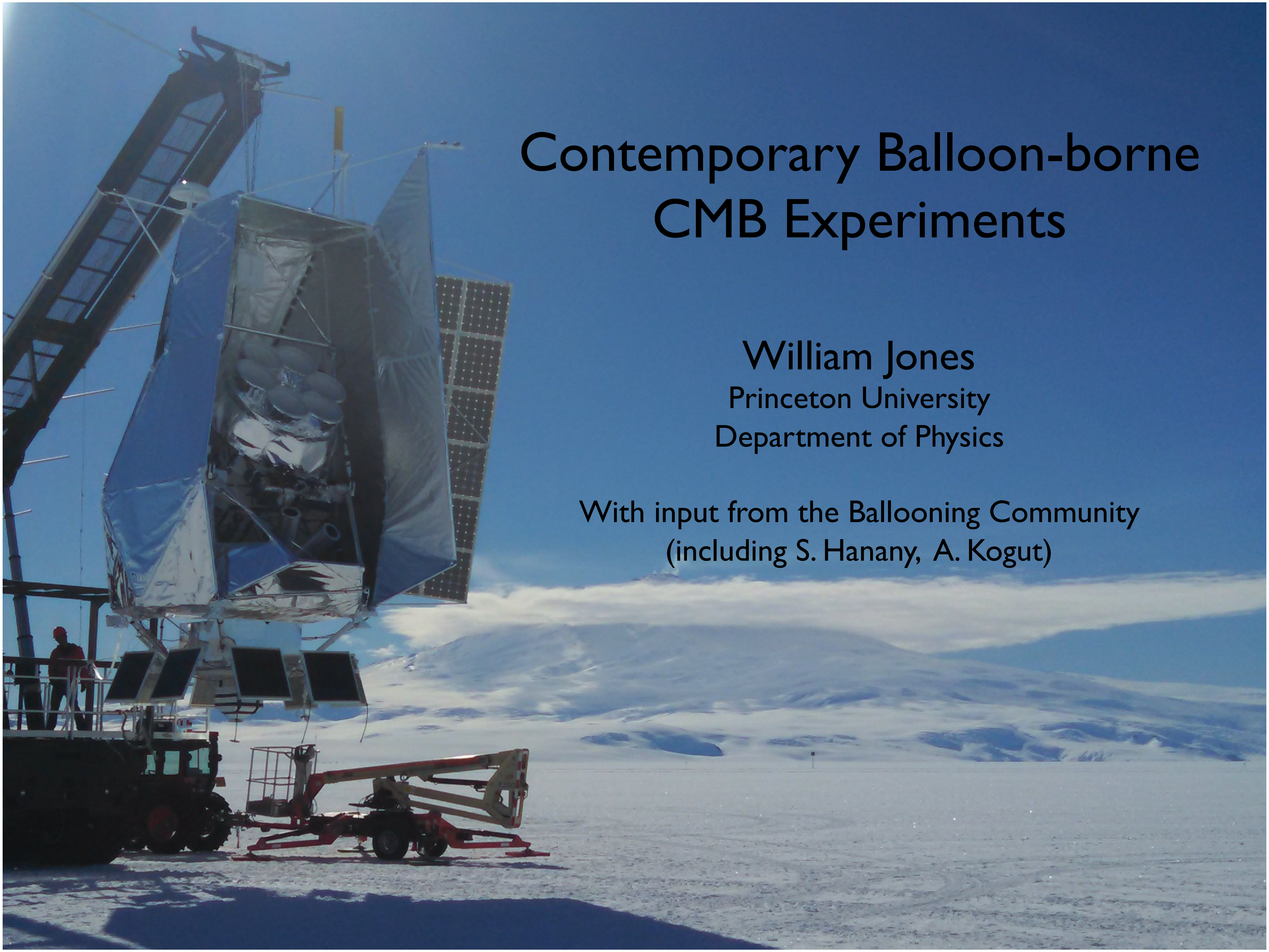


Contemporary Balloon-borne CMB Experiments

William Jones
Princeton University
Department of Physics

With input from the Ballooning Community
(including S. Hanany, A. Kogut)

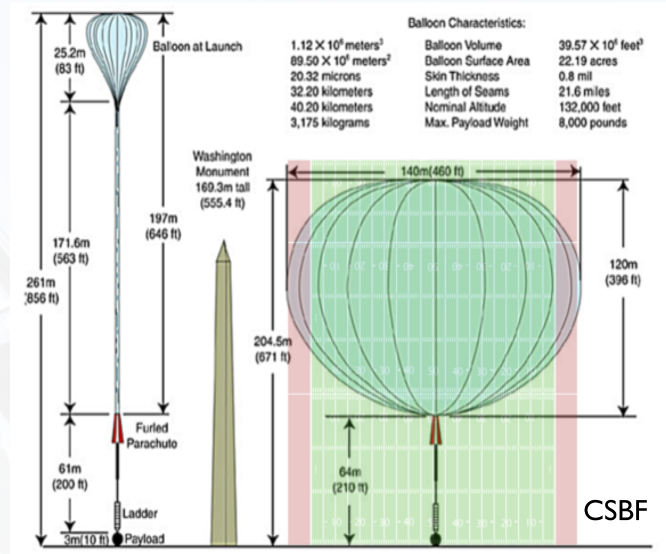
Long Duration Ballooning

Why Ballooning? Access to space.

- Wider frequency windows
  - Atmosphere makes > 150 GHz difficult
- Fidelity to large angular scales
- Space-like backgrounds
  - Sensitivity: one hour at 36km is like a day on the ground)
  - Analysis: data representative of a space mission
- Mission durations 5-100 days

At what price?

- Stringent limits on mass, power
- Complexity of automation
- Insane integration schedule
- Narrow, and scarce, flight windows
- Risky recovery



William C. Jones

CERN CMB Workshop, May 16, 2016

Long Duration Ballooning

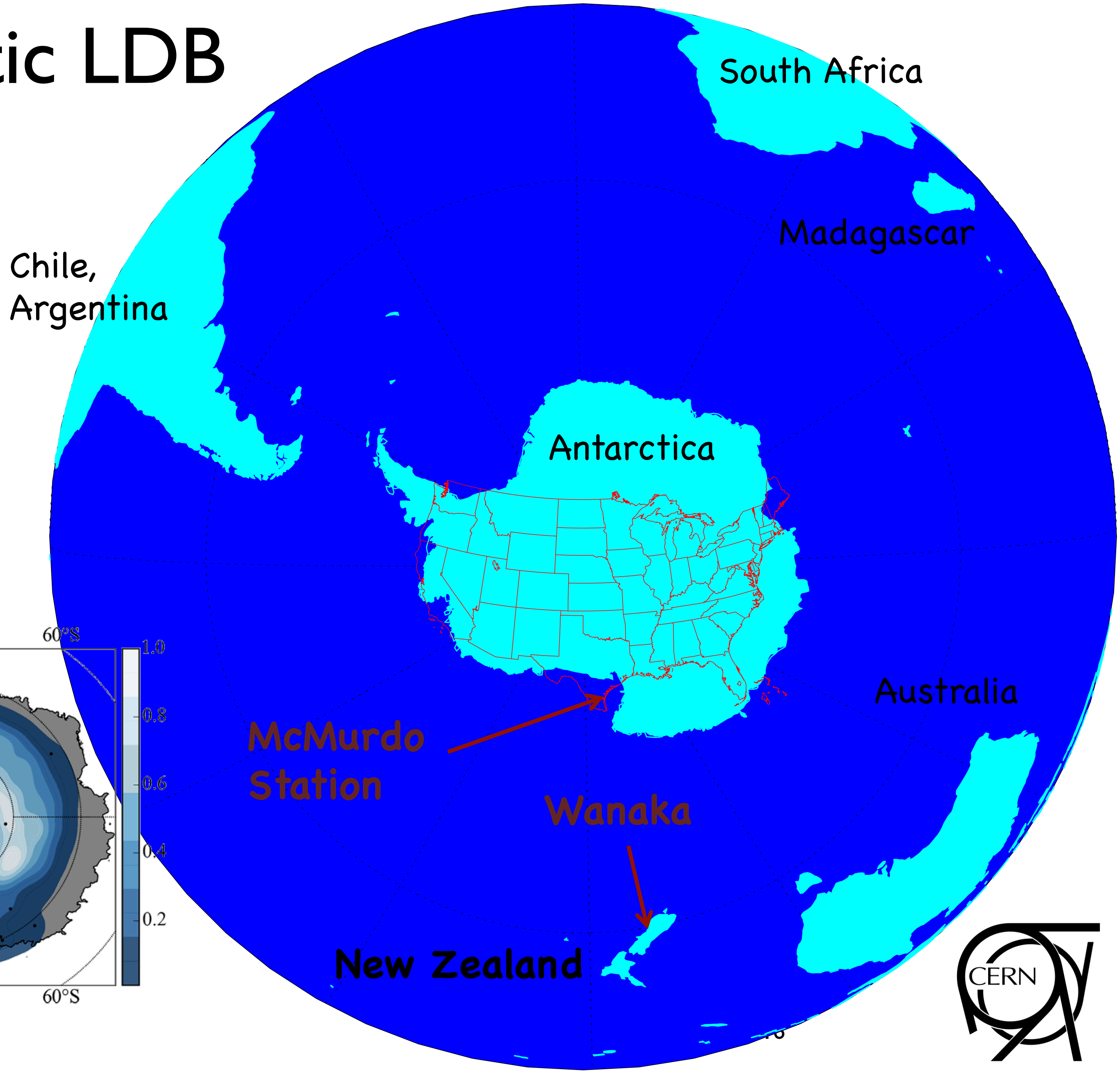
Flight Options

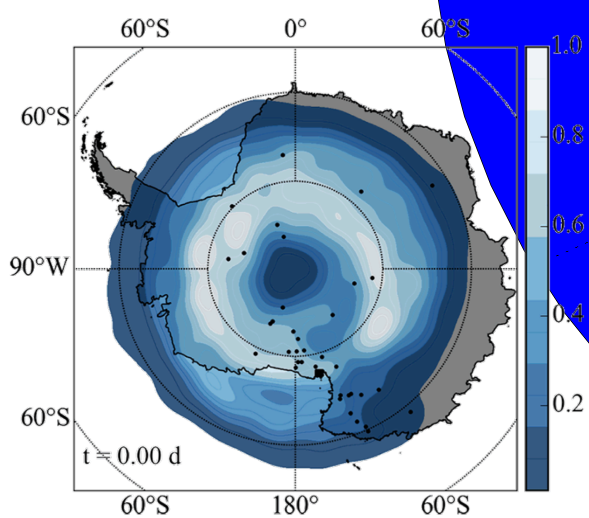
- Antarctic Long Duration Balloon (LDB) : 10 – 30 days / 3 tons
- Wanaka Super Pressure Balloon (SPB) : 30 – 100 days / 1 ton
- Polar Night Flights : ~ 10 days
- Conventional Flight (Ft. Sumner, Palestine, Timmons) : 1 day

