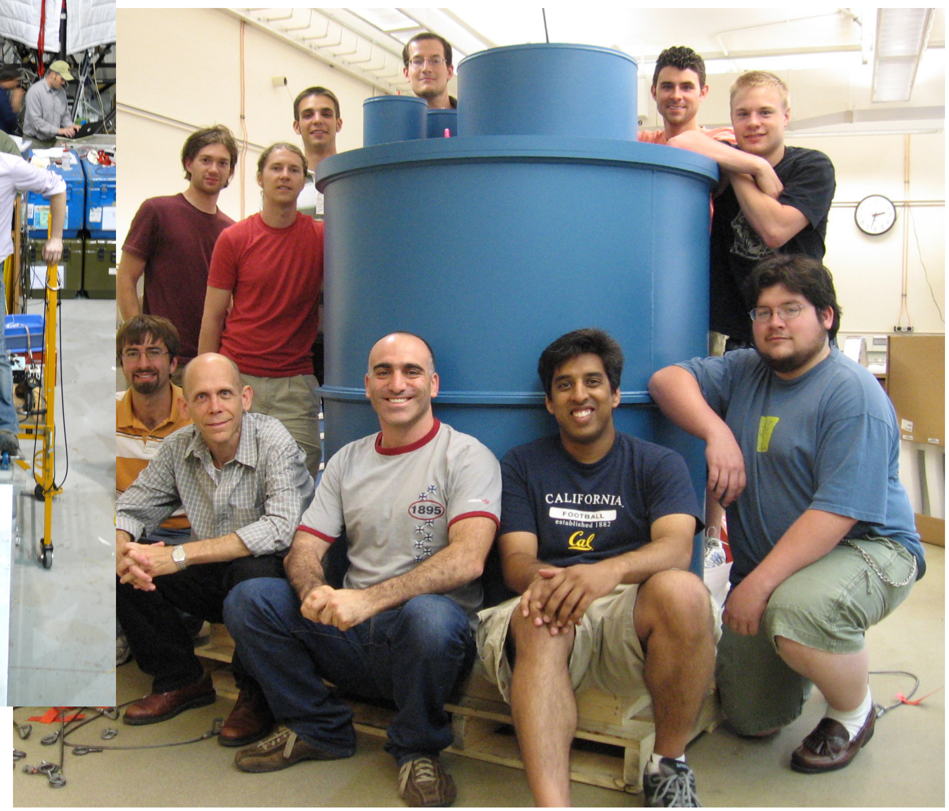




Both primary and secondary measured deviations < 50 microns rms
Conical horns adjust illumination on primary → same resolution at all frequencies

Optics and Cryostat





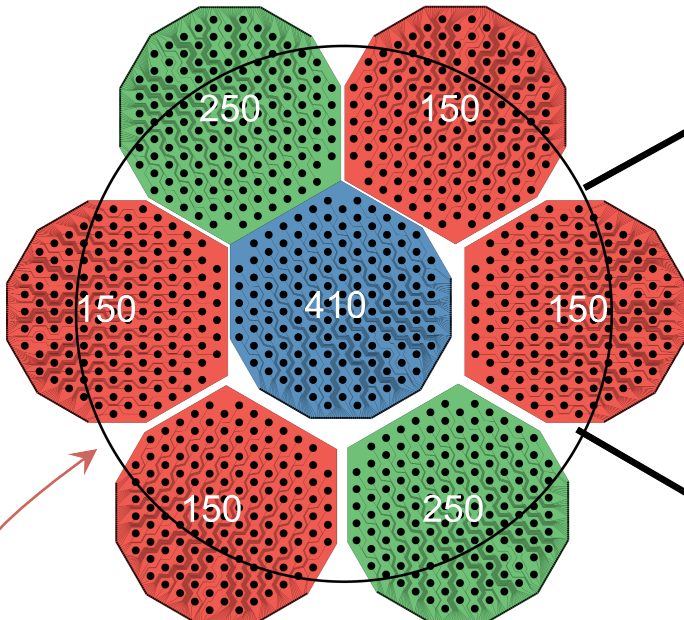
LN2, LHe loads match design
LN2 hold time = 21 days (measured)
LHe hold time = 20 days (measured)

