SPIDER

Probing Inflation with a Balloon-Borne Polarimetric Survey of the Southern Sky

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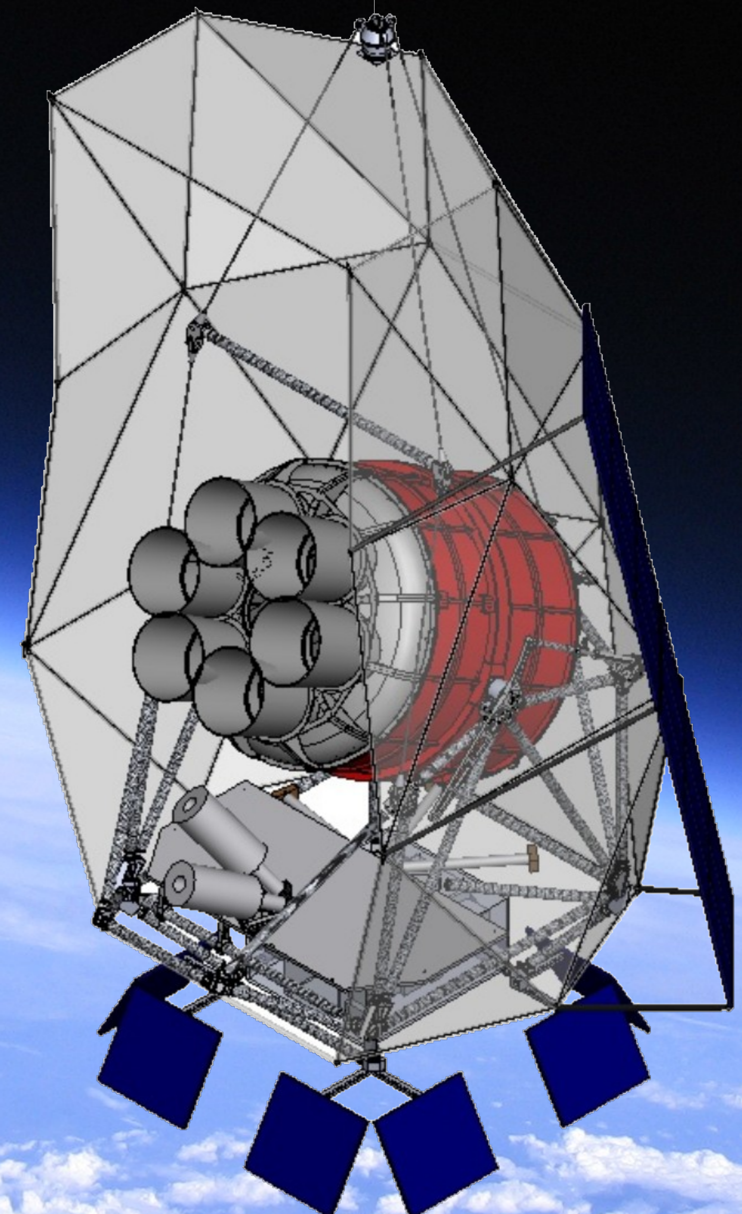
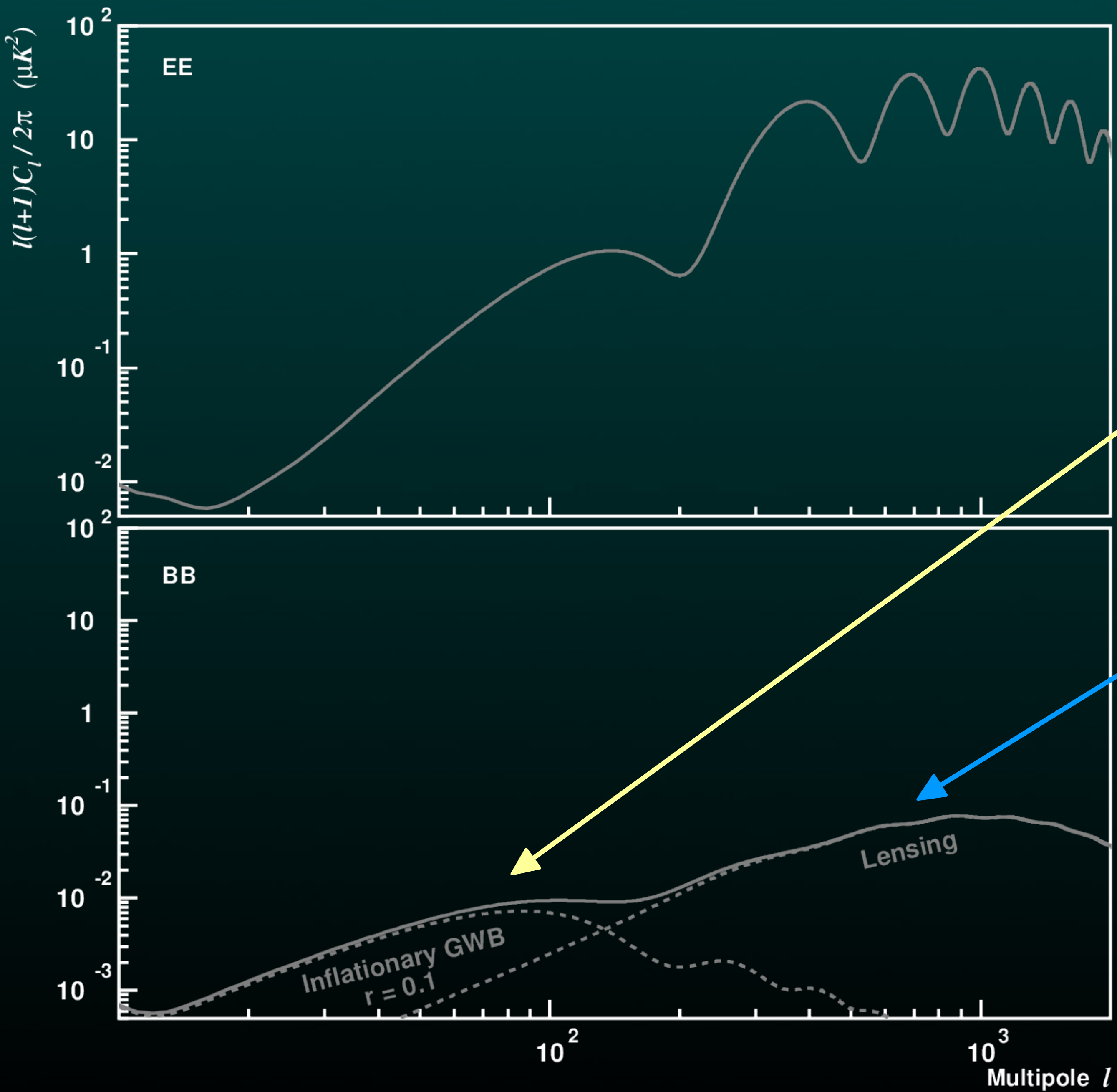