Flight Parameters

- 33-37 km altitude
- 1 km altitude stability (200 m for SPB)
- Annual flight windows
  - January (LDB, Svalbard), April (SPB, Wanaka), June (Palestine), September (Ft. Sumner)

Antarctic LDB

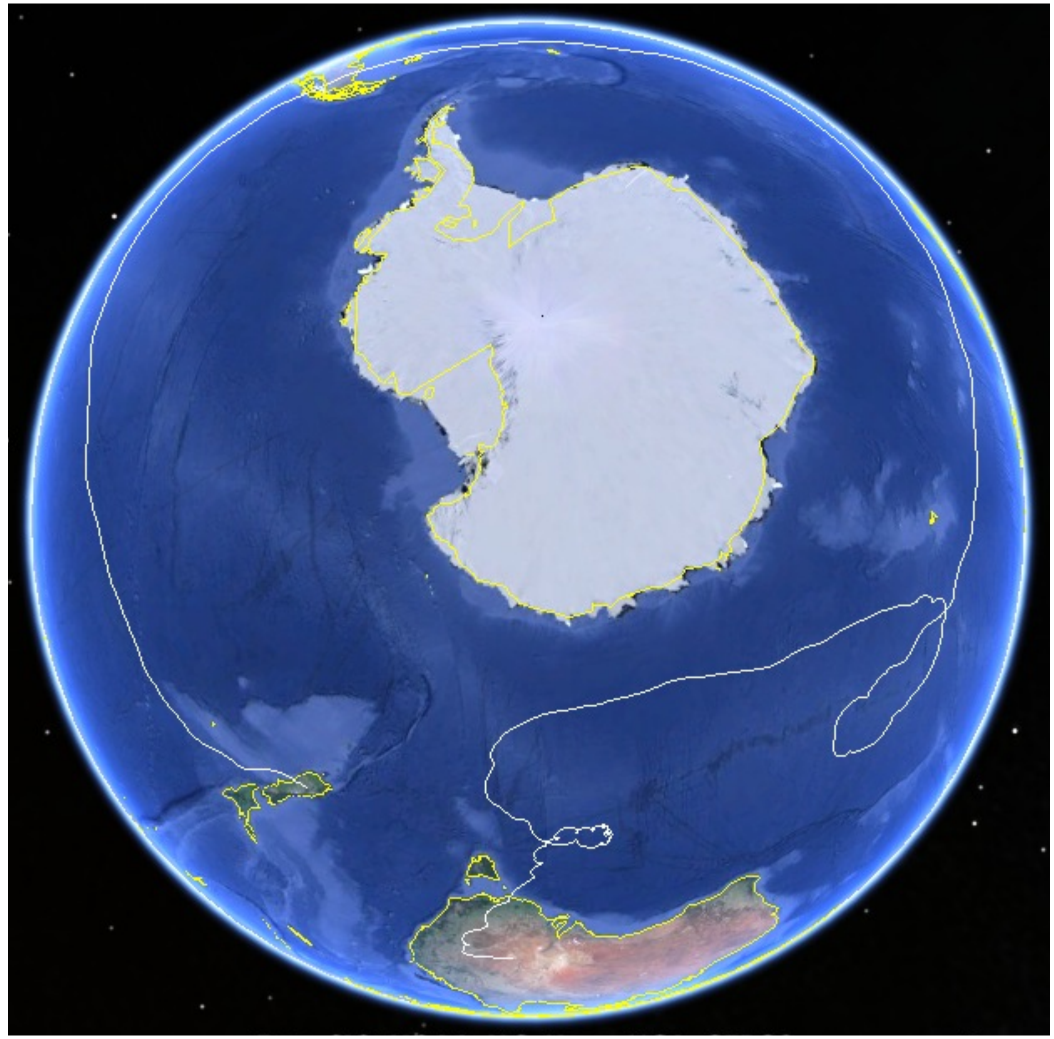




J. Gudmundsson

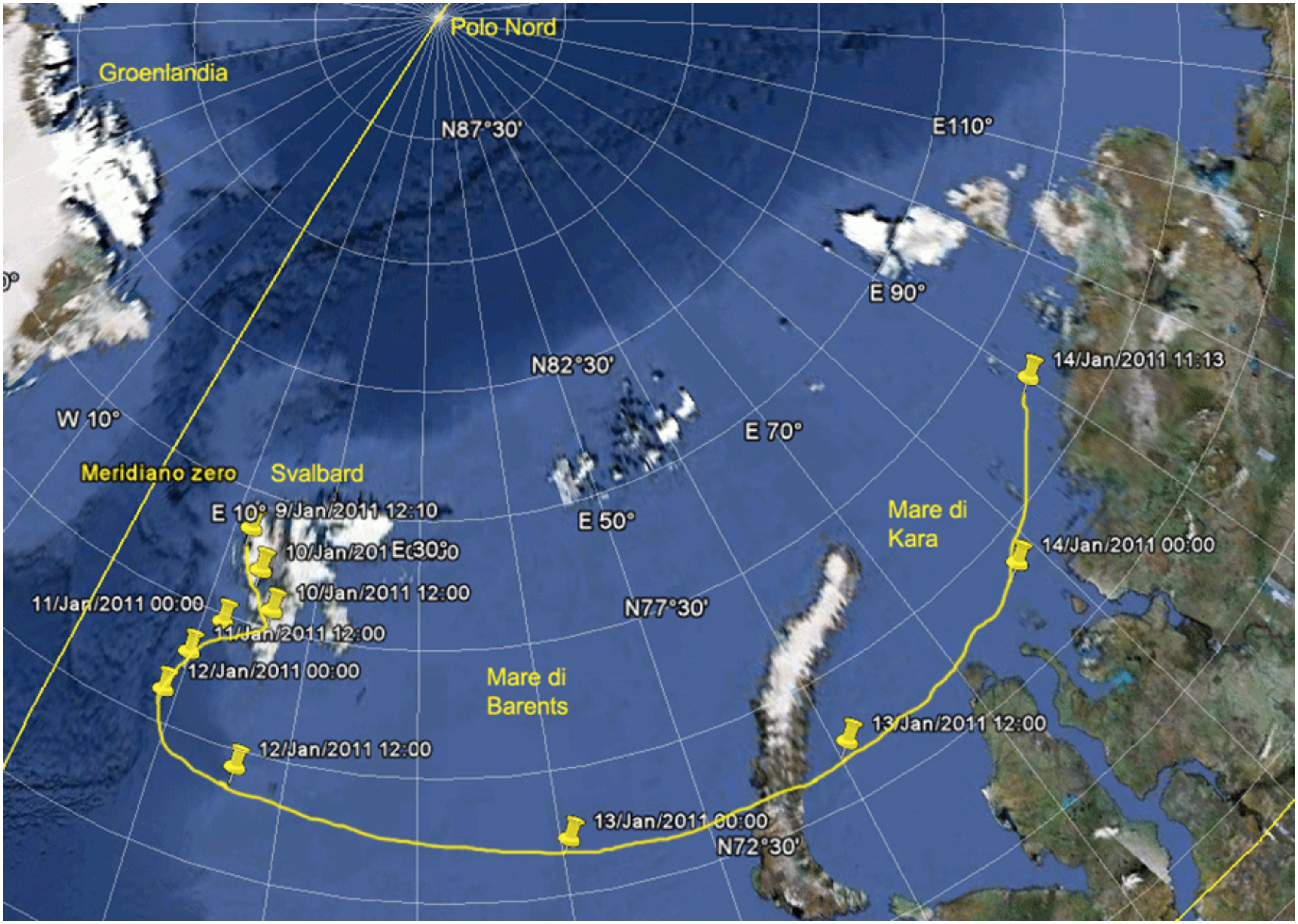
Super Pressure Ballooning

- 100 day flights
- 1 ton payload
- mid-latitudes (day/night cycle)



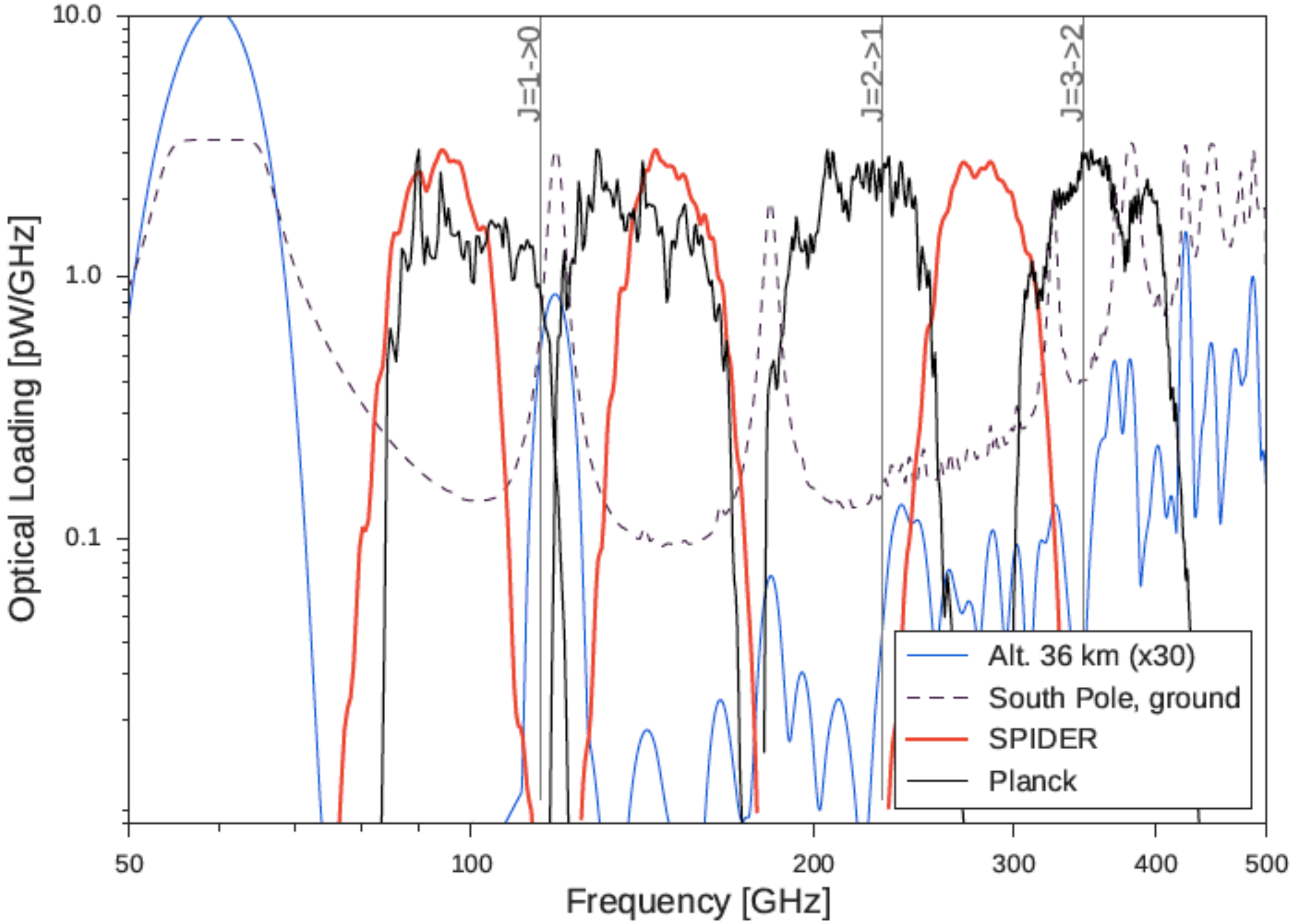
Second Flight Launched Yesterday!