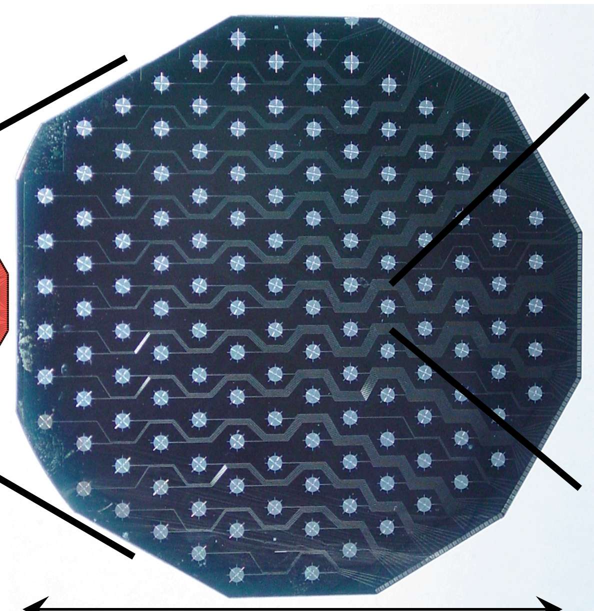
Detectors

738 element array

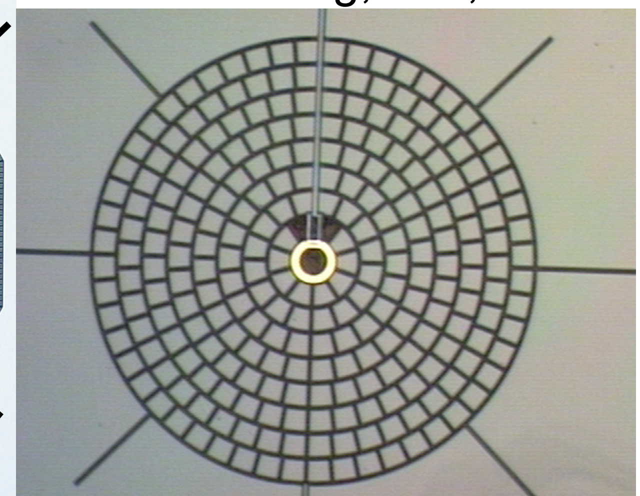
139 element decagon

Single TES





Meng, Lee, UCB



30 cm

8.6 cm

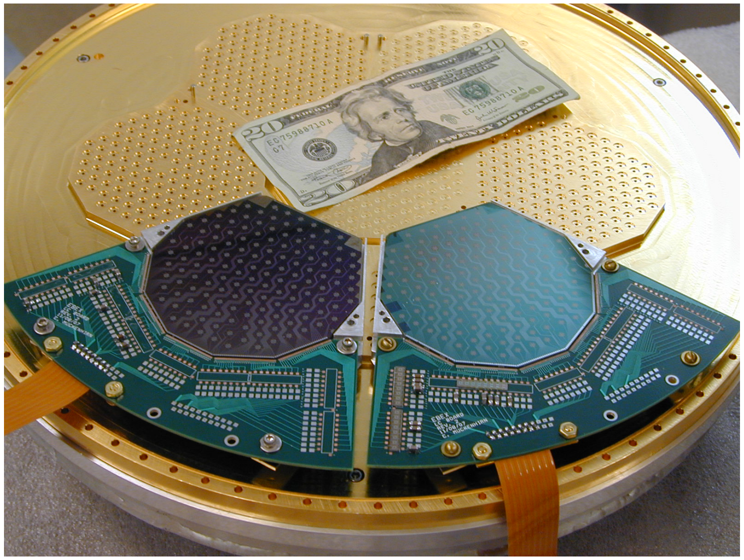
2.1 mm

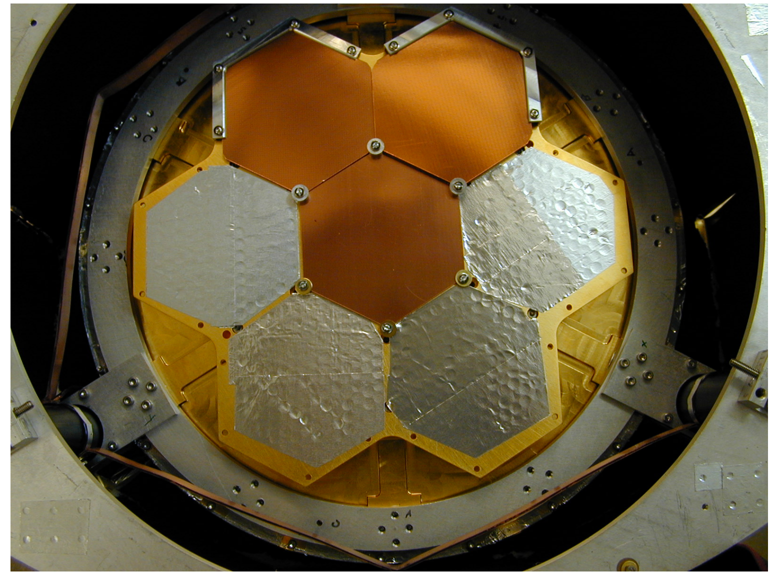
Strehl>0.85 at 250 GHz

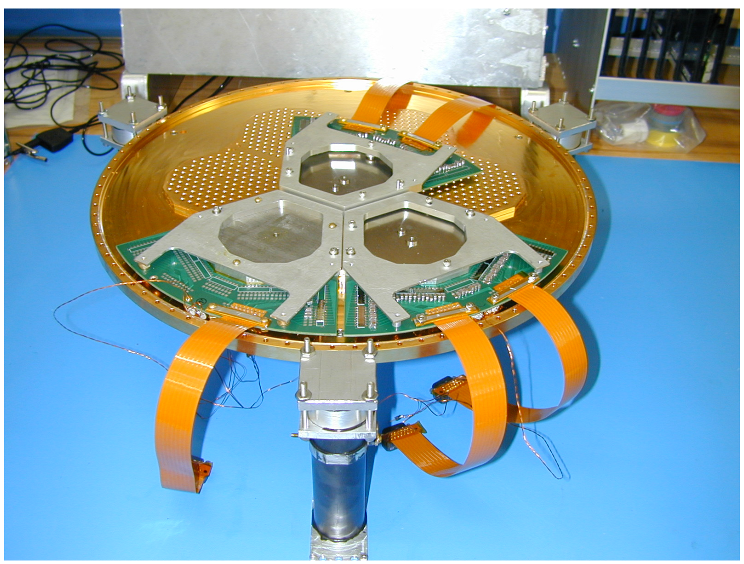
- Total of 1476 detectors (LDB)
- Maintained at 0.27 K
- 3 frequency bands/focal plane

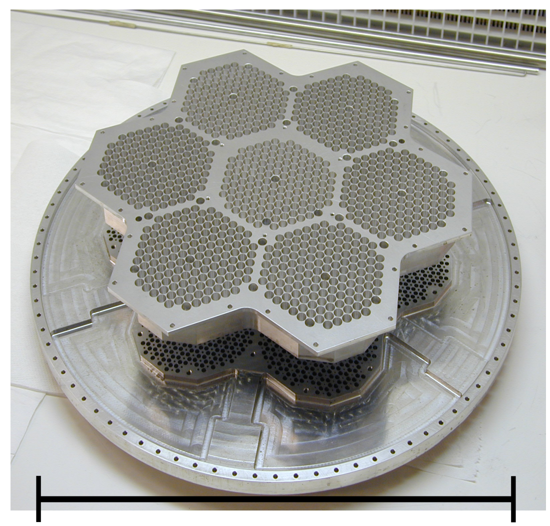
- G = 10 pWatt/K
- NEP = 1.1e-17 (150 GHz)
- NEQ = 136 μK*rt(sec) (150 GHz)
- τ = 3 msec,