CMB polarization power spectra

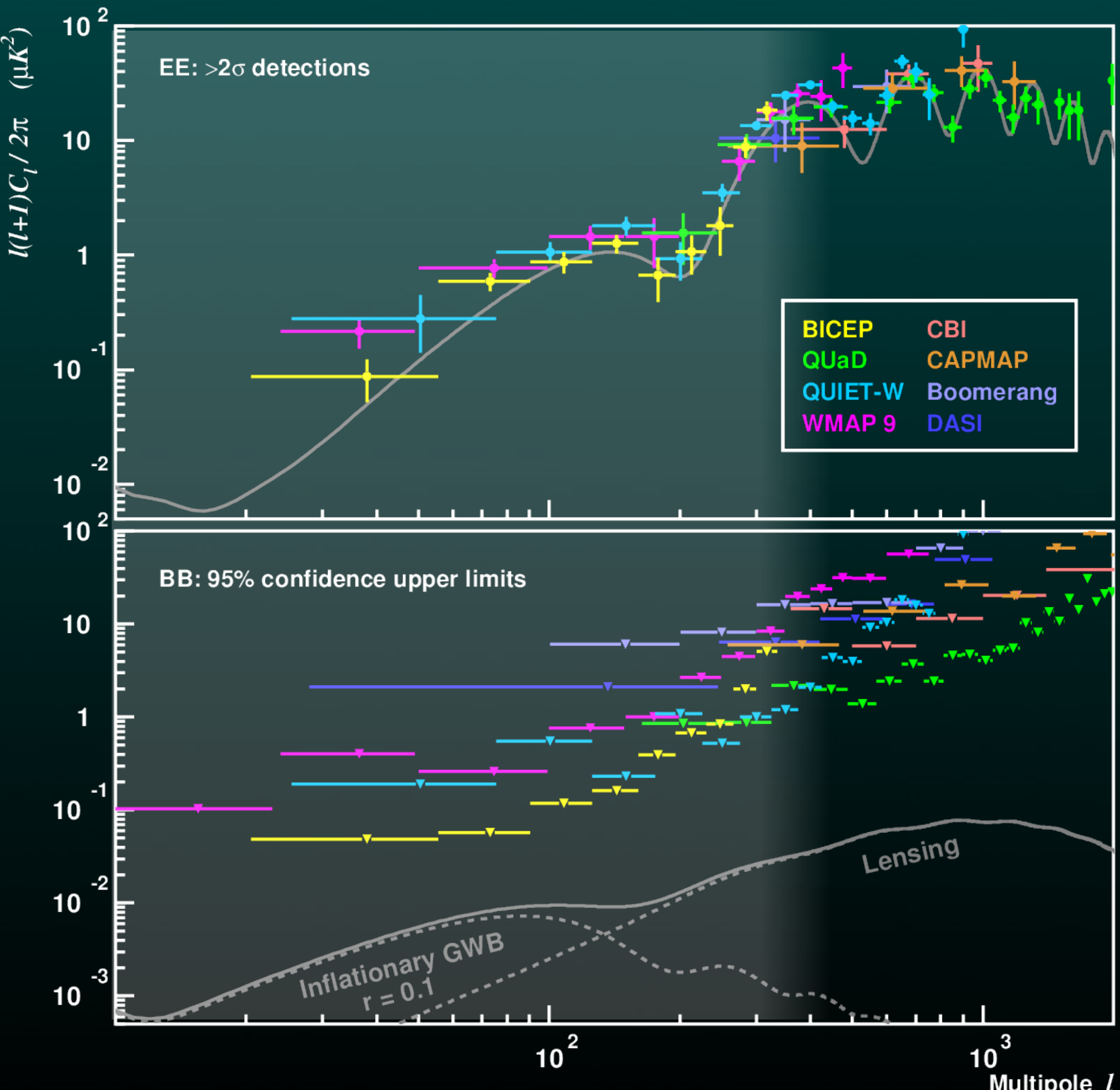


B-mode polarization from gravitational waves, amplitude ~ tensor-to-scalar ratio *r*. Current upper limit is $r < 0.1$, set mainly by TT data.

B-mode polarization from weak gravitational lensing by large-scale structure, partial conversion of E-modes

Both flavors of B-mode polarization are much fainter than E-mode, no detections yet.

Current CMB polarization measurements



E-mode polarization measured with high precision: acoustic peaks have been detected and are consistent with LCDM

B-mode polarization: most stringent upper limits correspond to $r < 0.72$, no lensing detection yet

SPIDER is optimized to target the inflationary BB bump at ell ~ 100

SPIDER: a new instrument for CMB polarimetry

SPIDER science goals

Constrain inflationary B-modes to $r < 0.03$ at 3σ

Characterize polarized foregrounds

Instrumental approach

Need high sensitivity, fidelity

Long duration balloon platform (2 flights, 20+ days each)

0.5 deg resolution over 8% of the sky, target 10 < ell < 300

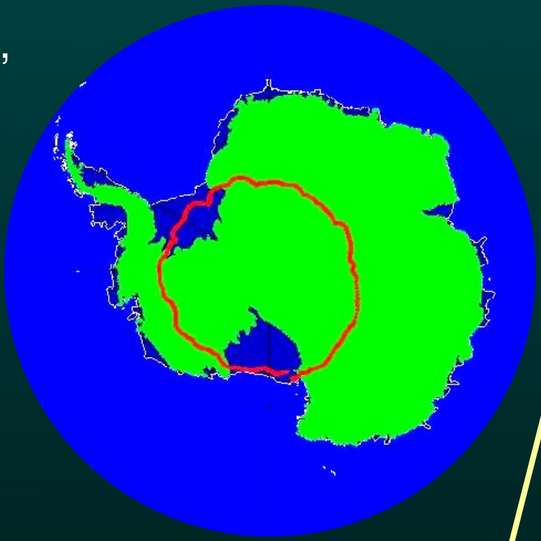
6 compact, monochromatic refractors in LHe cryostat

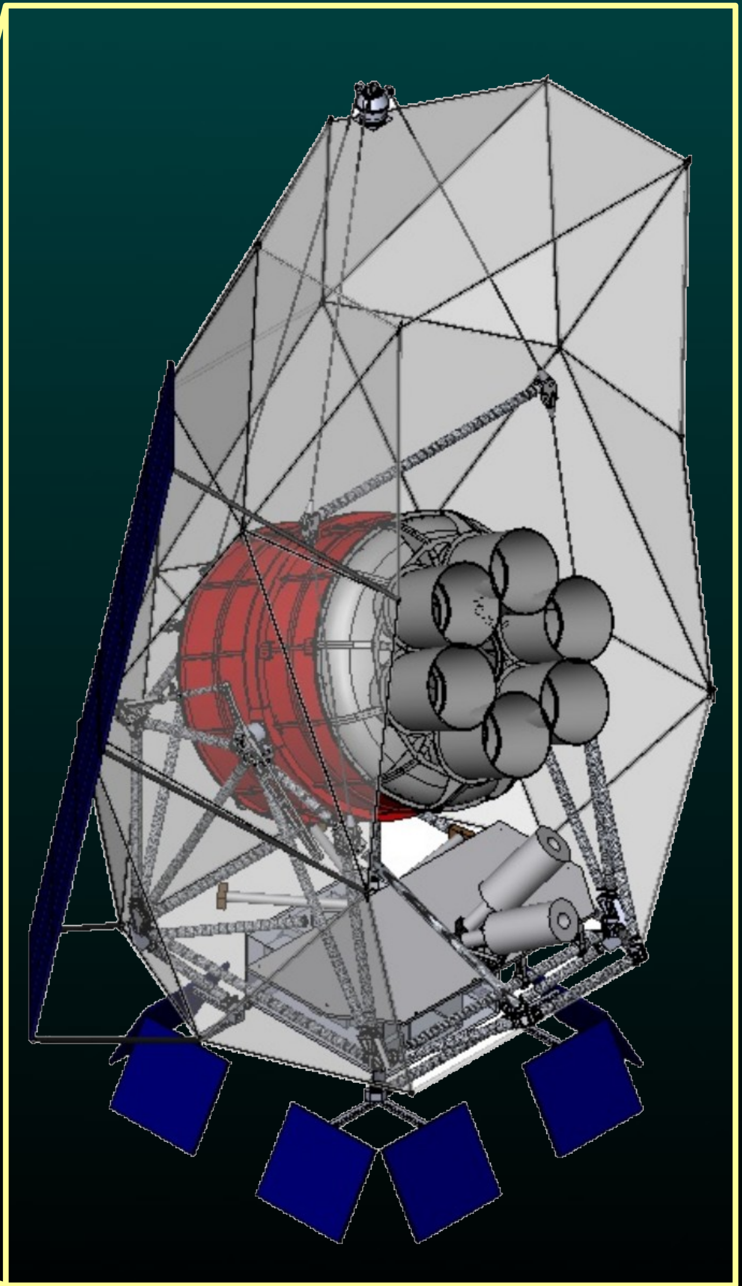
Polarization modulation: HWPs

2600 detectors split between 90,150, 280 GHz

Antarctic long-duration ballooning

- Launch from McMurdo station, circumnavigate continent in ~2 weeks
- Float altitude: 40 km
  Volume: 1 million m^3
  Max payload weight: 3600 kg
- More info: BLAST the movie, EBEX launch on youtube