Polar Night Flights



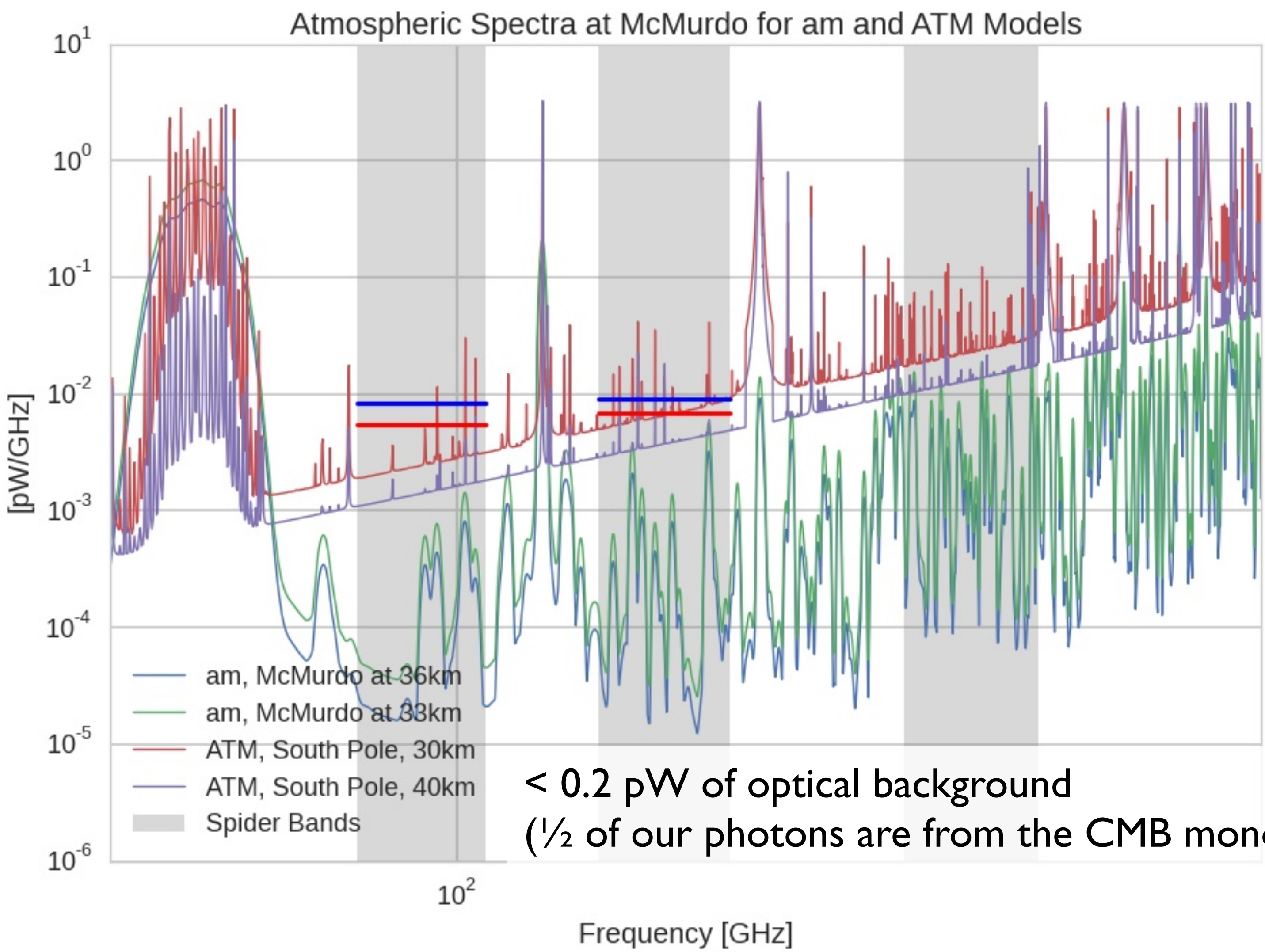
Sub-orbital radiative environment:

an overwhelming advantage above 200 GHz



Sub-orbital radiative environment:

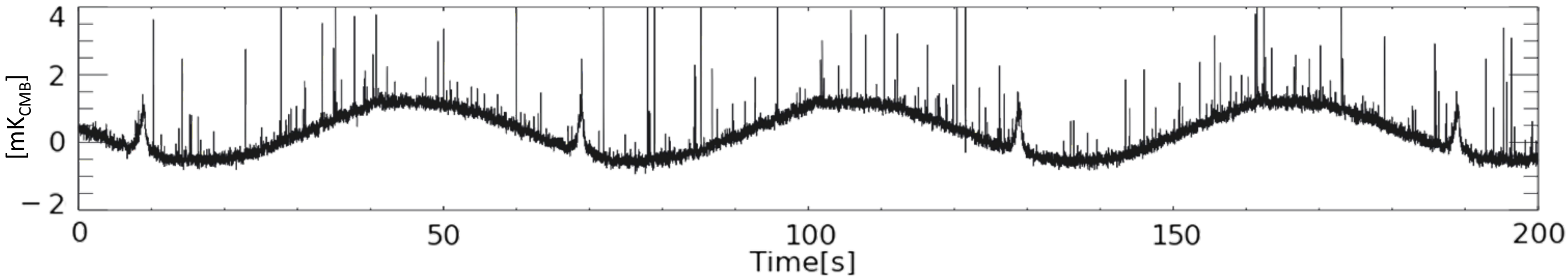
radiative backgrounds comparable to that of *Planck* HFI



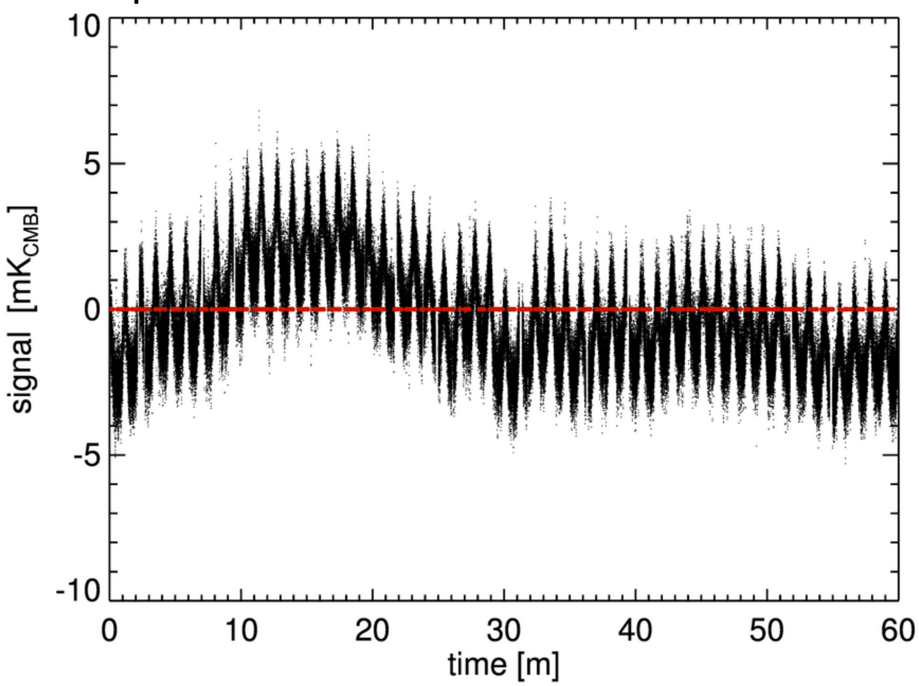
< 0.2 pW of optical background
(½ of our photons are from the CMB monopole!)

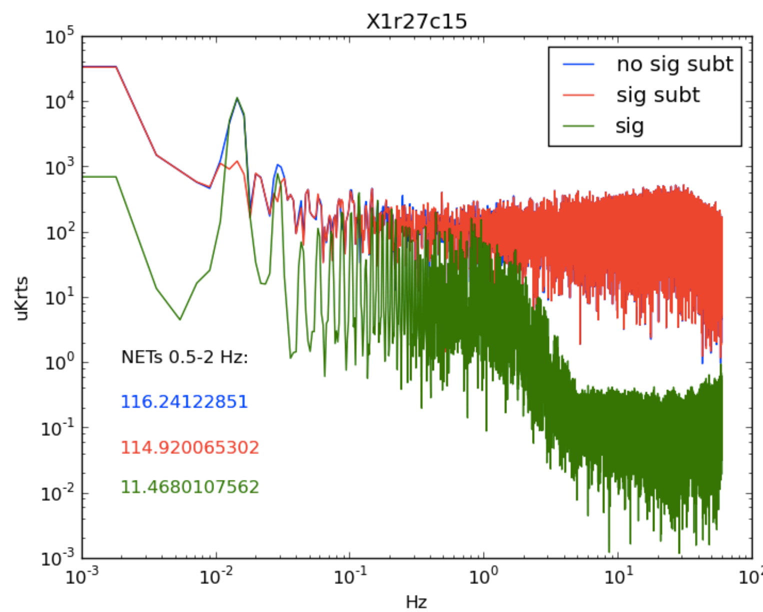
Balloon data representative of a space mission