Focal Plane Hardware



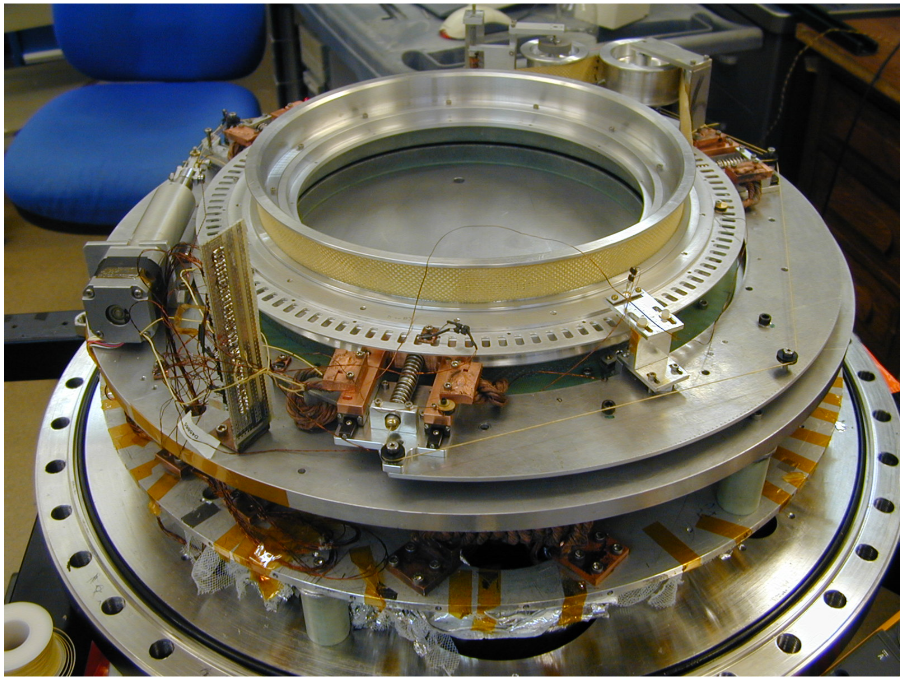


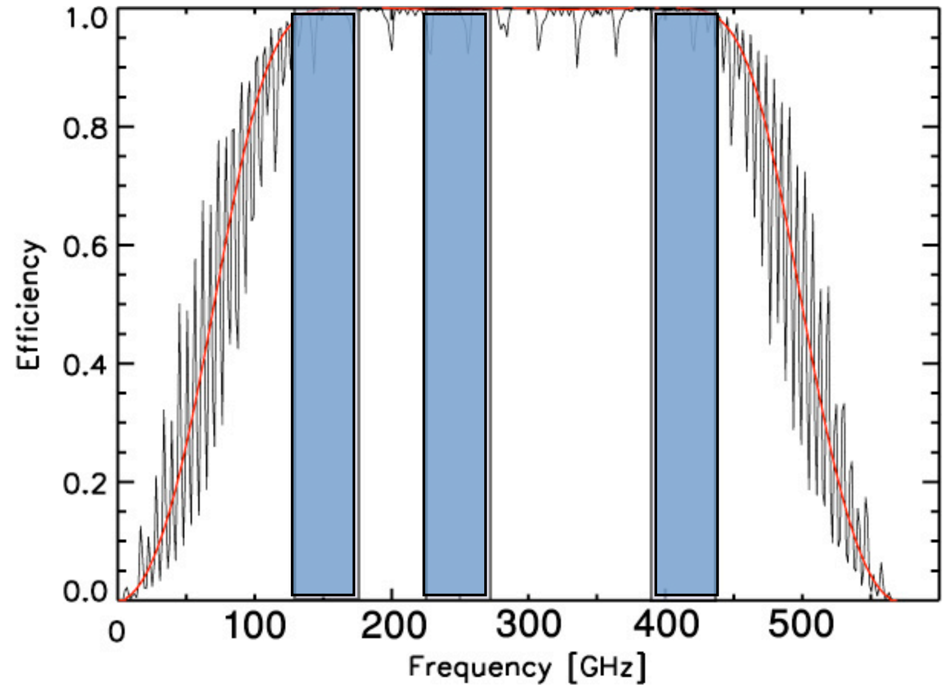




36 cm

Polarimetery with an achromatic Half Wave Plate





Rotates on a superconducting magnetic bearing

6 Hz rotation (2 Hz North American Flight)

0.25 degree angular encoding limited by sampling

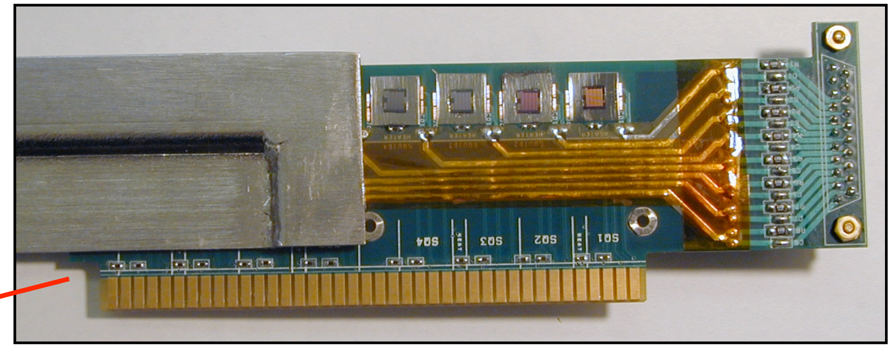
< 10% attenuation from 3 msec time constant

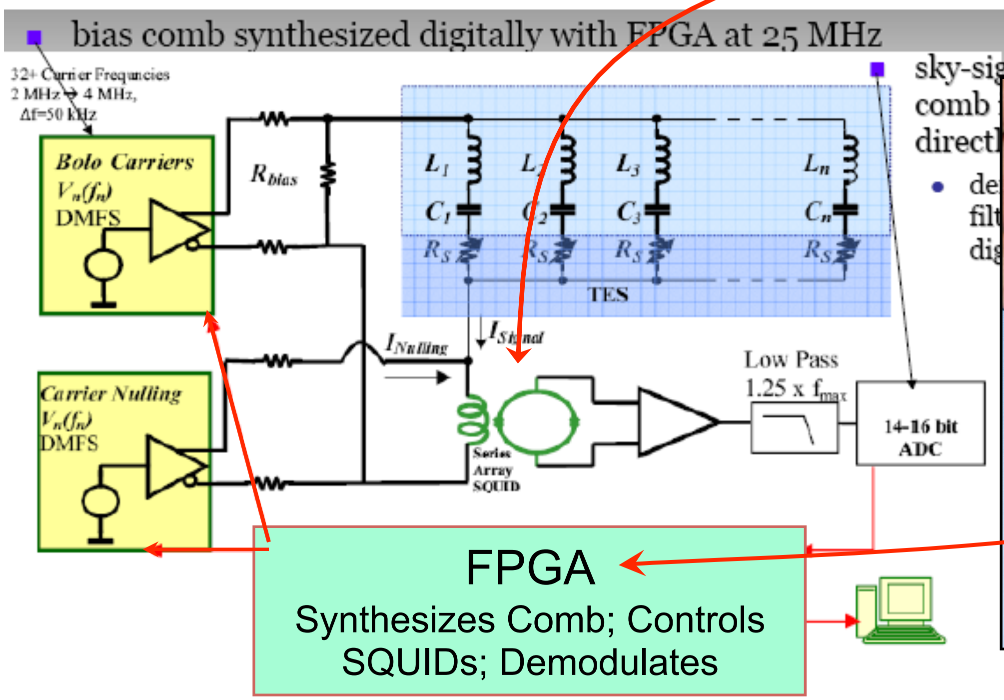
5 stack achromatic HWP (sapphire)

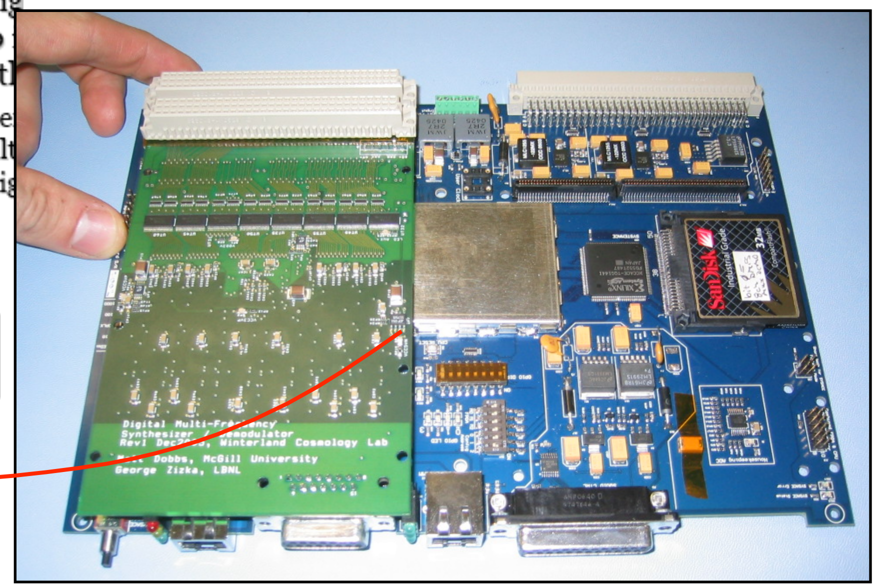
0.98 efficiency for 120< ν < 420 Ghz

Detector Readouts

- SQUID arrays (NIST)
- Digital Frequency Domain Multiplexing (McGill)