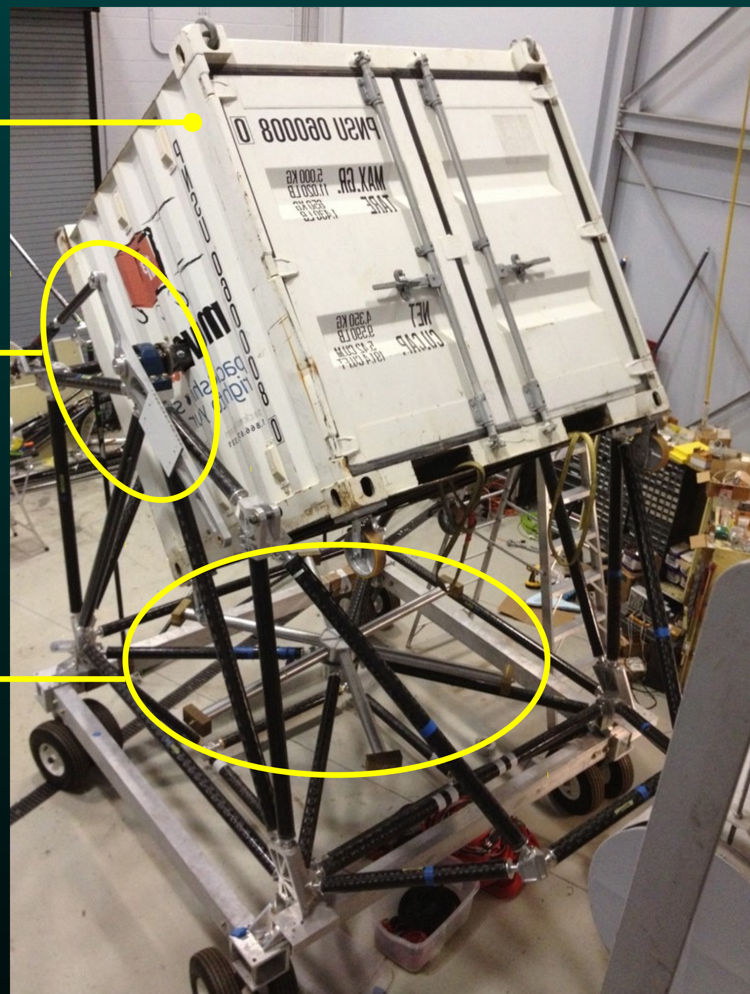
Carbon fiber gondola

Inner frame supports the cryostat

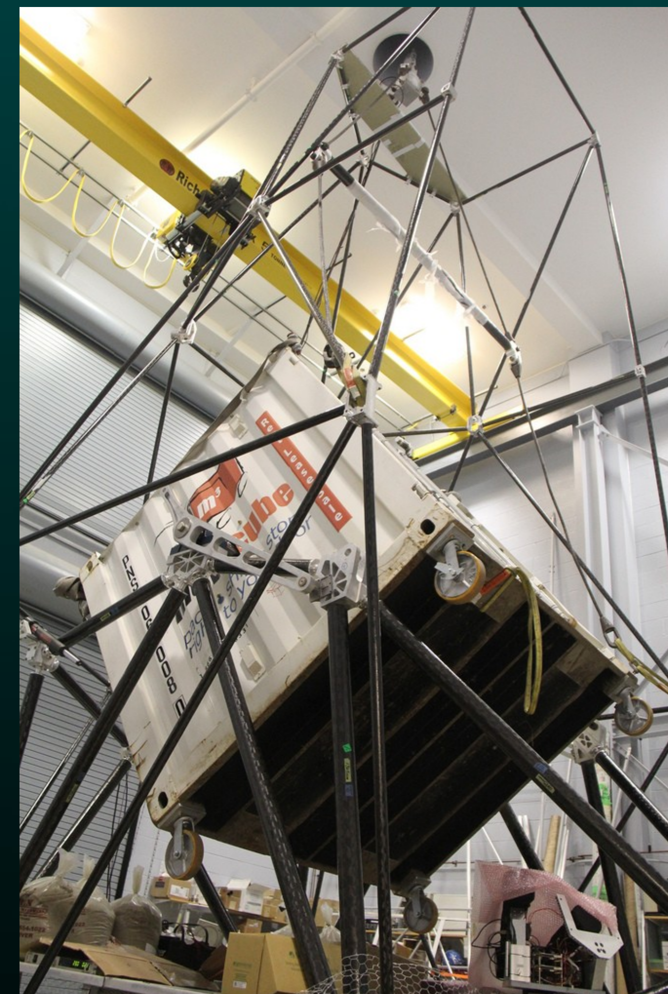
Cryostat mass proxy

Linear actuator elevation drive

Reaction wheel for azimuth scanning

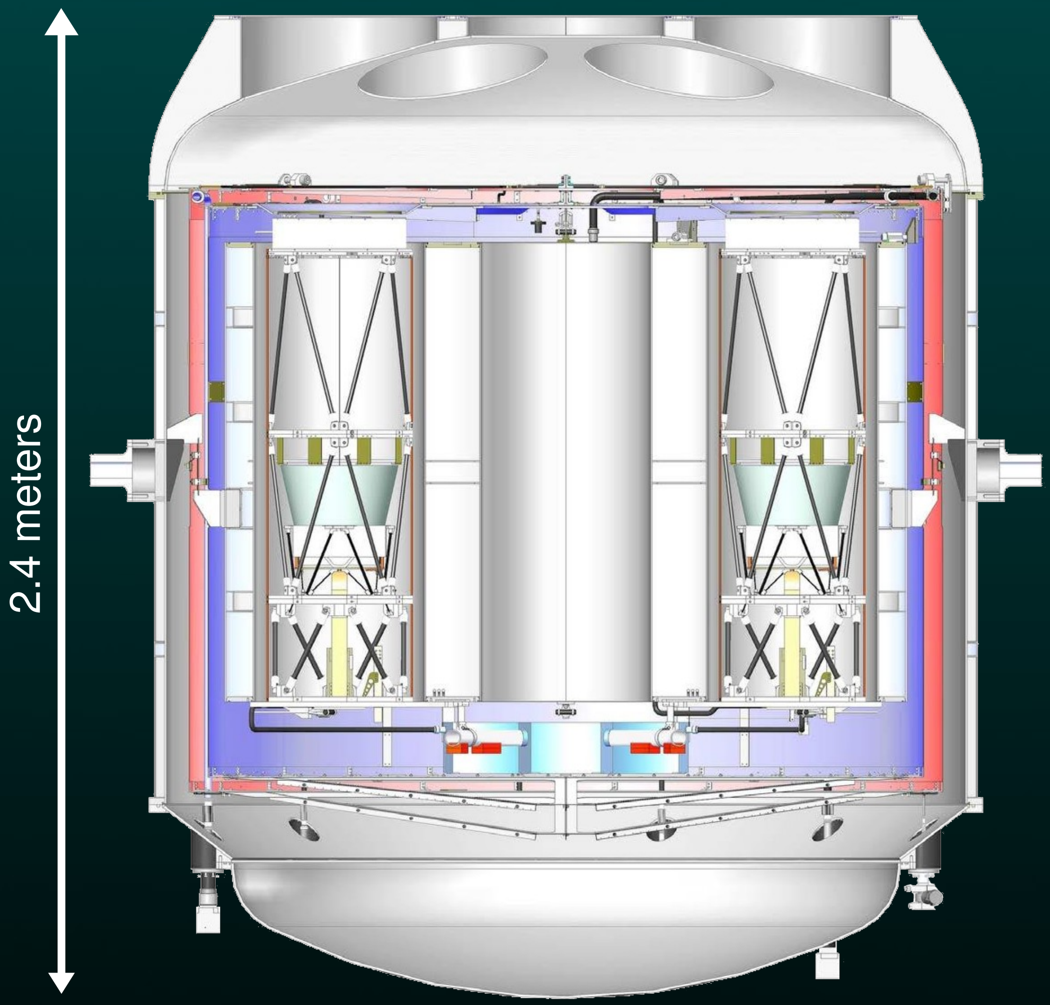


Outer frame for sun shields



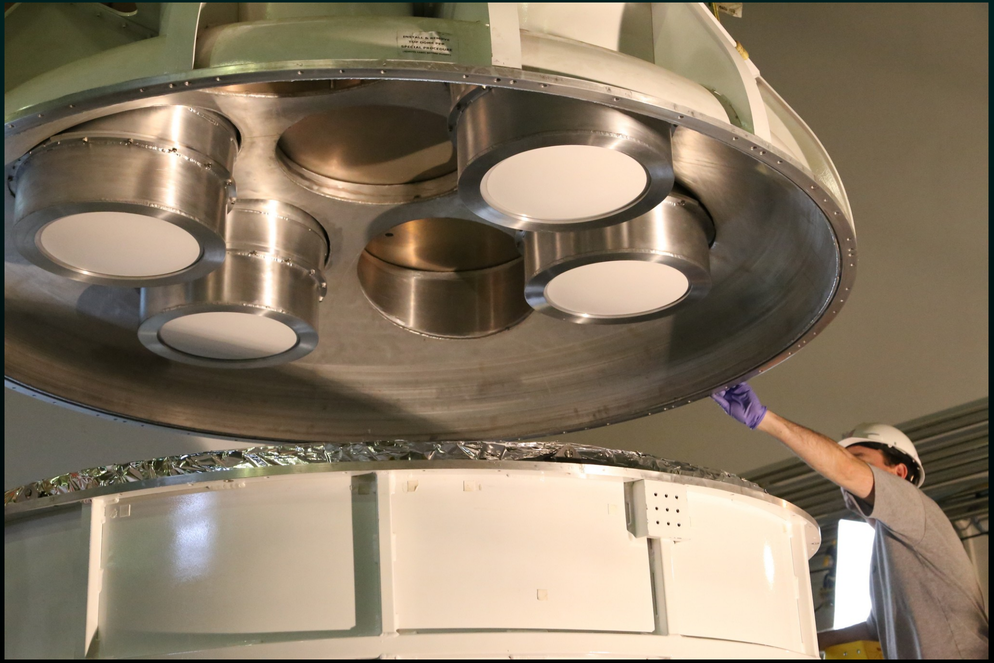
- Gondola design is derived from BLAST: carbon fiber provides high strength and low mass
- Pointing information from star cameras, rate gyroscopes, differential GPS, sun sensors