Planck HFI



Spider 2015

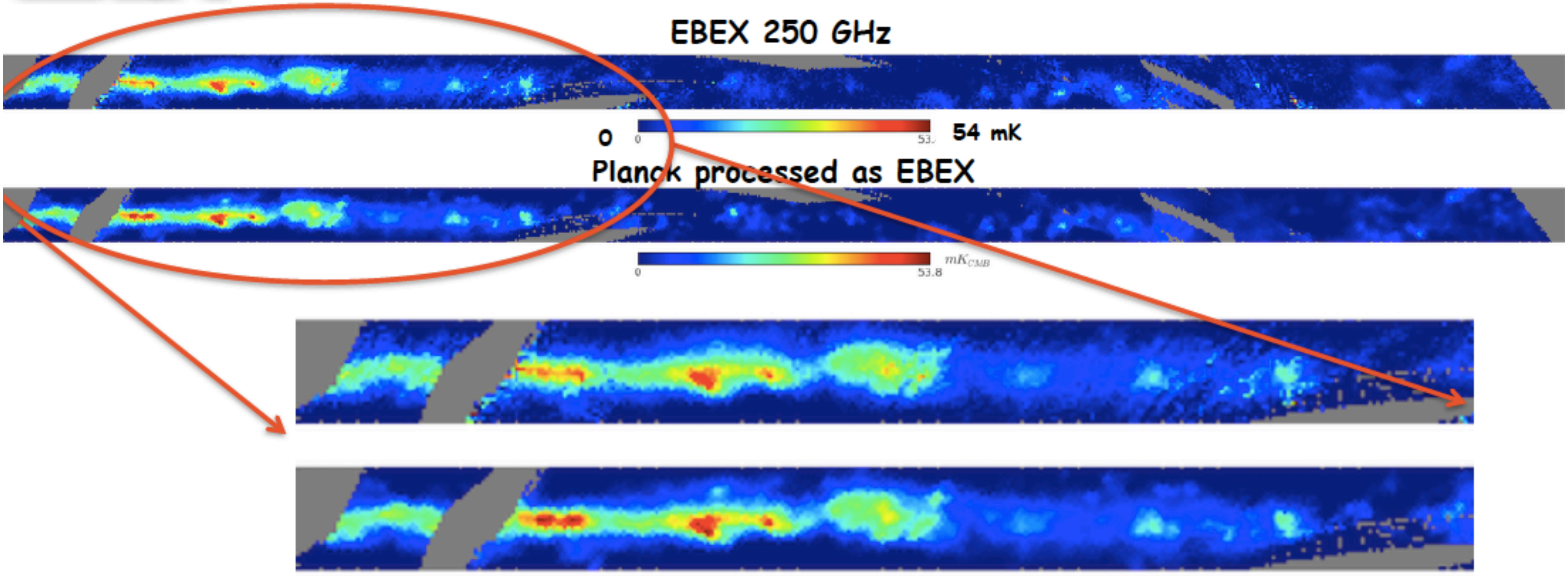




Current/Pending Balloon Missions

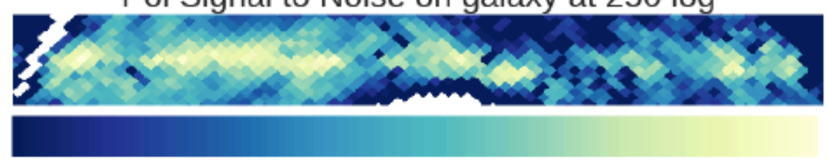
Missions Flown	survey area [sky fraction]	frequencies [GHz]	resolution [arcmin]
EBEX (2012/13)	0.2	150/250/410	8/5/5
Nobody (2013/14)			
Spider (2014/15)	0.1	94/150	42/28
Missions Planned	**survey area [sky fraction]**	**frequencies [GHz]**	**resolution [arcmin]**
Piper (2016)	0.8	200	36
Spider (LDB 2017)	0.1	94-285 (3)	42-15
LSPE (Night 2017)	0.25	44-240 (4)	85-20
Missions in Prep.	**survey area [sky fraction]**	**frequencies [GHz]**	**resolution [arcmin]**
Piper (2017-2020)	0.8	200-600 (4)	36-12
EBEX-IDS	0.035	150-360 (7)	8-3
BFORE	0.23	270-600 (3)	4

2013 Flight



Pol Signal to Noise on galaxy at 150 log

Pol Signal to Noise on galaxy at 250 log



Pol Signal to Noise on galaxy at 410 log

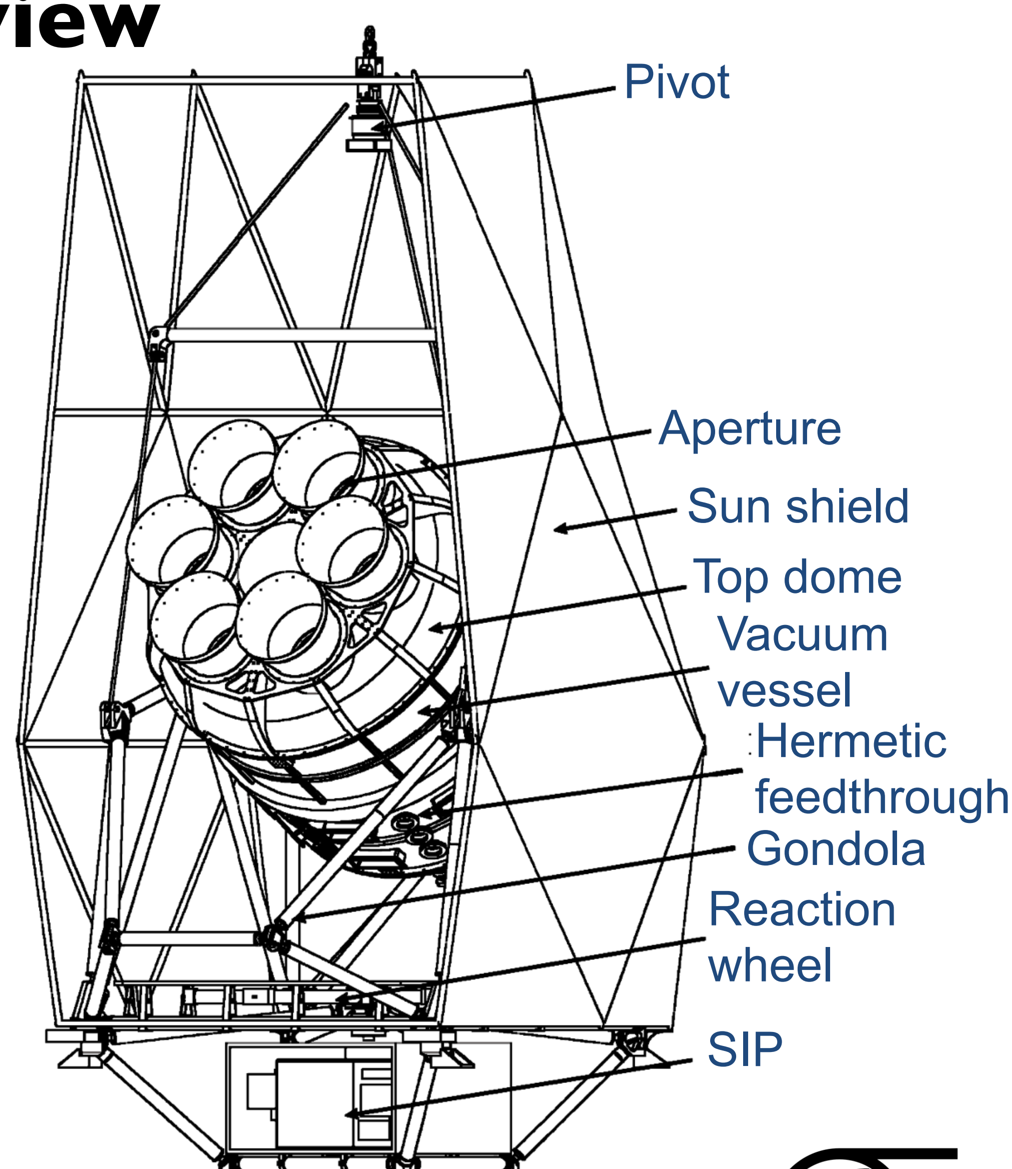
Spider 2015: Overview

Sky coverage	About 10 %
Scan rate (az, sinusoid)	3.6 deg/s at peak
Polarization modulation	Stepped cryogenic HWP
Detector type	Antenna-coupled TES
Multipole range	$10 < \ell < 300$
Observation time	16 days at 36 km
Limits on r†	0.03

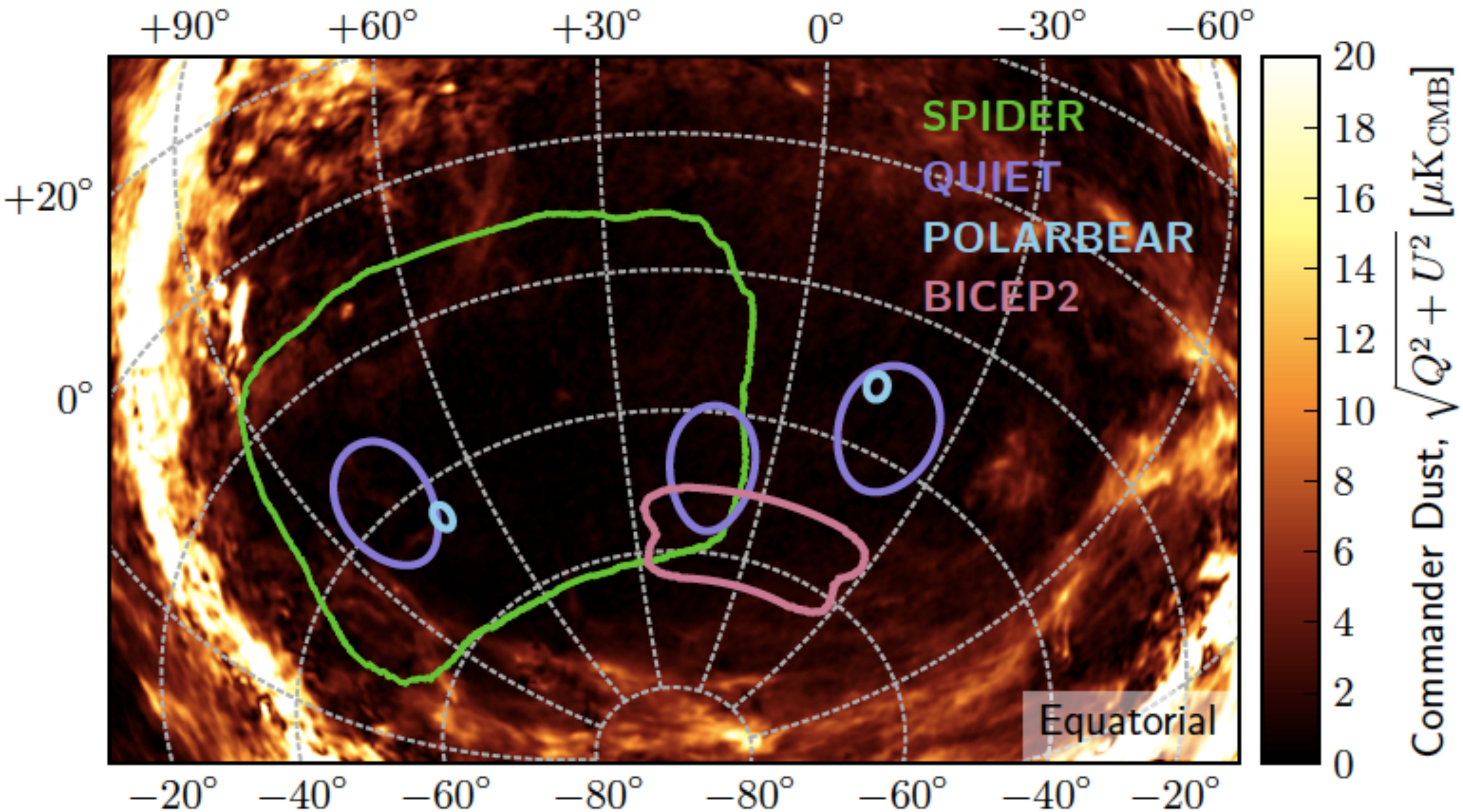
† Ignoring all foregrounds, at 99% confidence