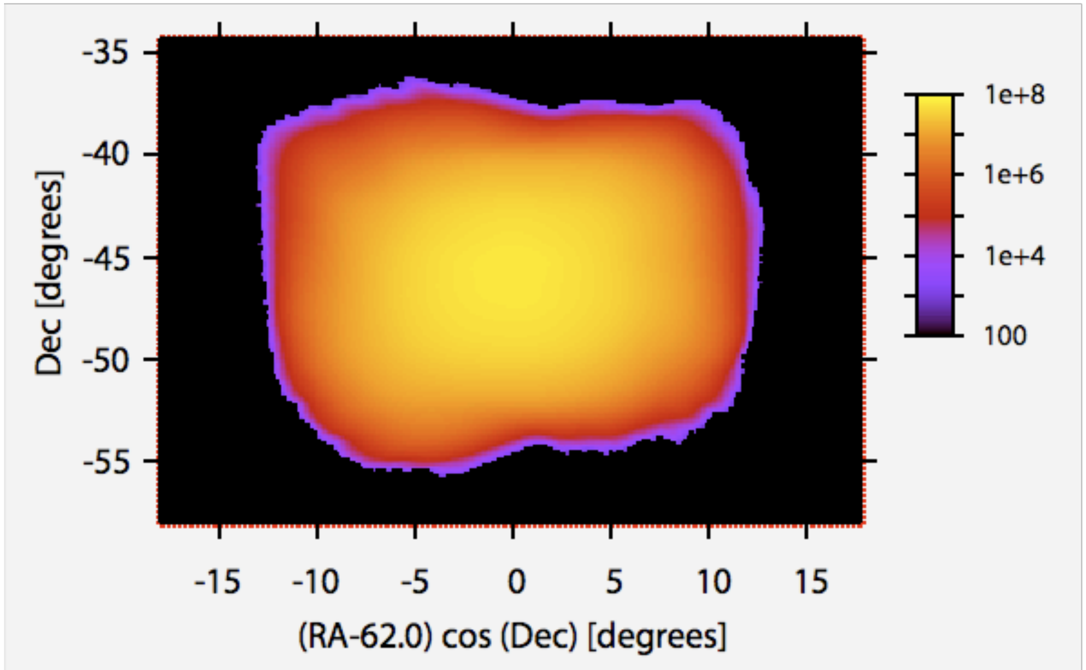






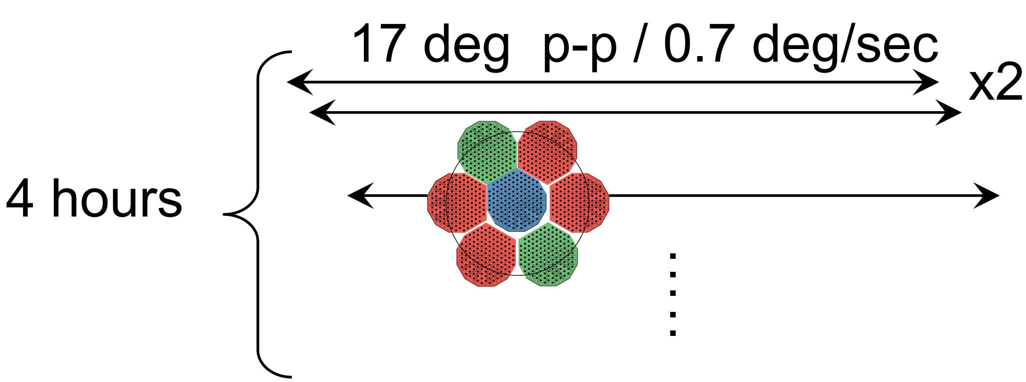
- LDB: 495 Watt for x12; 406 Watt for x16

Scan



(sample/beam in color scale)

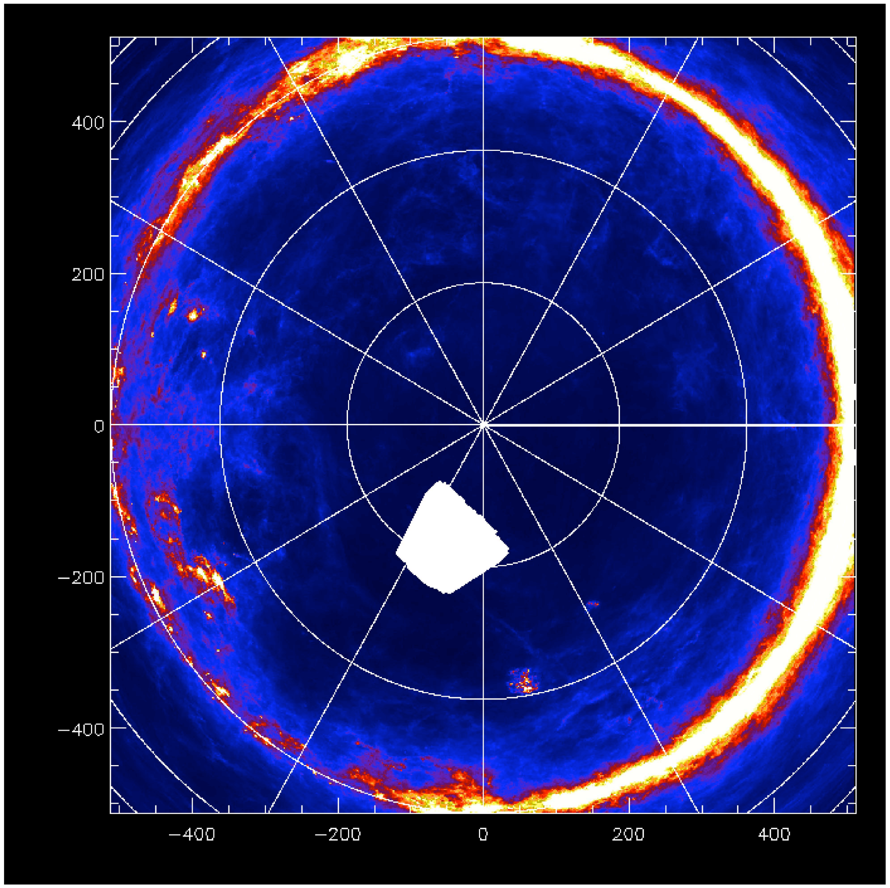
- Constant Elevation
- Speed: ~5 Q,U per beam
- Multiple visitations per pixel
- Relatively uniform coverage (designed to maximize cross-linking)
- Up to 10^8 samples/beam