Flight cryostat



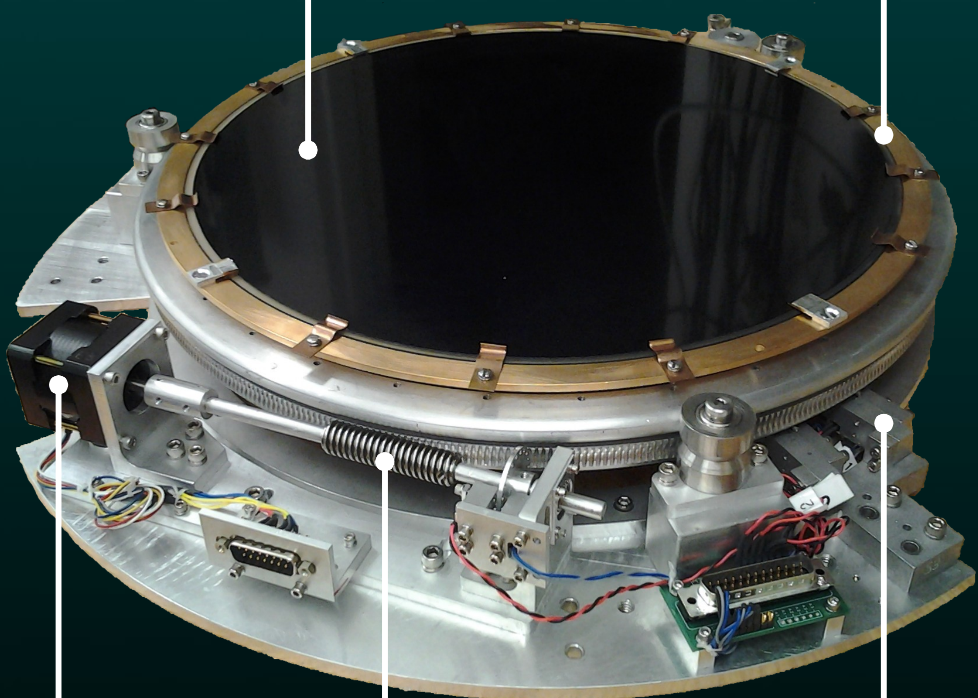
- Main tank: 1200 liters LHe, 4K
- Capillary-fed superfluid tank: 16 liters LHe, 1.4K
- Two vapor cooled shields, 30K and 150K
- Dry weight: 850 kg
- Hold time: 20+ days

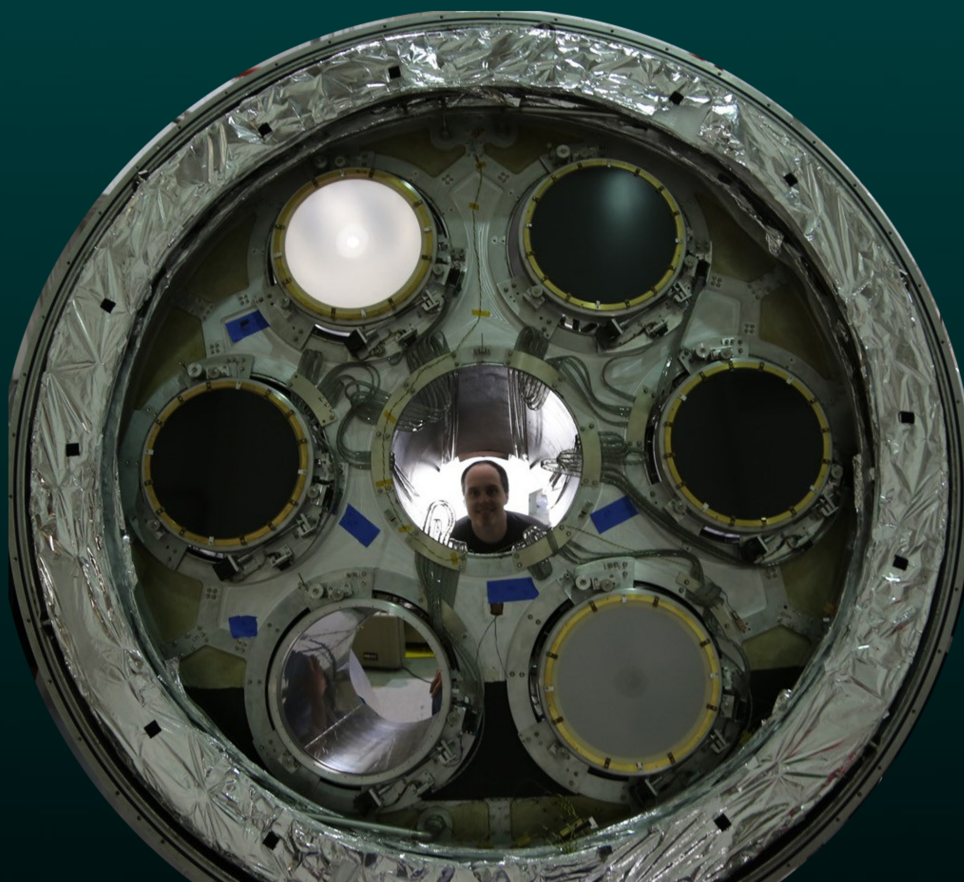
Windows and baffles



- UHMWPE windows, AR coated with porex
- <0.5% loss, less scattering than zotefoam
- Window “buckets” extend into the vacuum space and serve as part of the baffle
- External baffles are mounted to the window buckets, accordion section reduces far sidelobe response

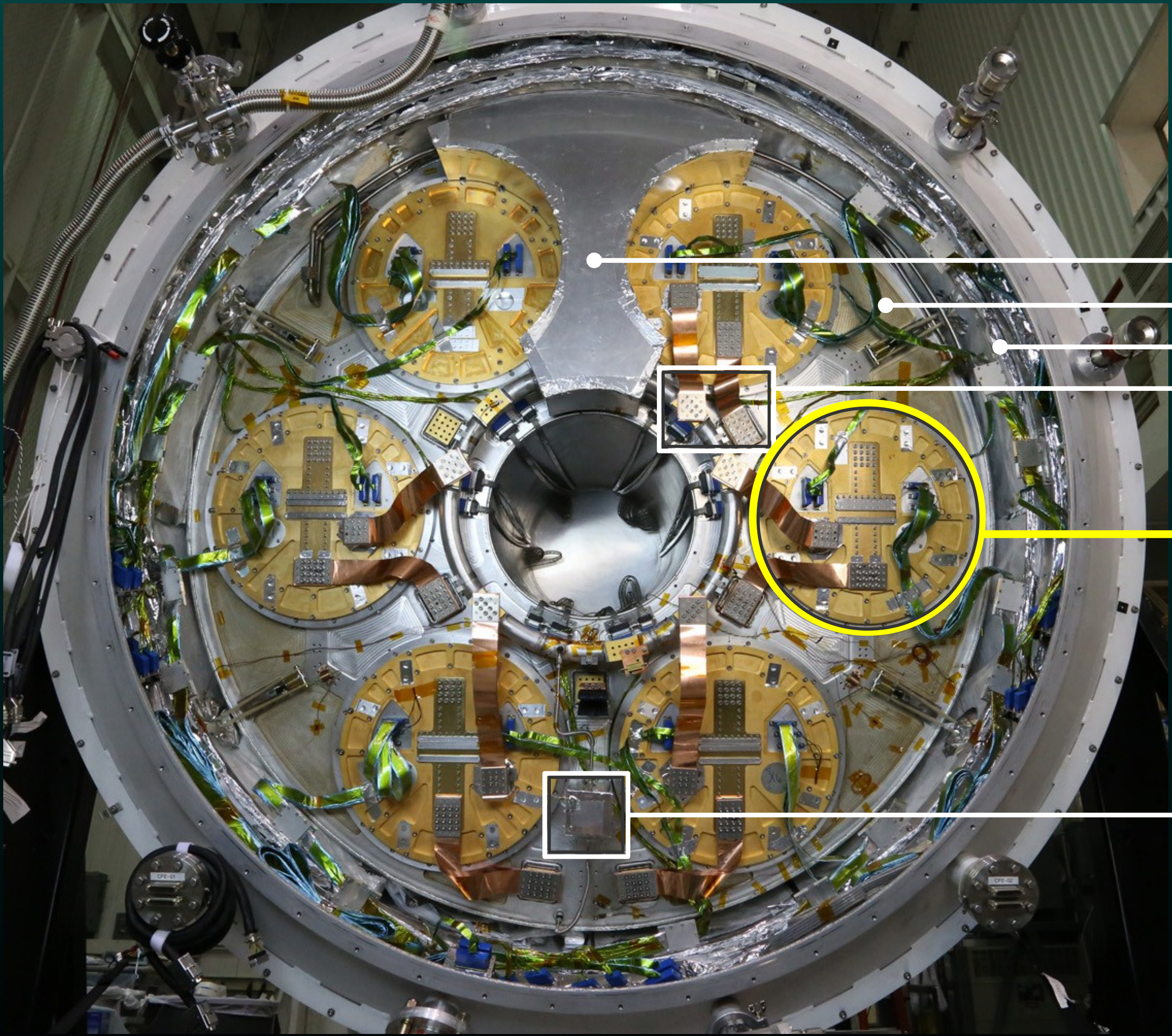
Waveplates





Five waveplates currently installed and cold in Palestine!