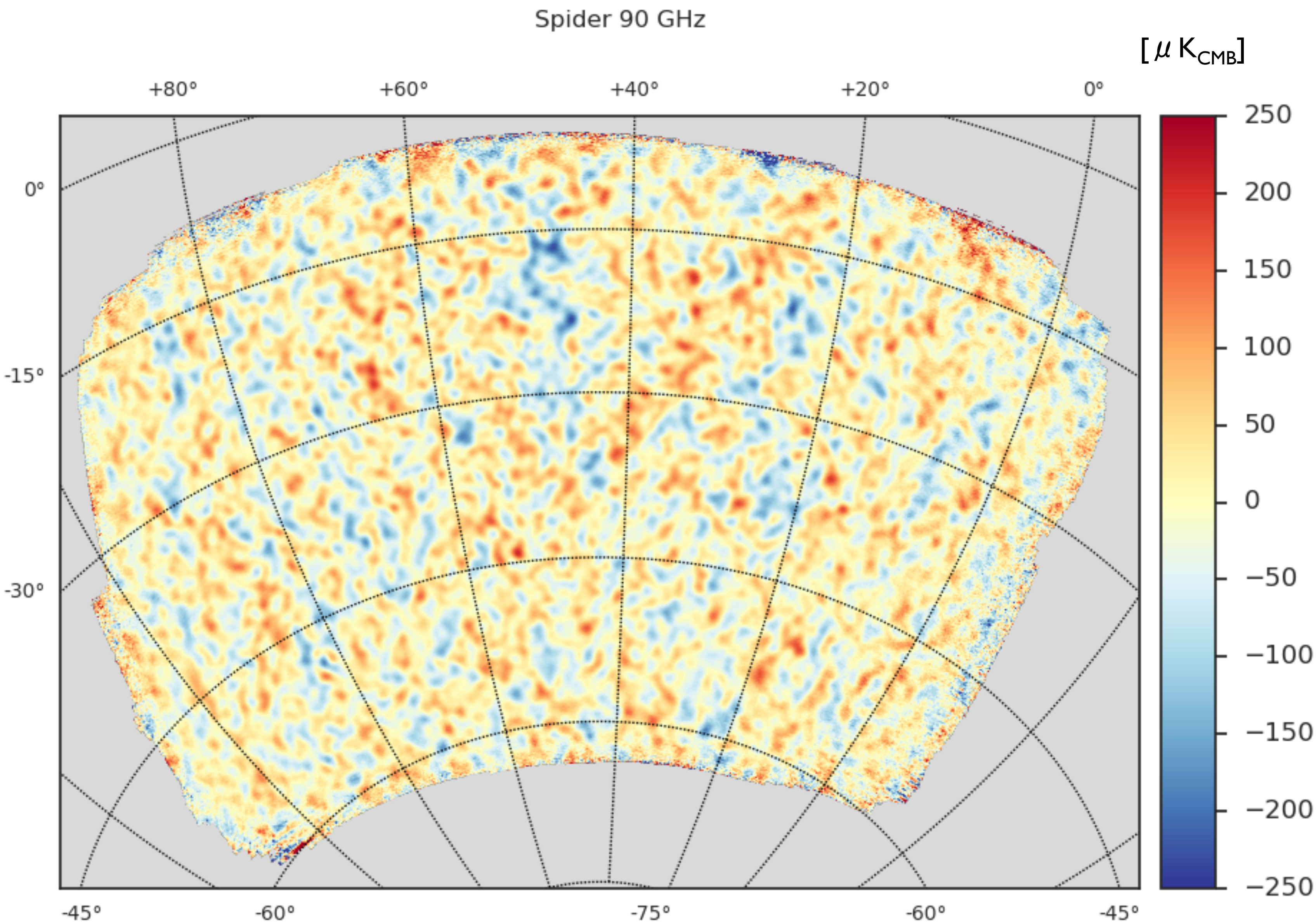
	Frequency [GHz]	
	94	150
Telescopes	3	3
Bandwidth [GHz]	22	36
Optical efficiency	30-45%	30-50%
Angular resolution* [arcmin]	42	28
Number of detectors†	652 (816)	1030 (1488)
Optical background‡ [pW]	≤ 0.25	≤ 0.35
Instrument NET† [μK·rts]	6.5	5.1

*FWHM. †Only counting those currently used in analysis
‡Including sleeve, window, and baffle