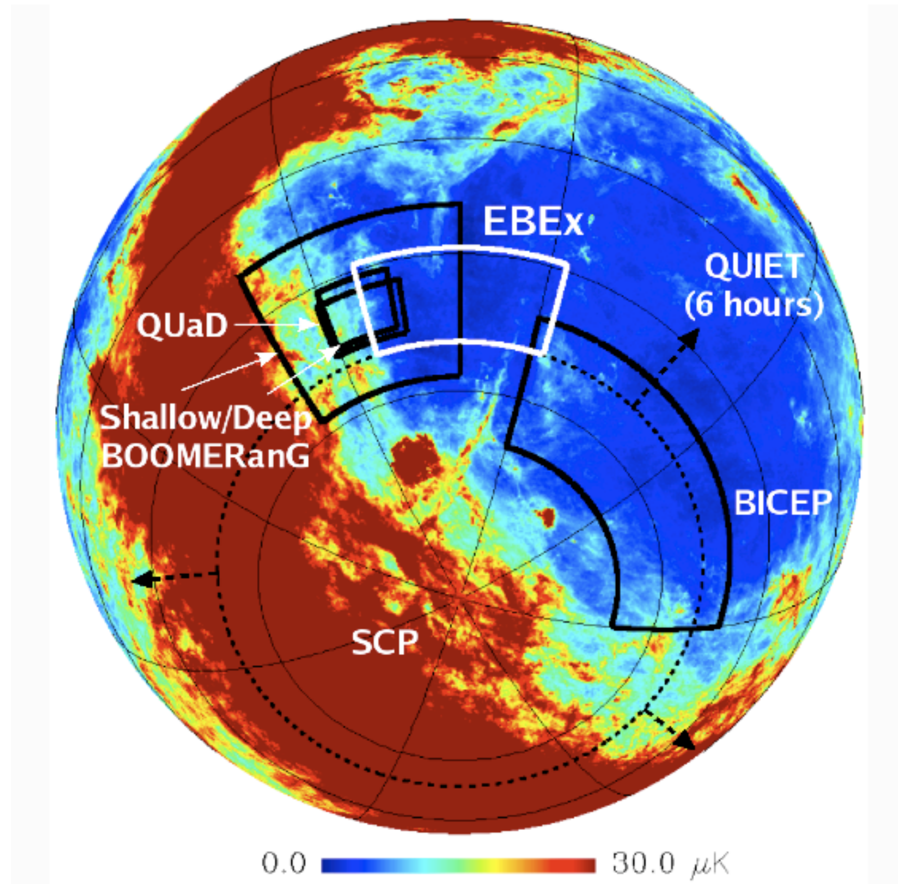


After two scans (~100 sec), elevation is stepped 1/3 FWHM and AZ is adjusted to maintain the same RA

After 4 hours, repeats with each starting elevation adjusted to match initial declination

Sky Coverage





- 14 day flight
- 420 deg^2
- ~24,000 8' pixels
- Low dust contrast (4μK rms)
- 796, 398, 282 TES detectors at 150, 250 ,410 GHz
- 0.7 μK/8' pixel - Q/U; 0.5 μK/8' pixel – T

Experiment Summary

Frequencies	150,250,410	GHz
Angular resolutions	8'	arcmin at each freq
Field centers and sizes	62/-45/420	Ra/Dec/Sq-Deg
Telescope type	Reflecting Gregorian Dragone	Refractor, Gregorian, Compact-range etc
Polarization Modulations	HWP	Waveplate, boresight rot., sky rot., scan etc. – list all that apply
Detector type	TES bolometer	Bolometer, HEMT etc.
Location	LDB Antarctica	
Instrument NEQ/U	$5\mu Ks^{1/2}$	$\mu K\ s^{1/2}$ for both Q *and* U
Observation start date	2010/2011	
Planned observing time	~14	Elapsed/effective days
Projected limit on *r*	0.02*	

* No foreground removal or systematics mitigation (however, see below on dust subtraction)

Calibration

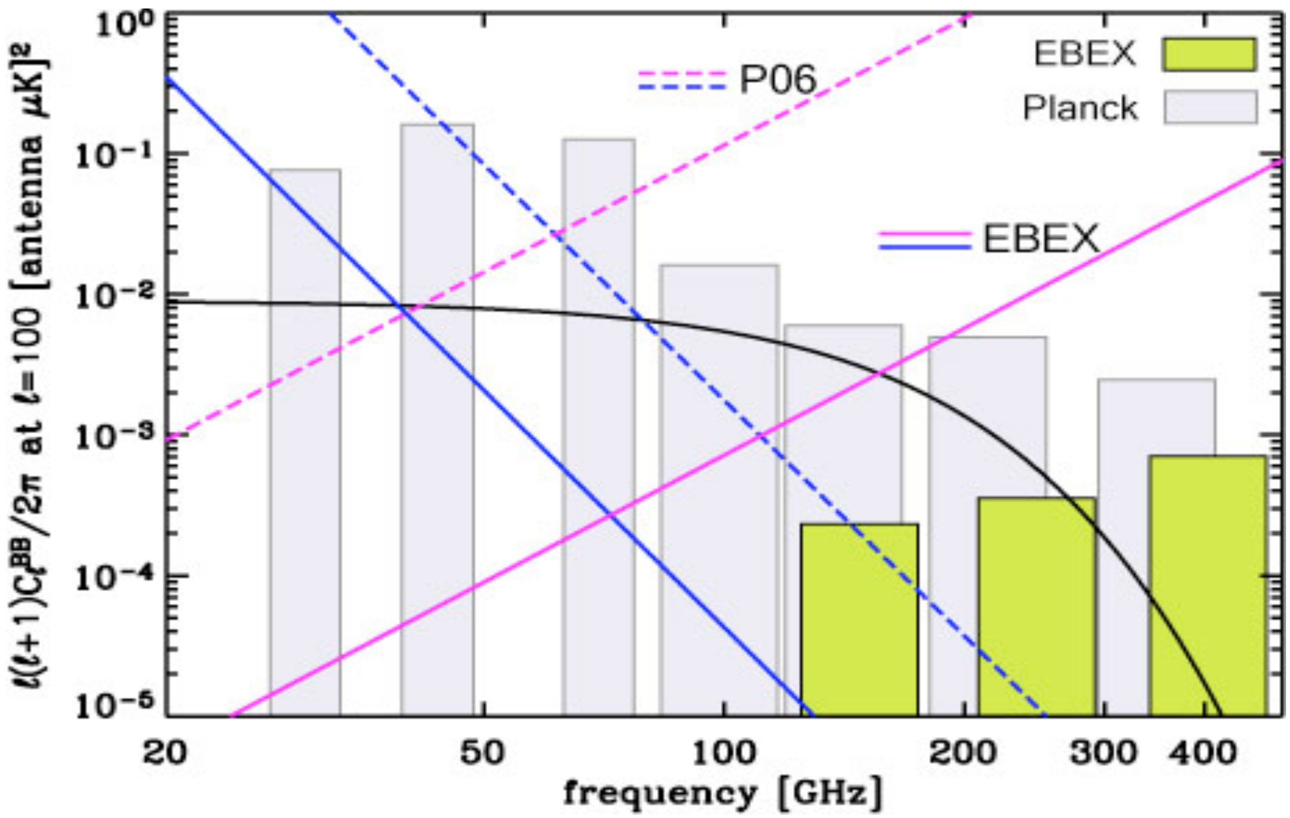
Absolute Calibration (better than 5%): WMAP temperature maps. Internal stable source