SPIDER's six telescopes

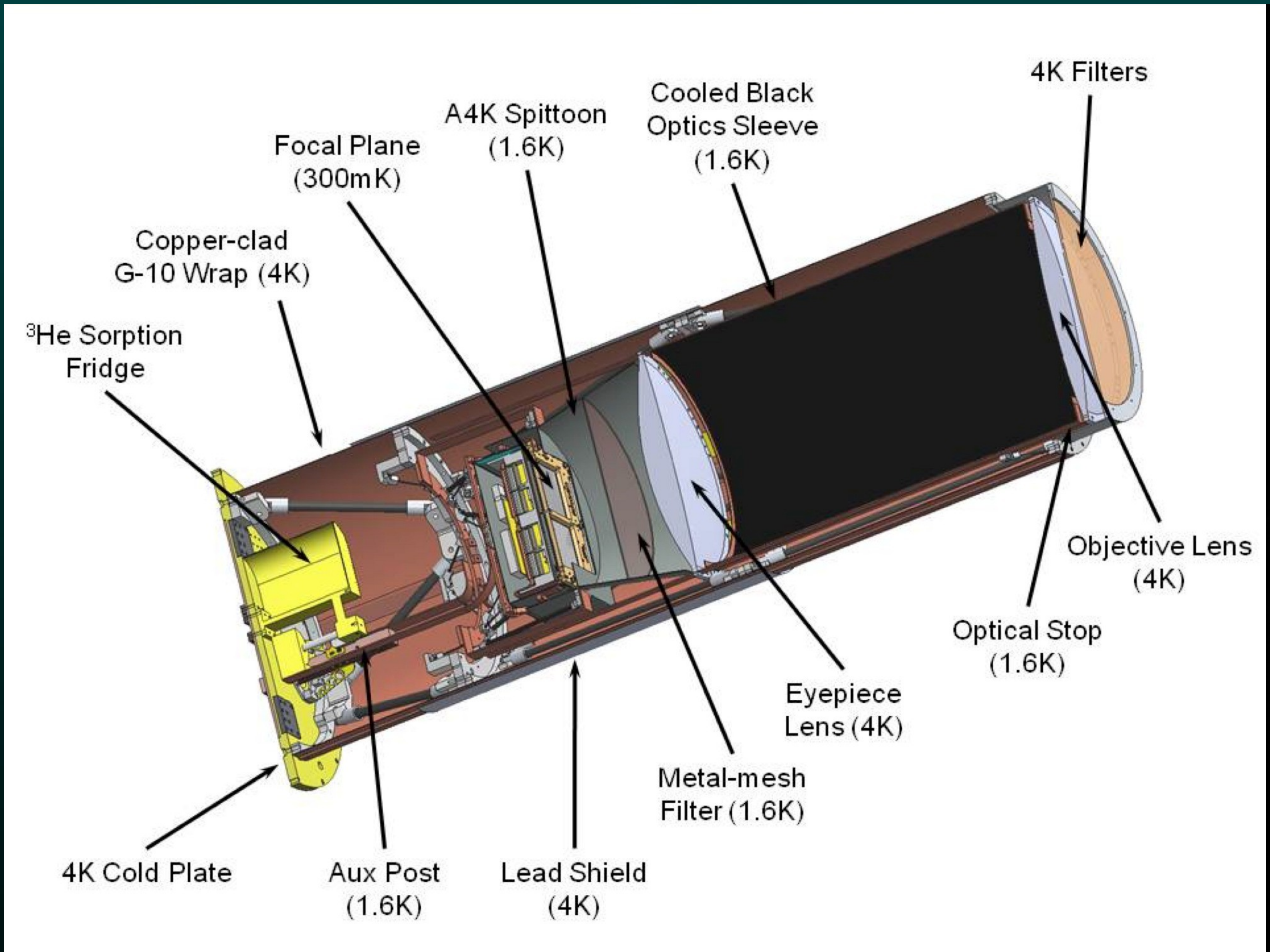


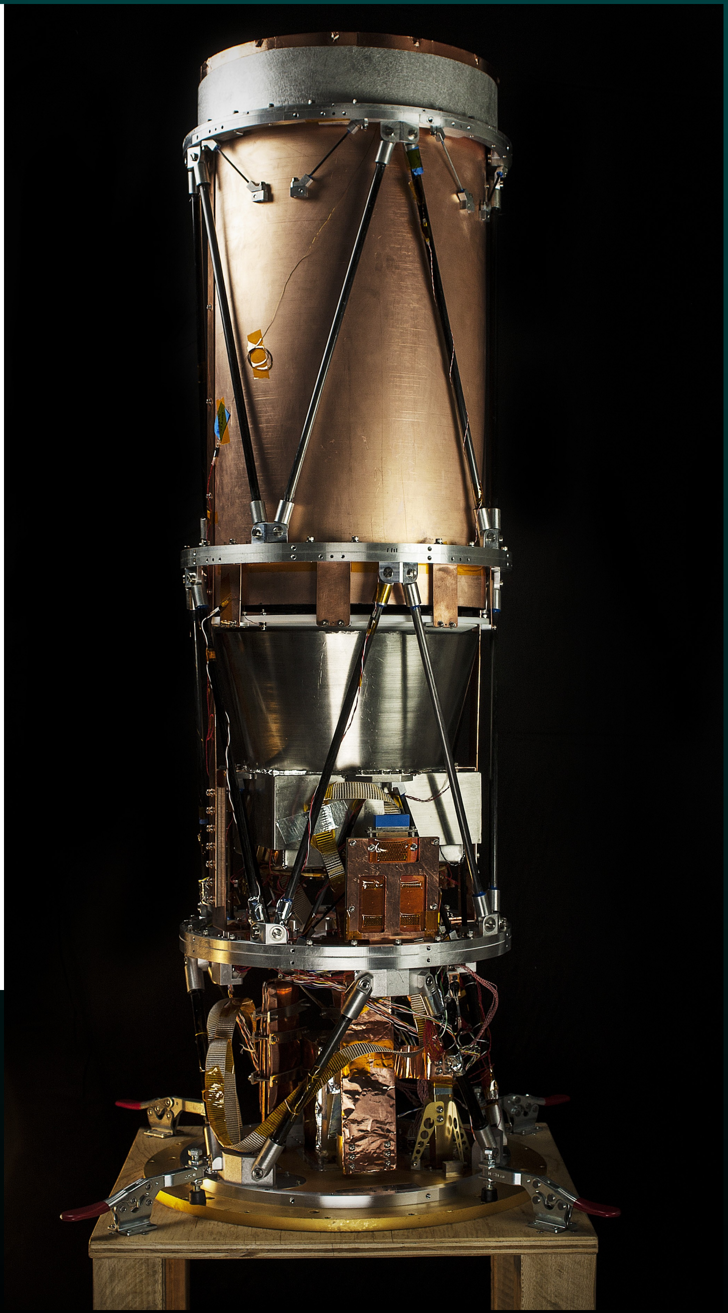
Superfluid tank
Main tank
Vapor cooled shields
Thermal contact pads