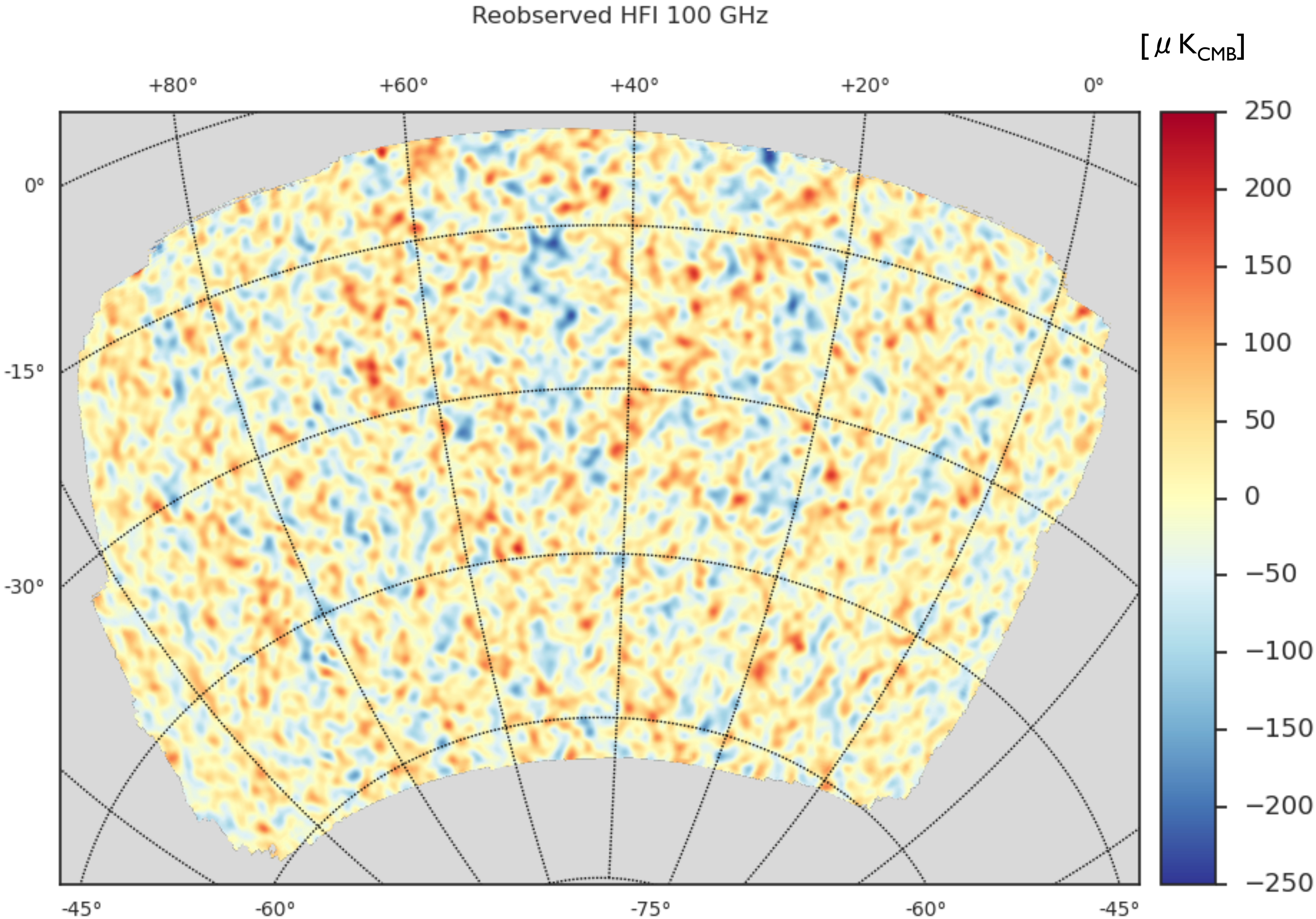


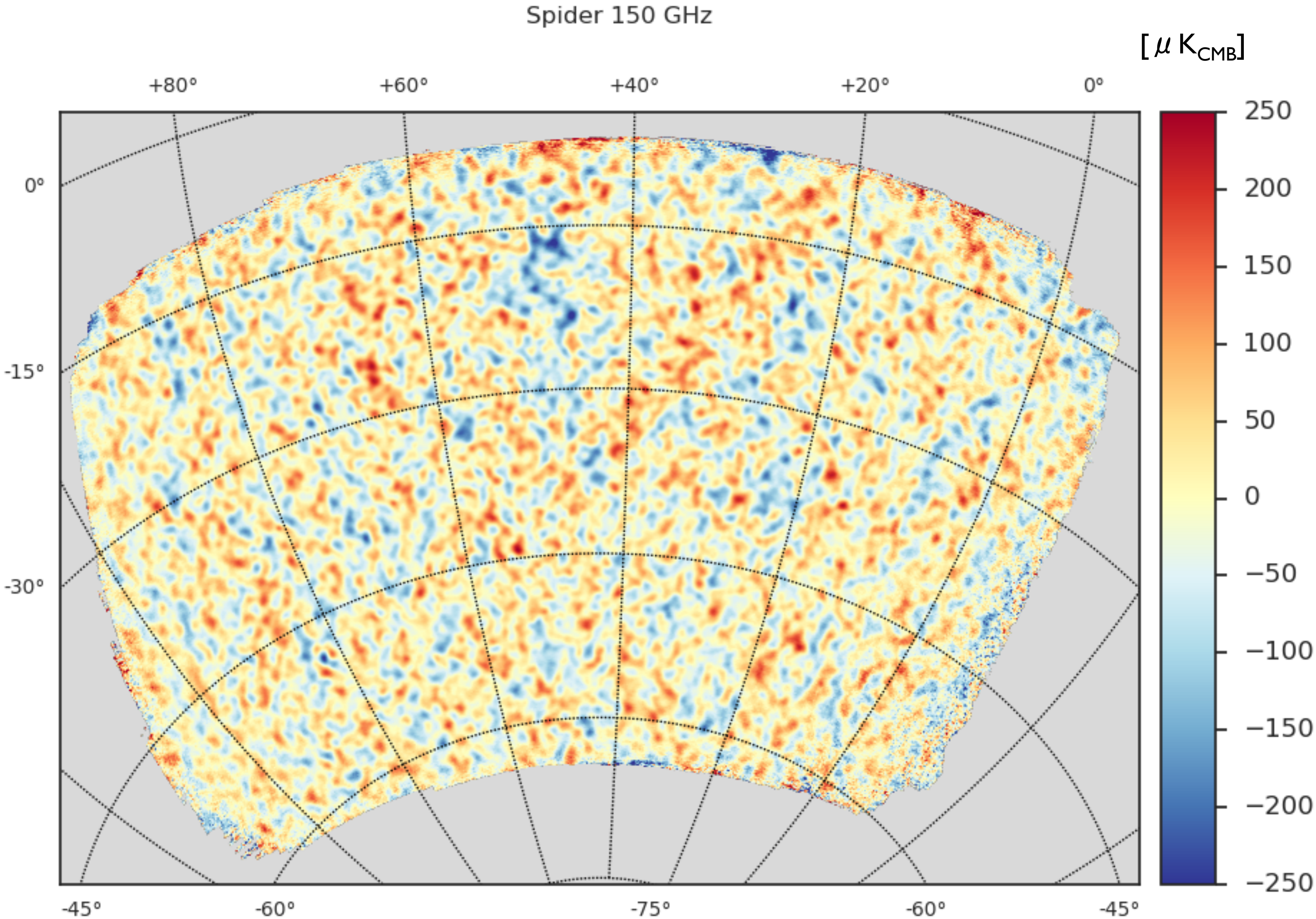
Spider 2015: survey coverage

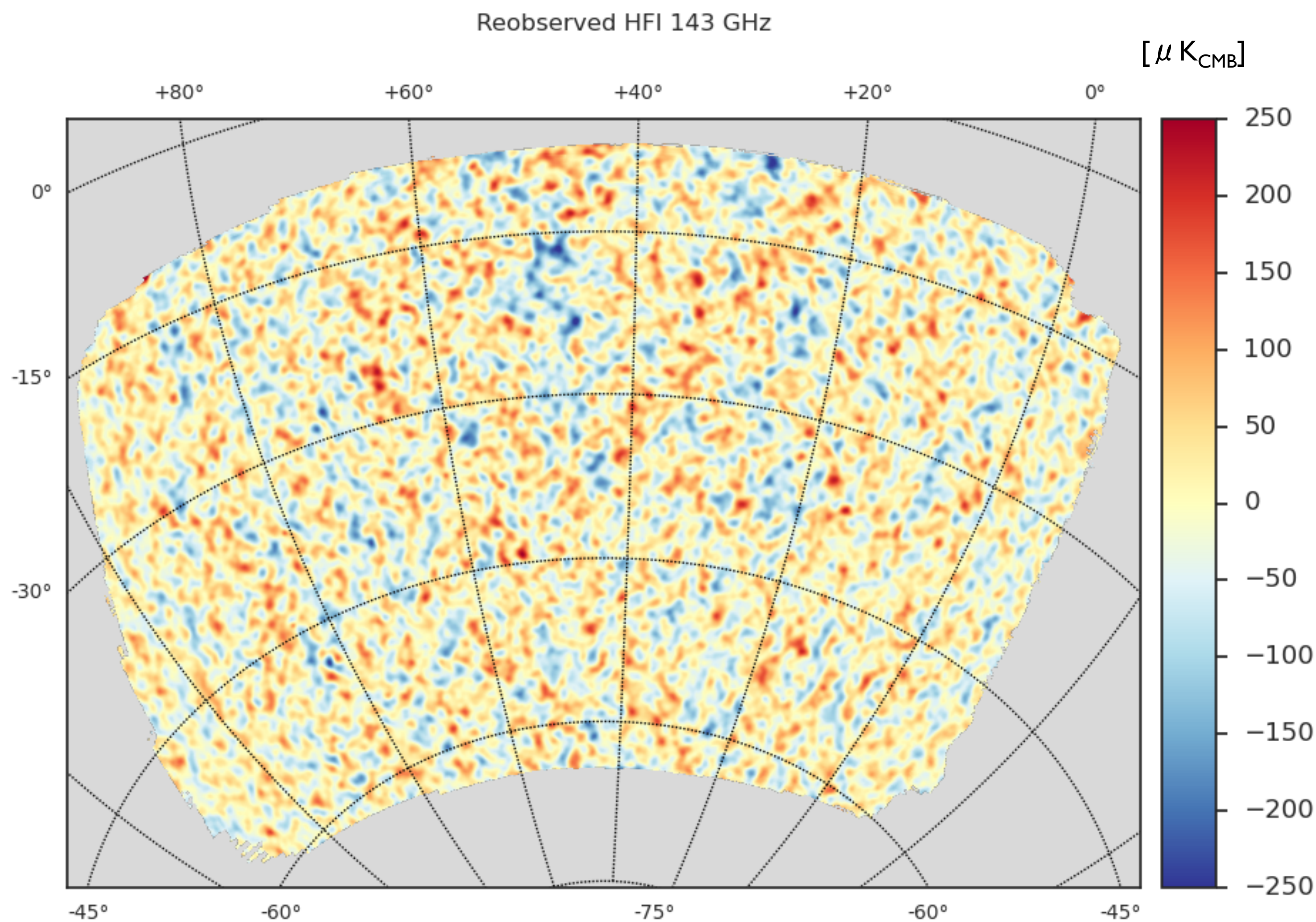




Spider 90 GHz
[μ K_CMB]
+80°
+60°
+40°
+20°
0°
0°
-15°
-30°
-45°
-60°
-75°
-60°
-45°
250
200
150
100
50
0
−50
−100
−150
−200
−250

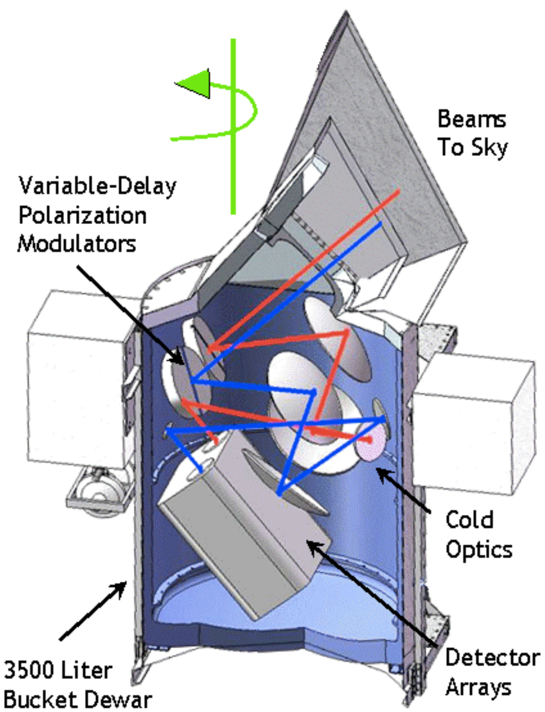

Reobserved HFI 100 GHz
[μ K_CMB]
+80°
+60°
+40°
+20°
0°
0°
-15°
-30°
-45°
-60°
-75°
-60°
-45°
250
200
150
100
50
0
−50
−100
−150
−200
−250


Spider 150 GHz
[μ K_CMB]
+80°
+60°
+40°
+20°
0°
0°
-15°
-30°
-45°
-60°
-75°
-60°
-45°
250
200
150
100
50
0
−50
−100
−150
−200
−250

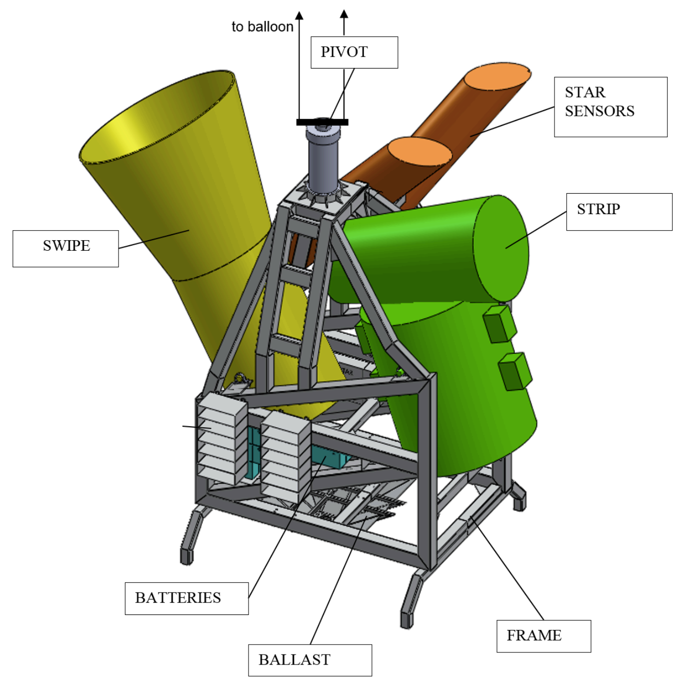

Reobserved HFI 143 GHz
[μ K_CMB]
+80°
+60°
+40°
+20°
0°
0°
-15°
-30°
-45°
-60°
-75°
-60°
-45°
250
200
150
100
50
0
−50
−100
−150
−200
−250

PIPER and LSPE

PIPER (Goddard)
2 short duration flights/year
Northern + Southern = ~80% sky/year
4 years = 8 flights (2016-2020)
200, 270, 350, 600 GHz

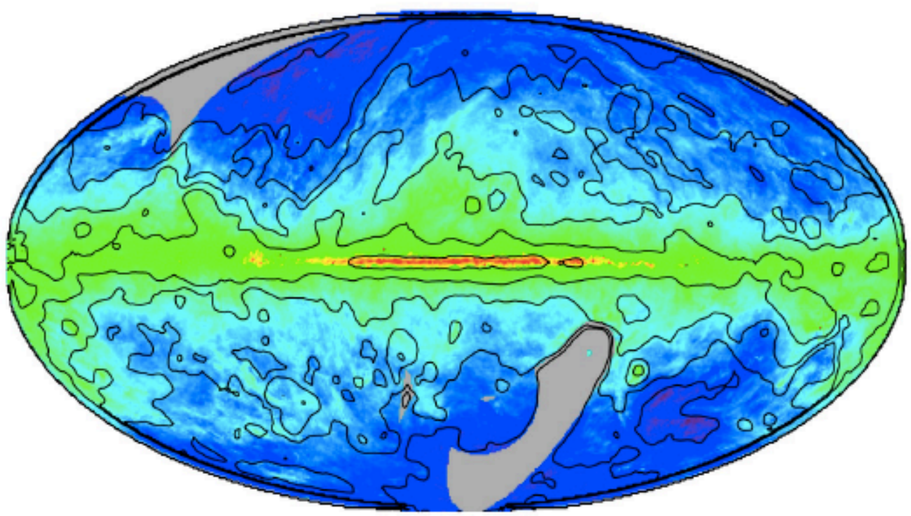


LSPE (Rome)
25% sky/flight (Svalbard, Norway)
1st Flight: 12/2017
44, 90, 150, 240 GHz