Main Beam and Near Sidelobes: Jupiter scans (visible roughly 7 hours/day and on average > 50 degrees away from the sun)

Polarization Modulation Efficiency (>90%) and polarization rotation (to ~0.1^o): "Artificial Planet" – blackbody source with a wire-grid polarizer at the focus of a 1 m parabolic mirror

Polarized Spectral Response: Ebert-Fastie Monochomator with resolving power $\lambda/\Delta\lambda=50$ in mm-wave band so 10 measurements across each frequency band

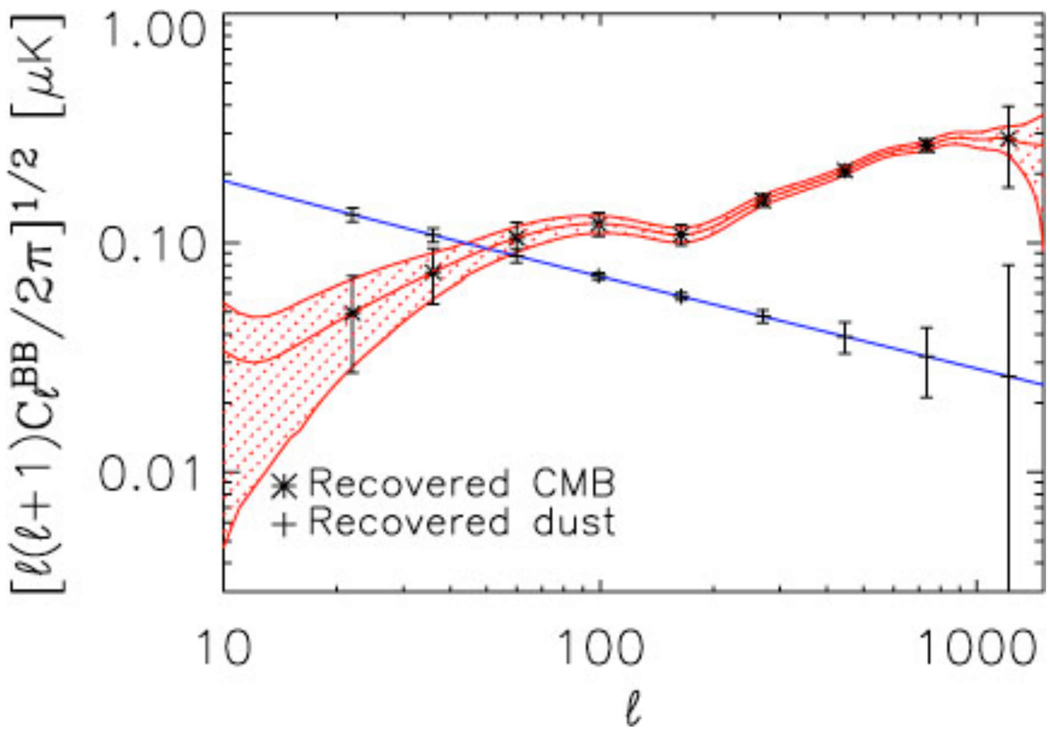
Dust Determination



Galactic Dust (solid – EBEX region, dotted – outside WMAP's P06 mask)
Synchrotron (solid – EBEX region, dotted – outside WMAP's P06 mask)
CMB B-mode

Note: at l=100, In antenna temperature
EBEX and Planck histograms account for both sky coverage and noise/pixel

Dust Subtraction



- Construct a dust map in EBEX region, add CMB E and B, instrument noise
- Apply dust cleaning algorithm and estimate E, B, and dust power spectra

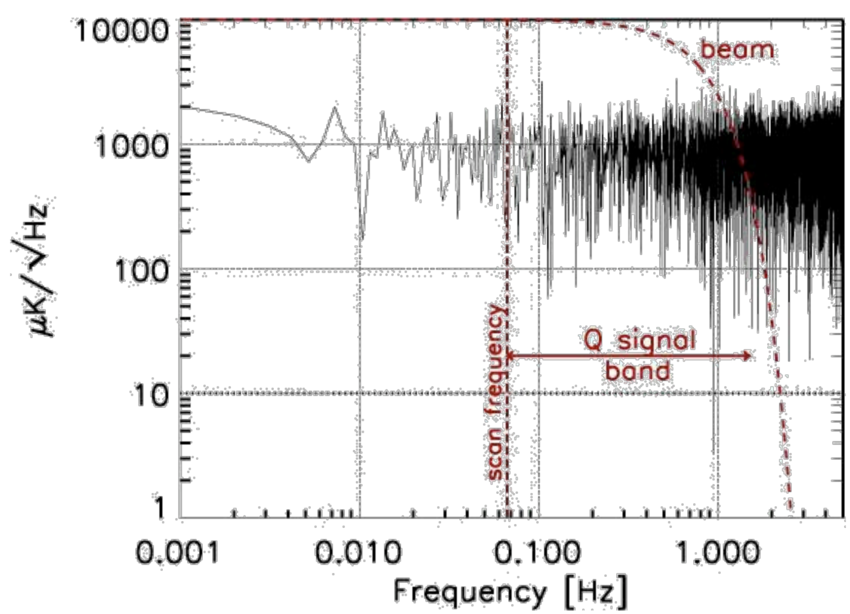
- Red = instrument noise + sample variance
- Blue = B-mode power spectrum of input dust map
- Black dust = errors of reconstruction
- Black CMB = variance of 10 simulations
- excludes systematic uncertainties