Six independent, monochromatic telescopes: 3 each at 90 and 150 GHz

Capillary system

Instrument insert

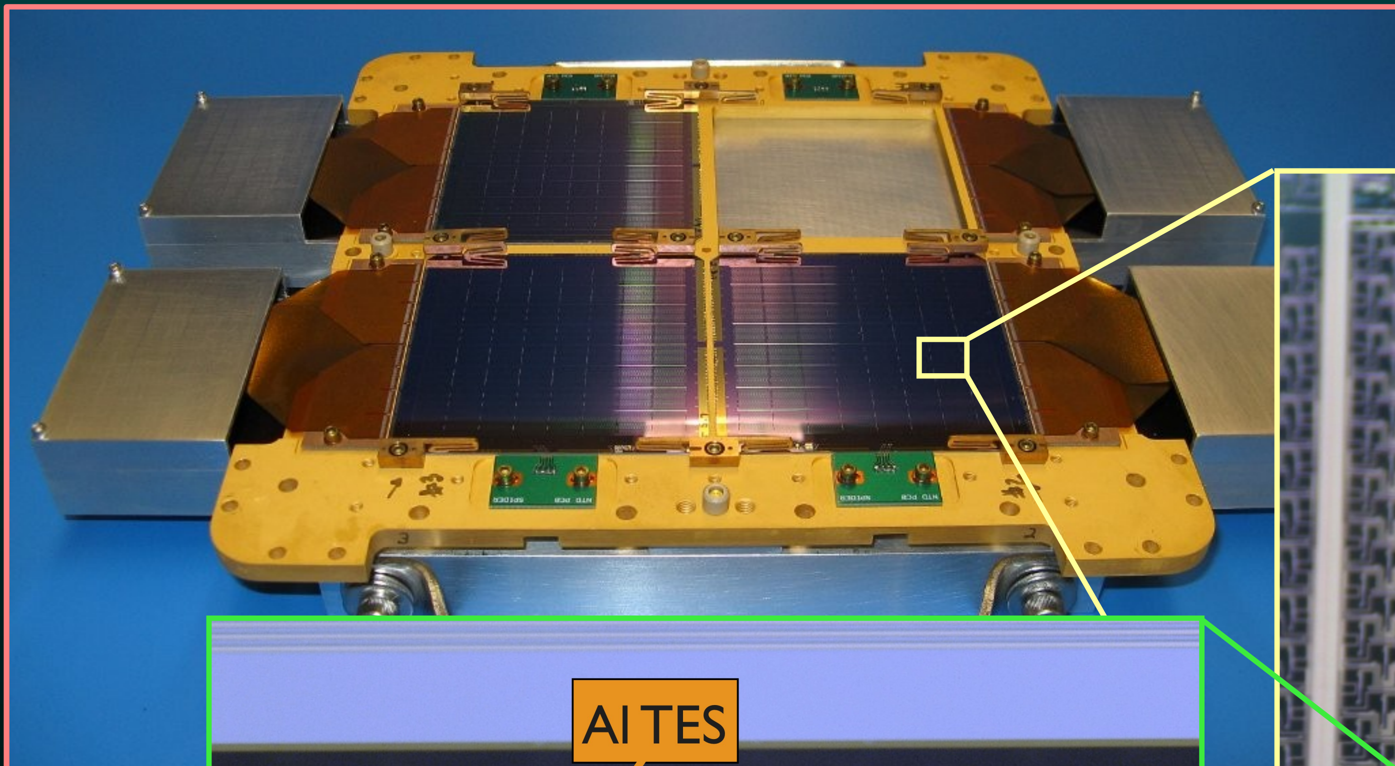


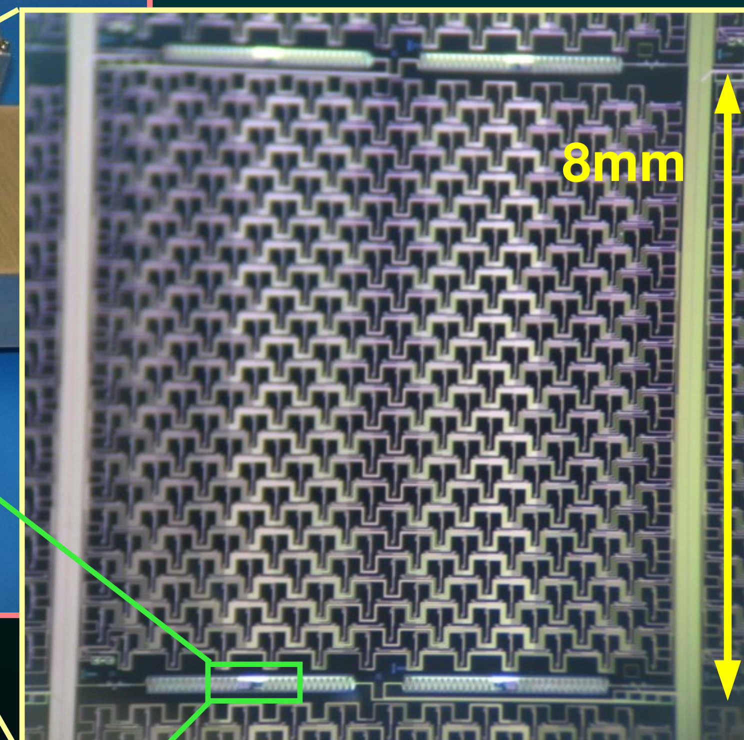


- Each insert tuned for a single frequency band
- 90 lbs each: lightweighting + stiff carbon fiber truss
- Two-lens optical design (based on BICEP)
- Extensive efforts to optimize magnetic shielding

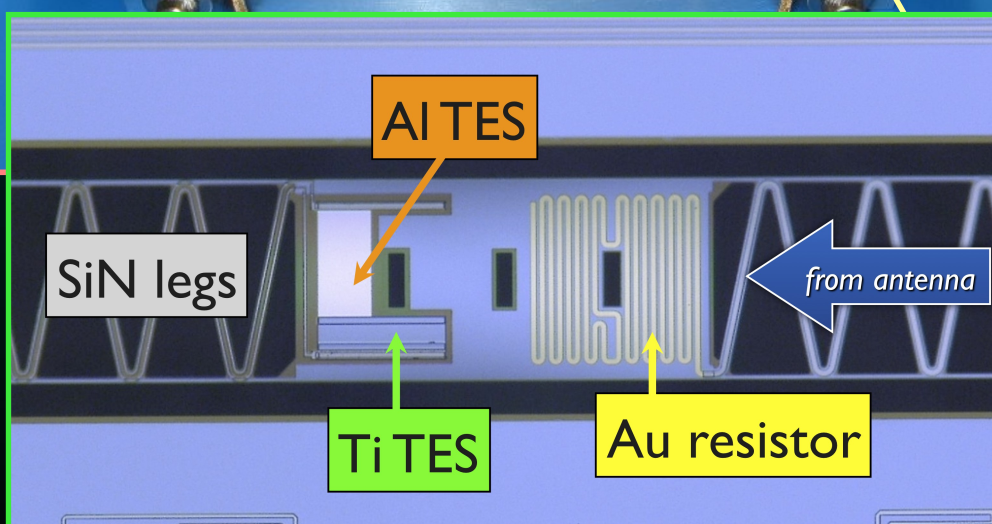
Focal plane: antenna-coupled TES bolometers

Each focal plane: 4 tiles x 64 pixels x 2 polarizations = 512 detectors





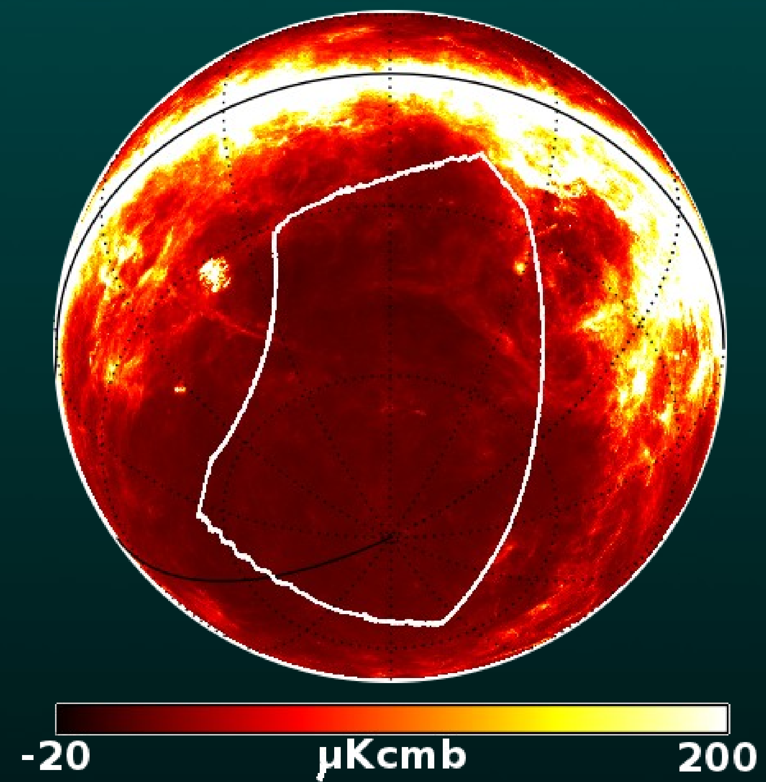
Each spatial pixel:
Two orthogonal antenna arrays
16 x 16 dipole slot antennas



Detectors: Al / Ti TES bolometers

SPIDER flight plan

- SPIDER will map 8% of the sky in an exceptionally clean region (encompasses the “southern hole”)
- First flight: 90 GHz and 150 GHz to maximize sensitivity for a B-mode detection
- Second flight: assuming that we see something in the first flight (could be foregrounds), expand frequency coverage to characterize the signal



Flight date	Focal plane and detector distribution			Cumulative noise, μK/deg^2		
	90 GHz	150 GHz	280 GHz	90 GHz	150 GHz	280 GHz
Dec 2013	3 x FPs = 864	3 x FPs = 1536	–	0.27	0.20	–
Dec 2014?	2 x FPs = 576	2 x FPs = 1024	2 x FPs = 1024	0.21	0.16	0.62

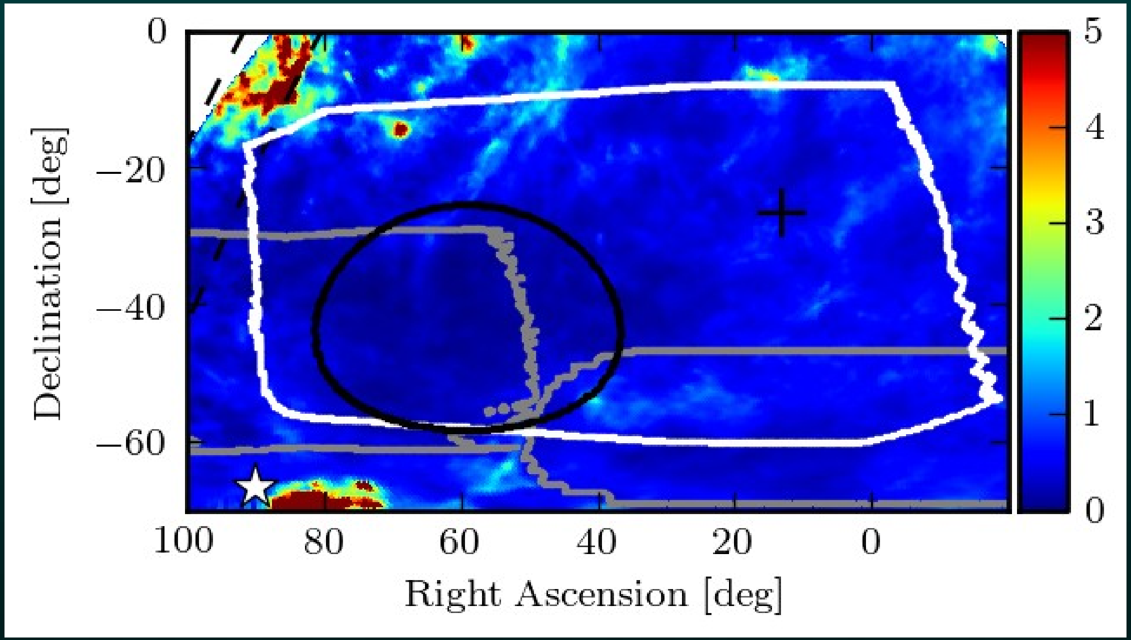
Potential instrument systematics

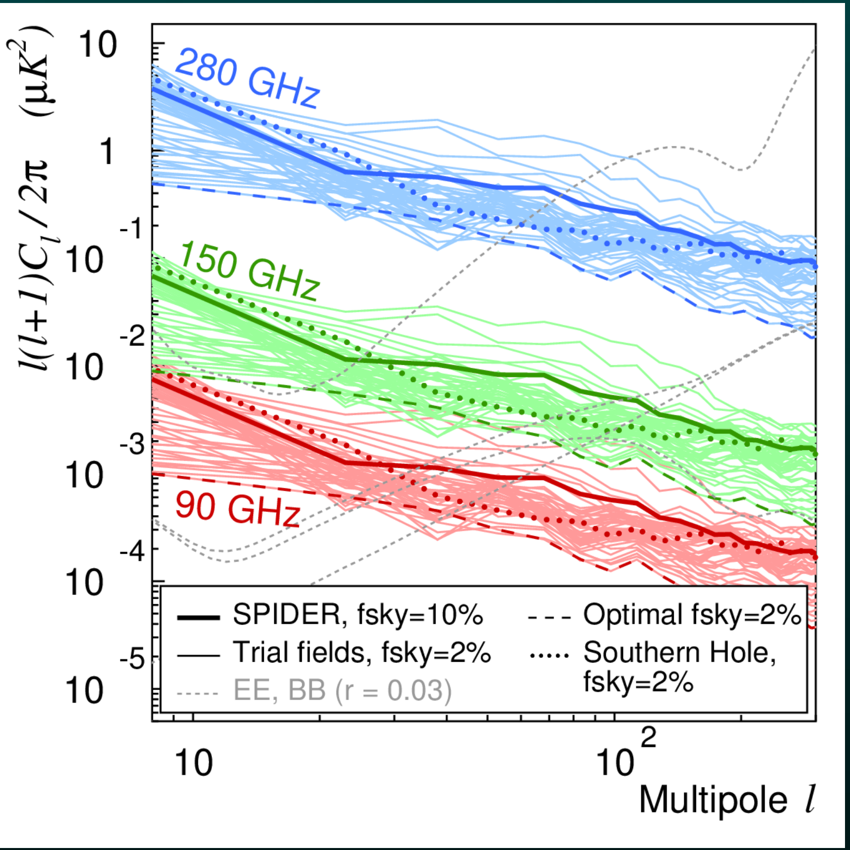
- Uncertainties in calibration quantities can leak T, E into B
- Define $r = 0.03$ benchmark for systematics: false BB < 0.002 μK^2 at ell ~ 100
- Use signal simulations to calculate false BB from systematic errors
- Instrument characterization is still work in progress, but we are cautiously optimistic based on experience with other similar experiments

Instrument property	**Benchmark ($r = 0.03$)**	**Status**
Relative gain uncertainty	0.5%	0.1% in Boomerang
Differential pointing	5%	1% in SPIDER
Differential beam size	0.5%	0.3% in SPIDER
Differential ellipticity	0.6%	0.15% in BICEP2
Absolute polarization angle	1°	0.7° in BICEP
Relative polarization angle	1°	0.1° in BICEP
Telescope pointing uncertainty	10 arcmin	2.4 arcmin in Boomerang
Beam centroid uncertainty	1.2 arcmin	Achieved by BICEP
Polarized sidelobes (150 GHz)	-17 dBi	Achieved by BICEP
Optical ghosting	-17 dB	Achieved by BICEP2
HWP differential transmission	0.7%	Achieved by SPIDER
Magnetic shielding at focal plane	10 $\mu K/B_e$	Achieved by SPIDER

Galactic foregrounds

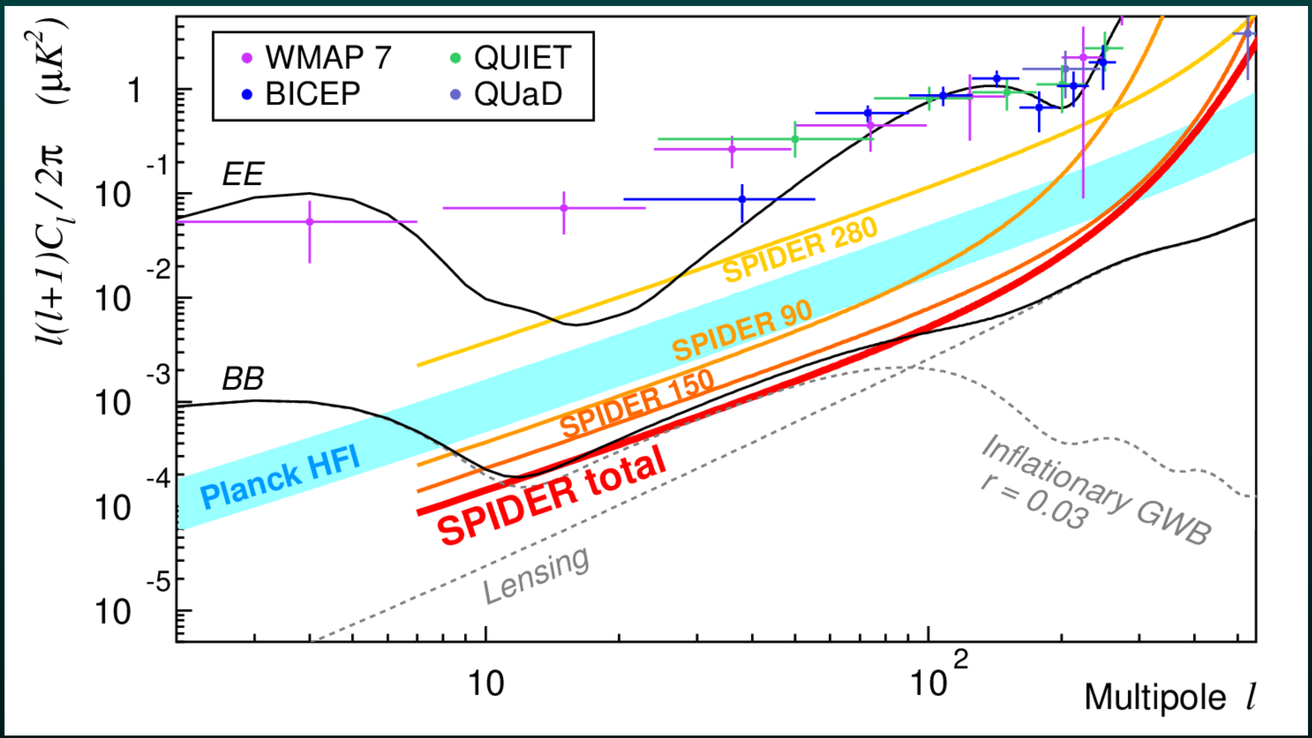
Polarization amplitude from dust model (μK)