Systematic Error Mitigation

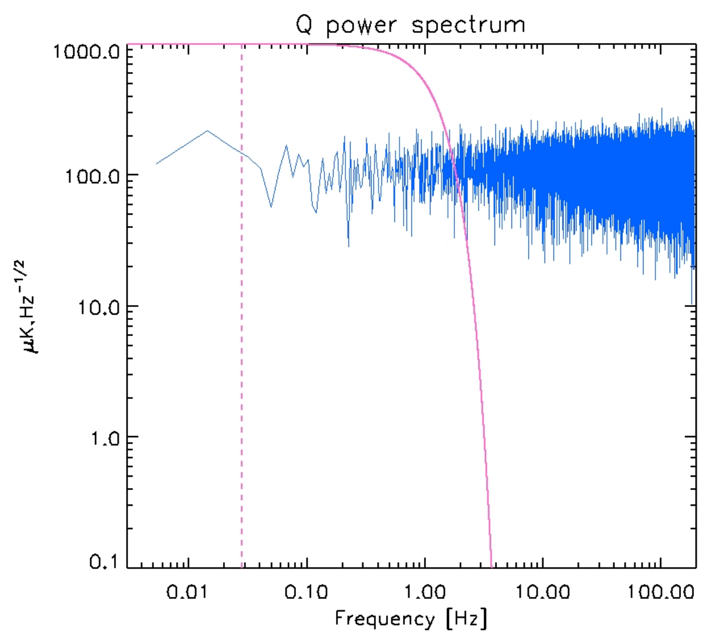
Continuously Rotating Half Wave Plate (HWP) Polarization Modulator

- Independent measurements of Q, U, T with each detector on each pixel on the sky (no differencing between different detectors)
- signals reside in well-defined sidebands of 4 x HWP modulation frequency (much higher than the ~0.1 Hz TES 1/f knee)
- Instrumental polarization from elements on the detector side of the HWP are not modulated so don't affect sky signals
- Instrumental polarization from elements on the sky side of the HWP (stable on scan timescales) can be high-pass filtered (~0.02 Hz corresponding to 50 Hz scan frequency) our of the data stream

MAXIPOL Q Power Spectrum (measurement)



EBEX Q Power Spectrum (simulation)



Systematic Requirements

EBEX design goals based on keeping the contamination from systematic effects controlled to less than the signal expected from T/S=0.004
(5 times less than the 2 sigma upper limit of $r < 0.02$)

Effect	Size	Strategy
Polarization rotation E→ B	0.3°	Ground-based cal: ~0.1° absolute, 0.03° relative In-flight Check: Two detectors same E,B → rel. rot 2° E B Cross-correlation = 0 → overall rotation to 0.04°
Pointing uncertainty E→ B	9”	Star camera + gyros, multiple revisits/pixel
Instrument Polarization T→ Q, U	0.05%	HWP modulation, calibration and subtraction using T map (WMAP for GW, EBEX for lensing)
Beam Mismatch T→ B	0.2%	HWP rotation: Beam size changes on average < 0.1% across focal plane, signal at $2f_o$
Sidelobes response	85 dB	Measurements at this level been demonstrated

Also: Spatial (power spectrum), temporal (map, power spectum) null tests
Detector-to-detector (map, power specrum) null tests
Consistency with B-mode lensing

The EBEX North America Flight

- Goals:
  - Test the optical system
  - Test daytime operation of all systems at float altitudes
- Took place on June 11th, 2009 from Ft. Sumner, NM
- ~ 10 hours at float
- ~ 115,000 ft.

North America Detector/Polarimetry Configuration

- TES bolometers operating at 150, 250, and 410 GHz (single focal plane, three wafers)
- 220 TES detectors (80 at 15O GHz, 50 at 250 GHz, 80 at 510 GHz) operating at at 0.27 K throughout flight
- 48 SQUID amplifiers
- Digital frequency domain multiplexing; muxing factor = x8
- Polarimetry: Rotating HWP (2 Hz), suspended on magnetic bearing