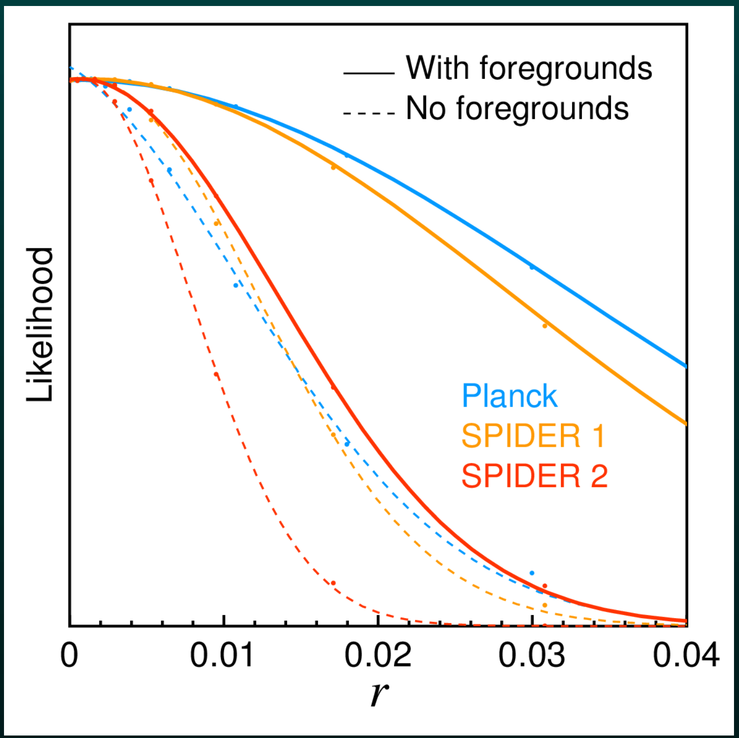




- Polarized emission from Galactic dust is the main source of foreground confusion for SPIDER
- SPIDER will observe one of the cleanest parts of the sky, but foreground models predict that we'll see dust in the first flight. The plan: fly a second time and add 280 GHz.
- Models also predict that you can't ignore foregrounds by restricting observations to a smaller, cleaner patch of sky. (But if such a spot exists, SPIDER will find it.)

What will Spider do for you?





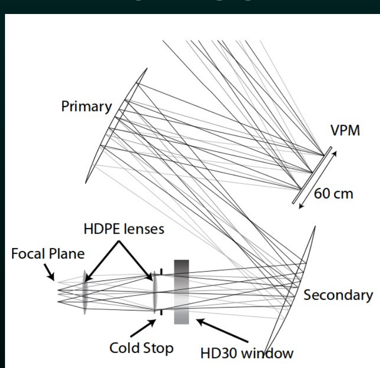
- SPIDER's science goal: ***r* < 0.03 at 3σ**
- Without foregrounds, SPIDER has the raw sensitivity to achieve this goal in one flight
- With foregrounds, we can still achieve this goal with two flights and expanding our frequency coverage to 280 GHz

The extended CMB polarimetry family

(Data yet to be published && Some hardware exists)

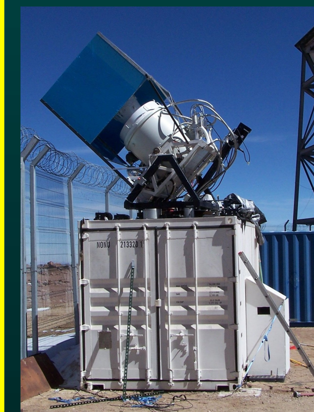
Planck

CLASS

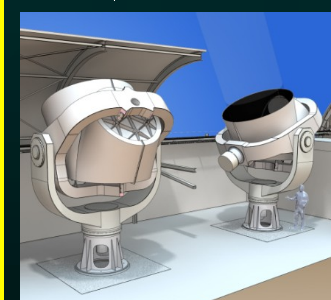


Large angular scales

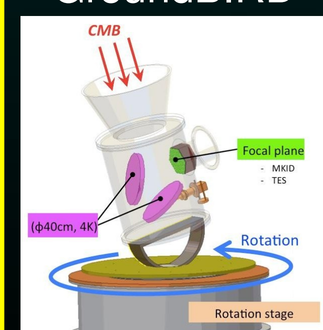
ABS



QUIJOTE

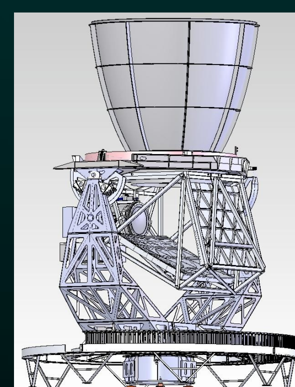


GroundBIRD

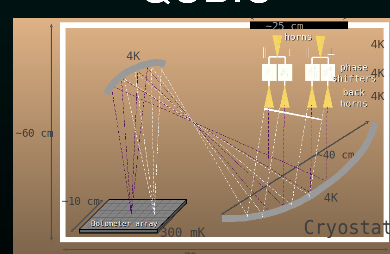


BICEP2/Keck

POLAR-1

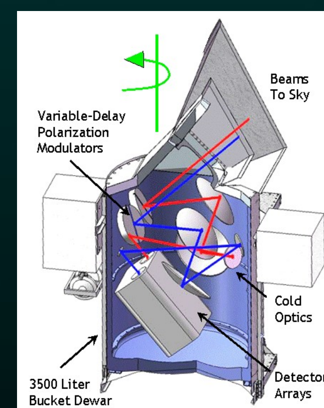


QUBIC



SPIDER

PIPER



Medium angular scales

EBEX

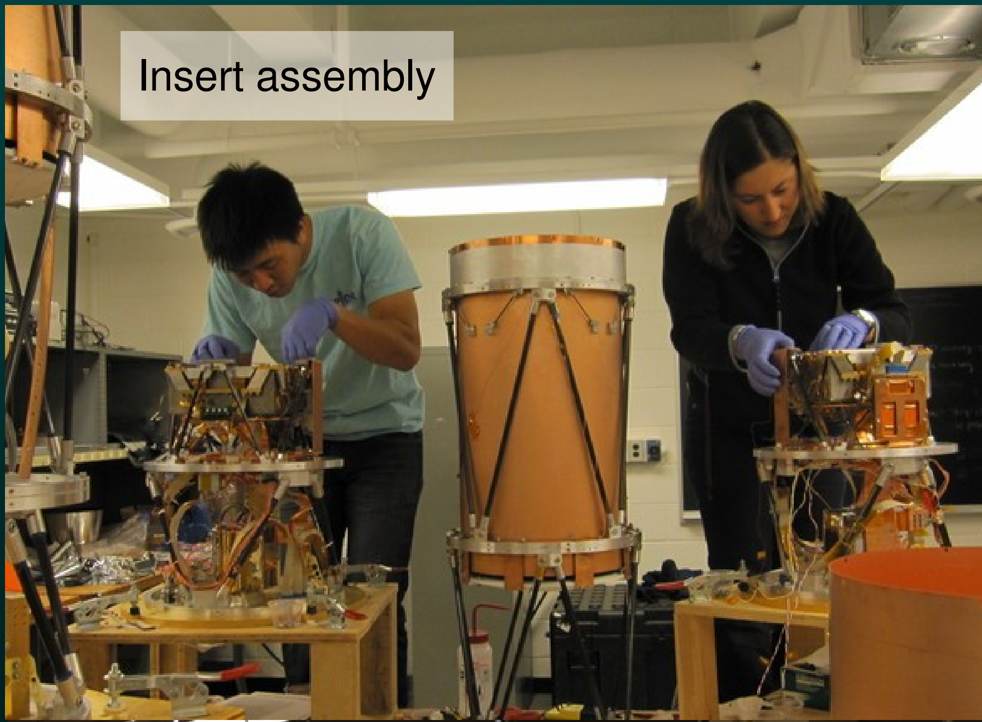
Polarbear

ACTpol

SPTpol

Small angular scales

SPIDER status: counting down to a December flight!


Insert assembly


LDB cryostat on the gondola


Team SPIDER owns the machine shop!


Preparing for cooldown

Greetings from Palestine