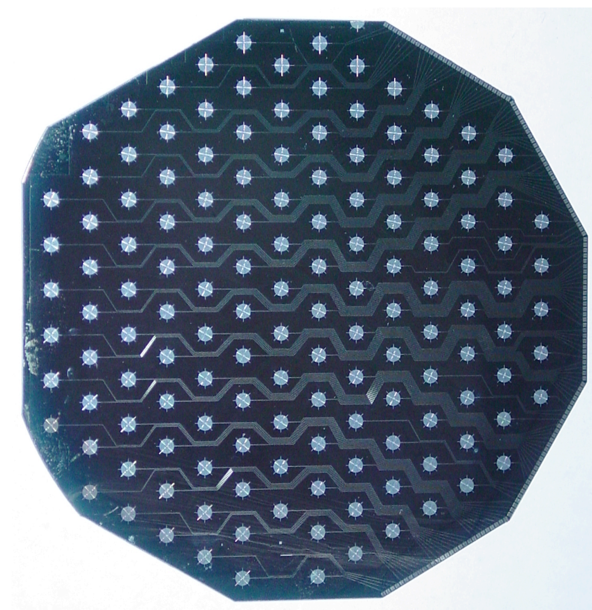



Photo:Dan Polsgrove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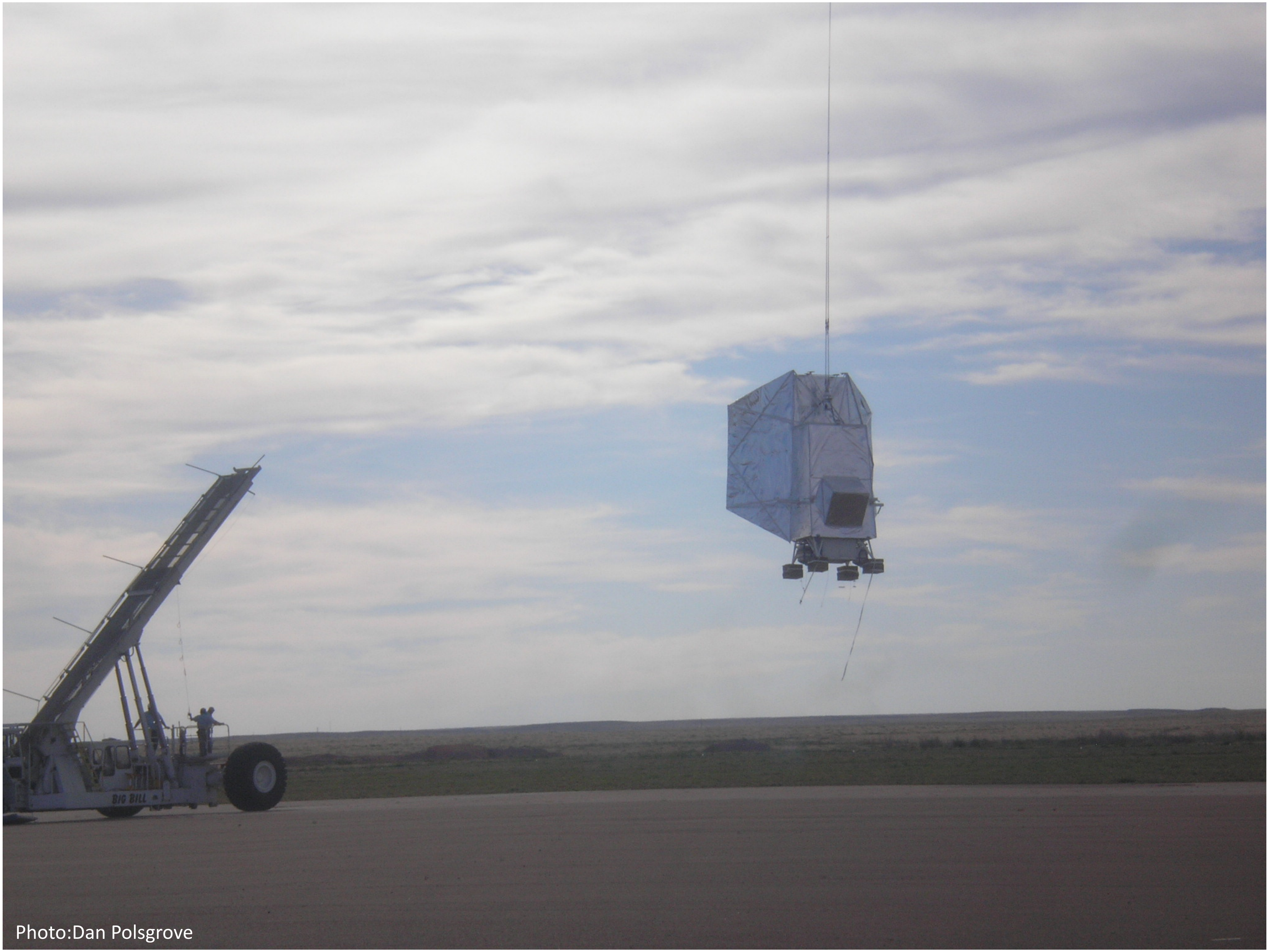
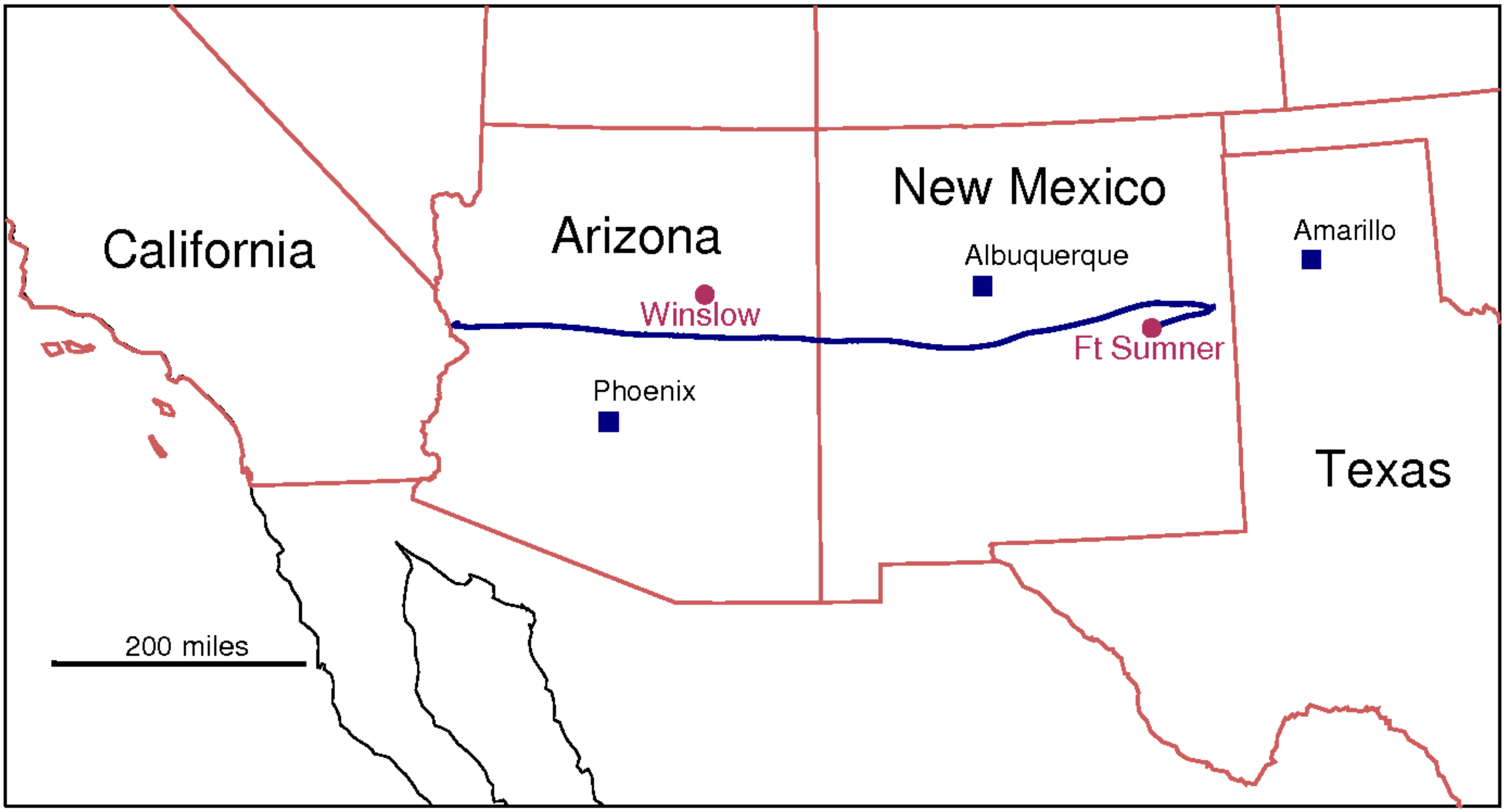


Photo:Dan Polsgrove

EBEX Test Flight, 11th June 2009



10 hours at float
115,000 ft.

EBEX seen by others

Lowell Observatory

Ted Dunham, Lowell Observatory

Phoenix, Arizona

Bright UFO over Phoenix Arizona 11th June 2009

Everyone is emailing me about this!
Did you see the huge bright Ufo over Phoenix Arizona 11th June 2009?
Real Ufos wants to know, please respond to this post your information asap!

Real UFOs The UFO Forum

Preliminary Achievements
Successful Test Flight

- Millimeter-wave TES operated in space-like environment for the first time
- Detectors + readout system tuned end-to-end in flight
- Detectors operated in the transition
- Cryogenics functioned maintaining detectors at 0.27K
- Half wave plate rotating during entire flight
- Temperatures of all systems maintained within operating range
- Attitude Control System functional
- Telemetry maintained throughout flight
- Scans performed

- Experiment has been recovered, sent back to Minnesota (cryostat) and Columbia (gondola/ACS)
- Data is being analyzed
- Working toward LDB…

Summary – Status and Plans

- Successful North American flight completed spring 2009
- Currently preparing for 2010-2011 Antarctic LDB flight
- 796, 398, 282 TES detectors at 150, 250 ,410 GHz (1476 total)
- ~24,000 8' pixels over 420 deg^2
- 0.7 μK/8' pixel - Q/U;
  0.5 μK/8' pixel – T