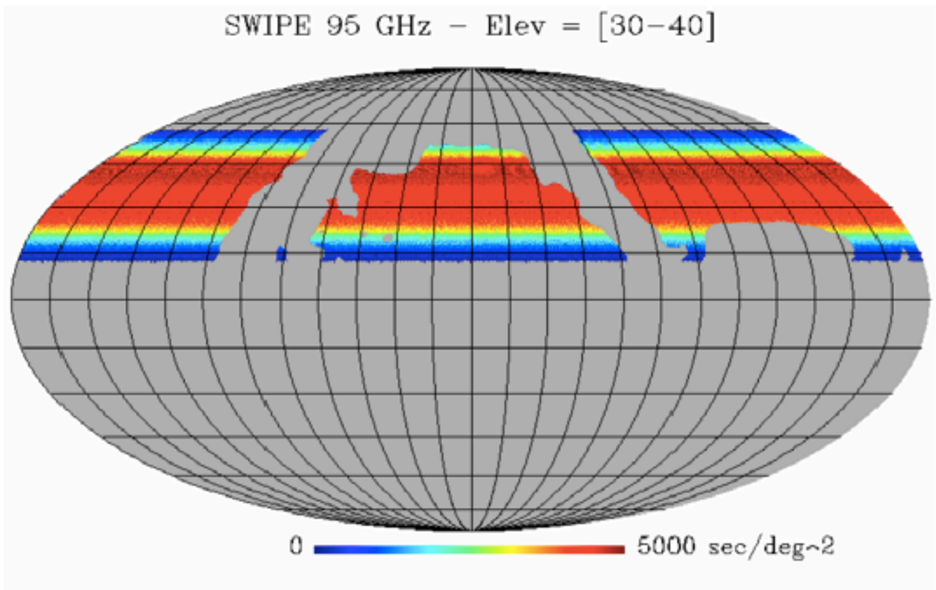


PIPER and LSPE

PIPER (Goddard)
2 short duration flights/year
Northern + Southern = ~80% sky/year
4 years = 8 flights (2016-2020)
200, 270, 350, 600 GHz



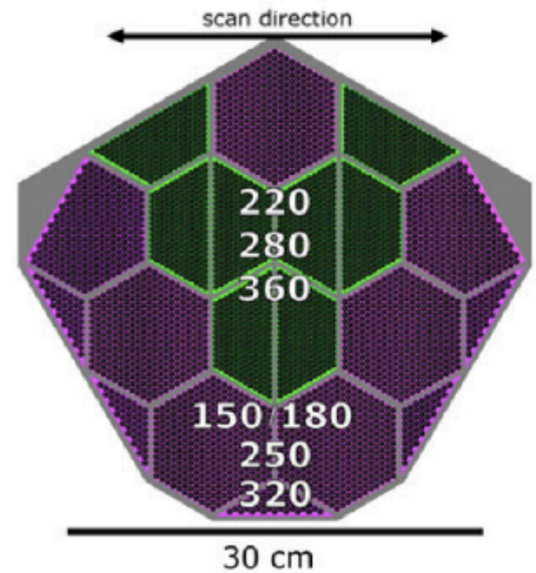
LSPE (Rome)
25% sky/flight (Svalbard, Norway)
1st Flight: 12/2017
44, 90, 150, 240 GHz



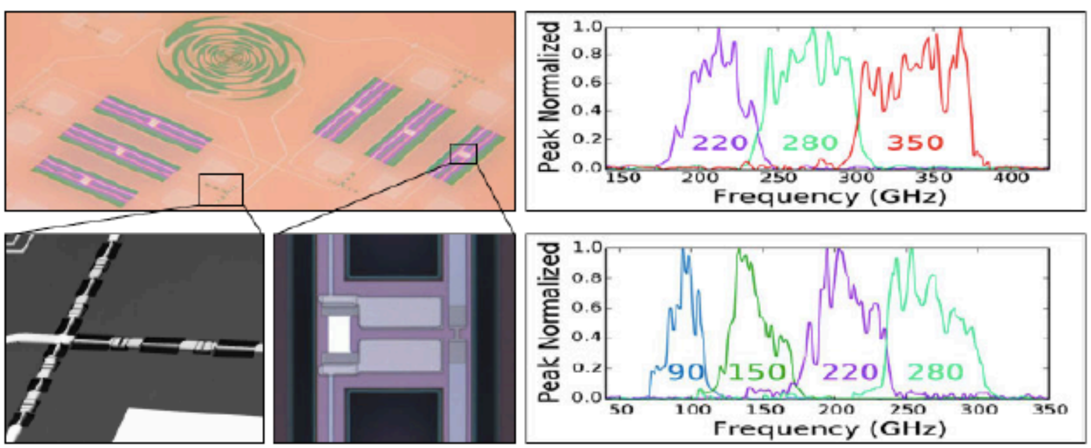
S. Hanany

EBEX-IDS

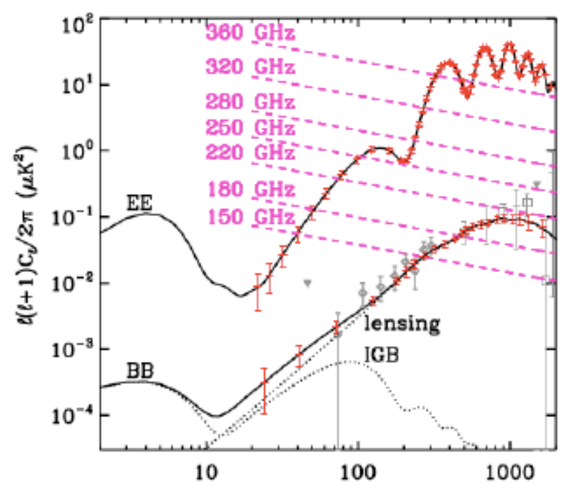
- 7 bands: 150, 180, 220, 250, 280, 320, 360 GHz
- 1500 sq. deg. Co-observe with BICEP/Keck + Simmons Array
- Sinuous Antenna Trichroic Pixels (PB2, SPTPol, LiteBIRD)



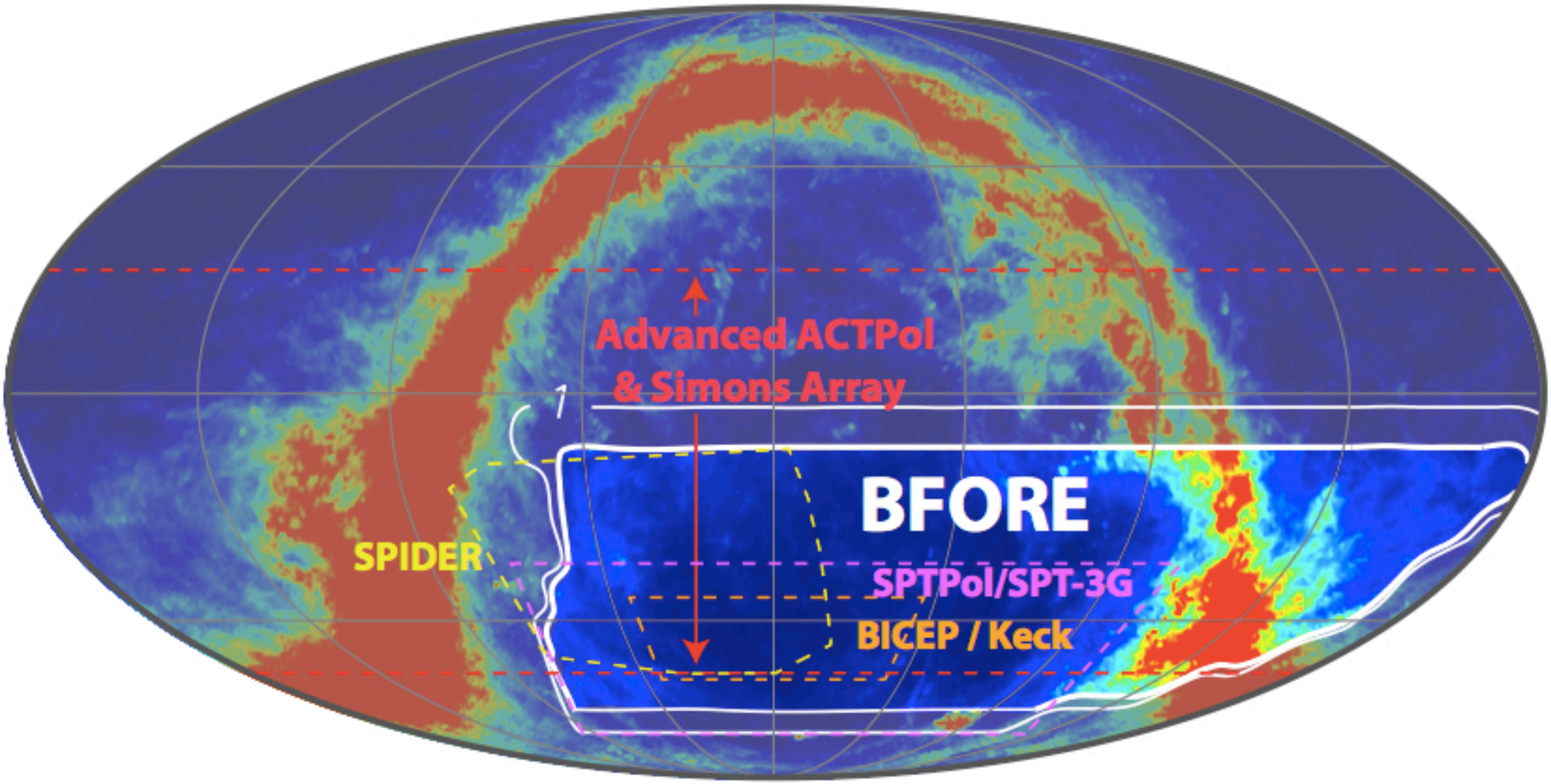
Total of 20562 detectors



Lee + Westbrook, UCB



BFORE


Advanced ACTPol
& Simons Array
BFORE
SPIDER
SPTPol/SPT-3G
BICEP / Keck

The observational challenge:

A detection of *primordial* fluctuations must confirm:

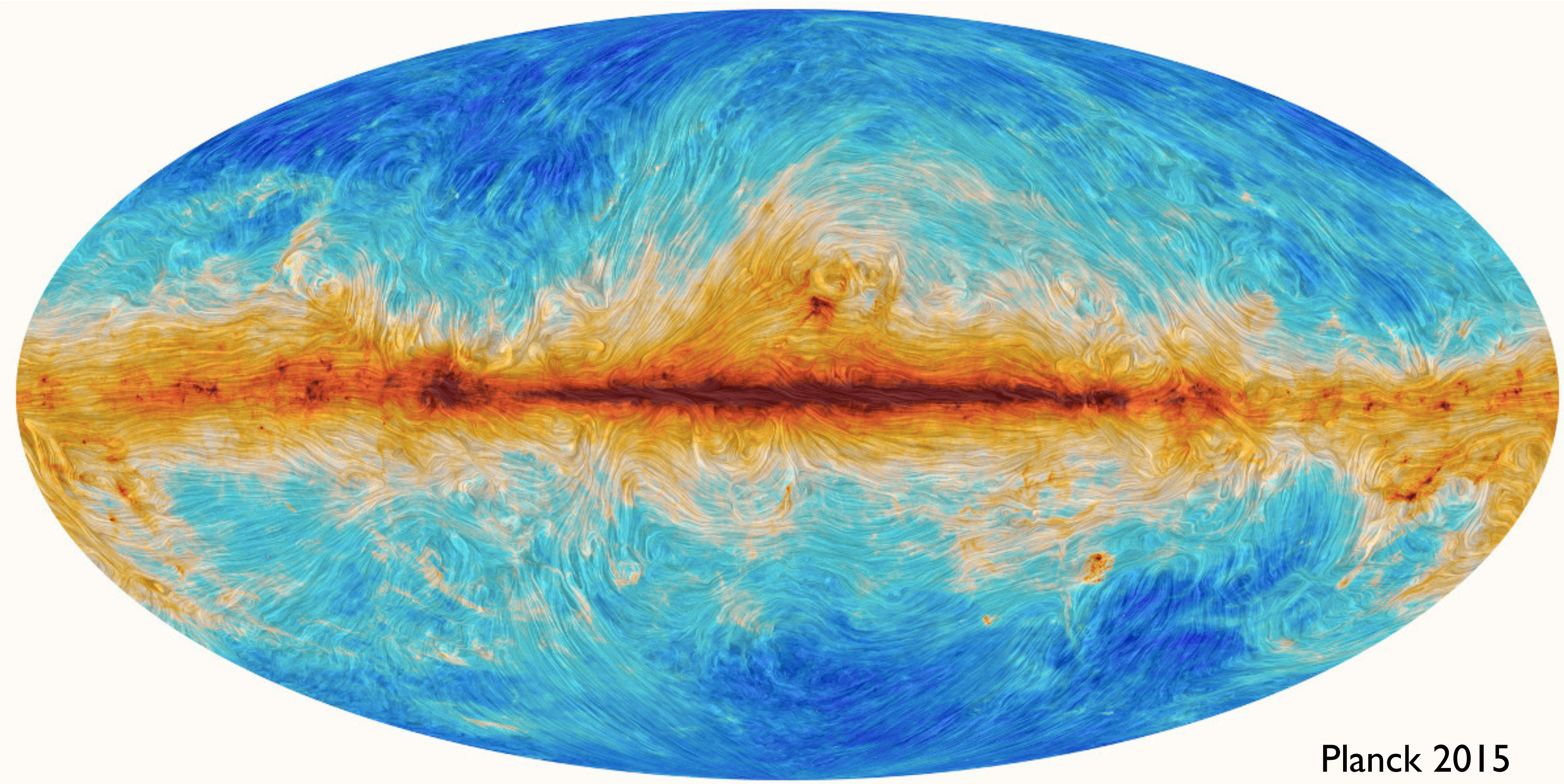
- Spectral energy distribution
- Angular power spectrum
- Statistical isotropy

Experimental requirements:

- Extreme sensitivity [primordial signal < 100 nK_{rms}]
  (and control of systematic effects)
- Large survey area [signal is ≥ degree-scale]
- Multiple frequencies [as many as you can – we don't know how many are needed…]

Balloon experiments are able to address all these, with data representative of a space mission.

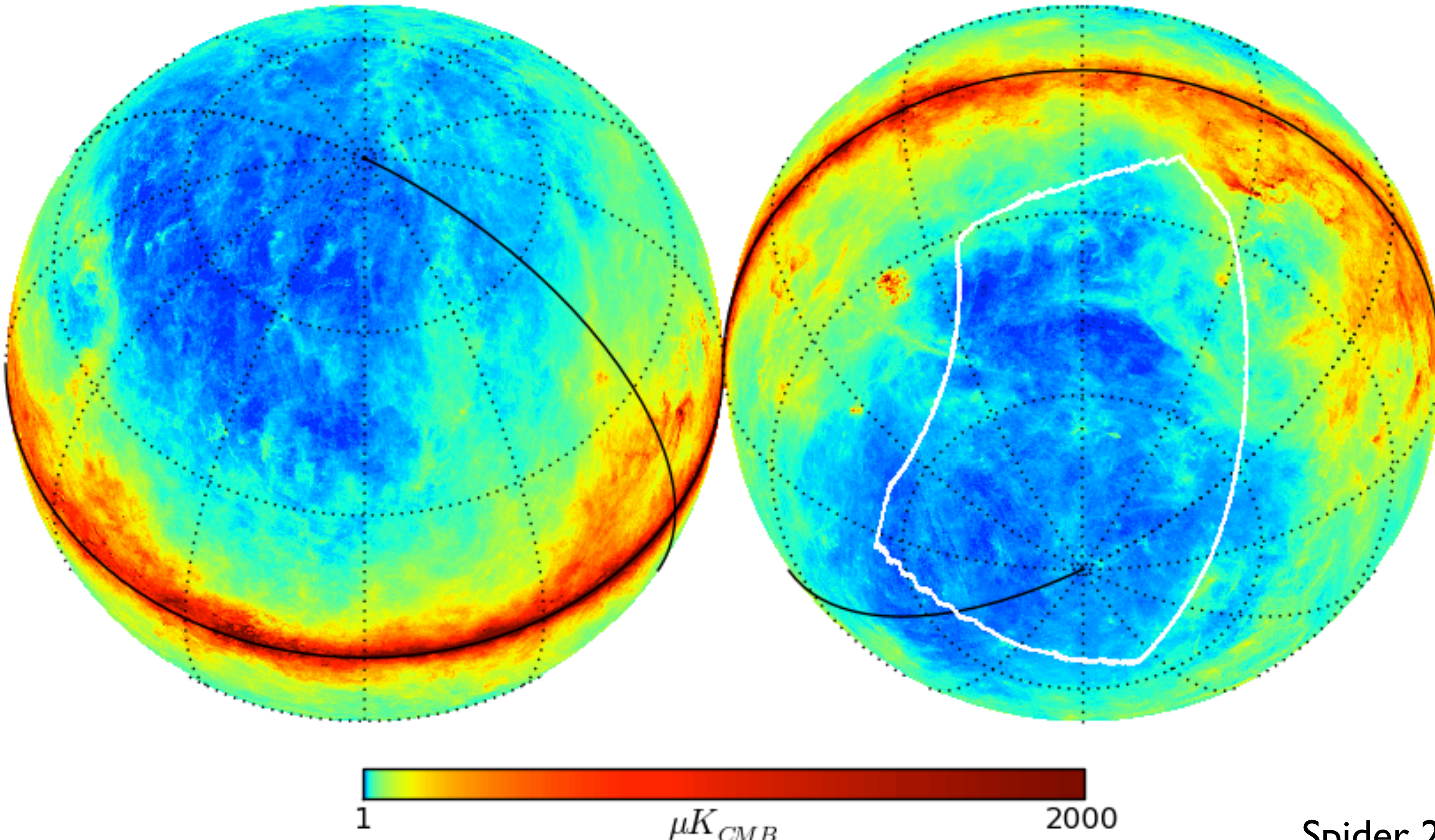
The observational challenge:


Planck 2015

William C. Jones

CERN CMB Workshop, May 16, 2016

The observational challenge:



Spider 2015

SPIDER: **Probing the early Universe with a suborbital polarimeter**

Fraisse, et al. (2011)
arxiv: 1106.3087

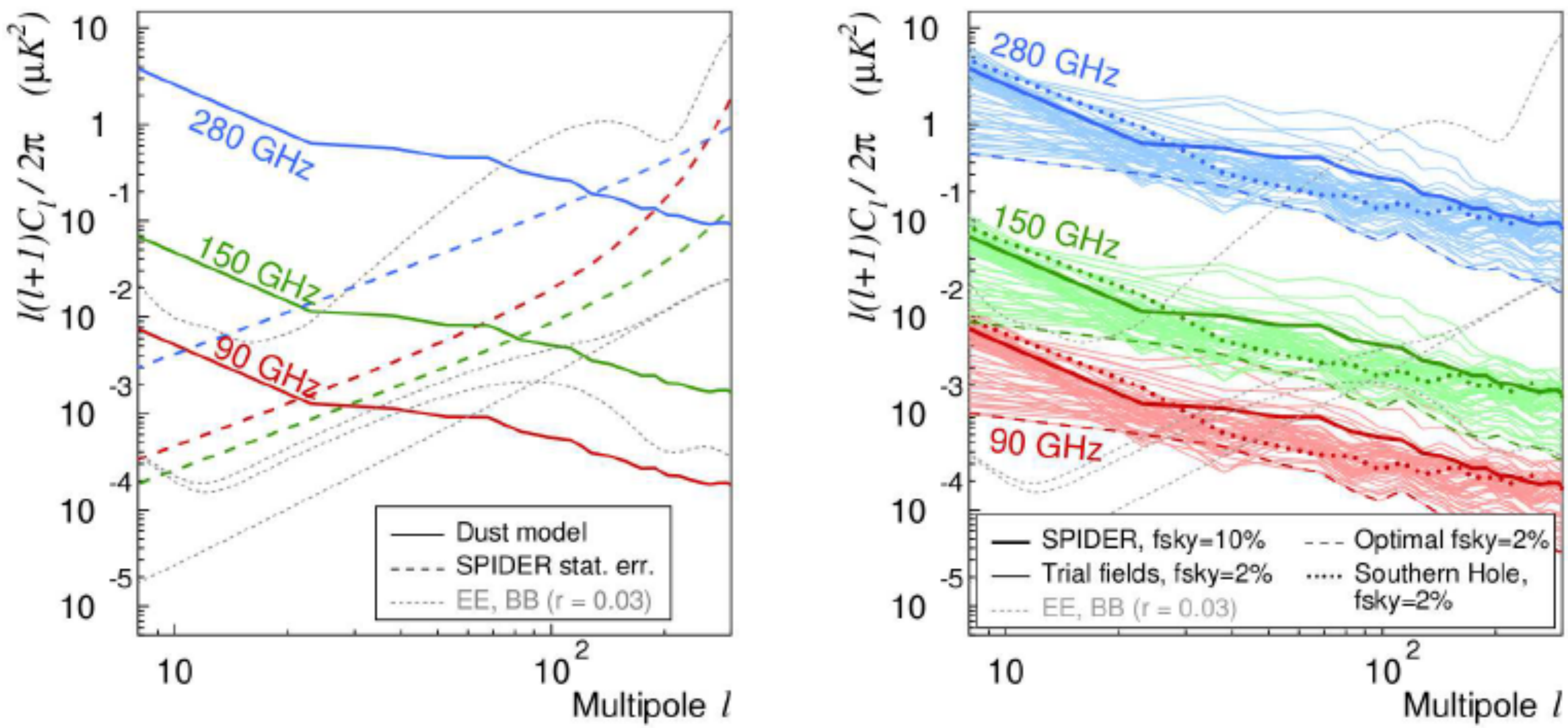


exhibit significantly less polarized dust emission. This study suggests that without component separation, degree-scale polarized dust emission will limit the constraints of *any* experiment at or above the level of $r \sim 0.03$, *even in the portions of the southern sky most free of Galactic dust emission.*

SPIDER: Probing the early Universe with a suborbital polarimeter

Fraisse, et al. (2011)
arxiv: 1106.3087

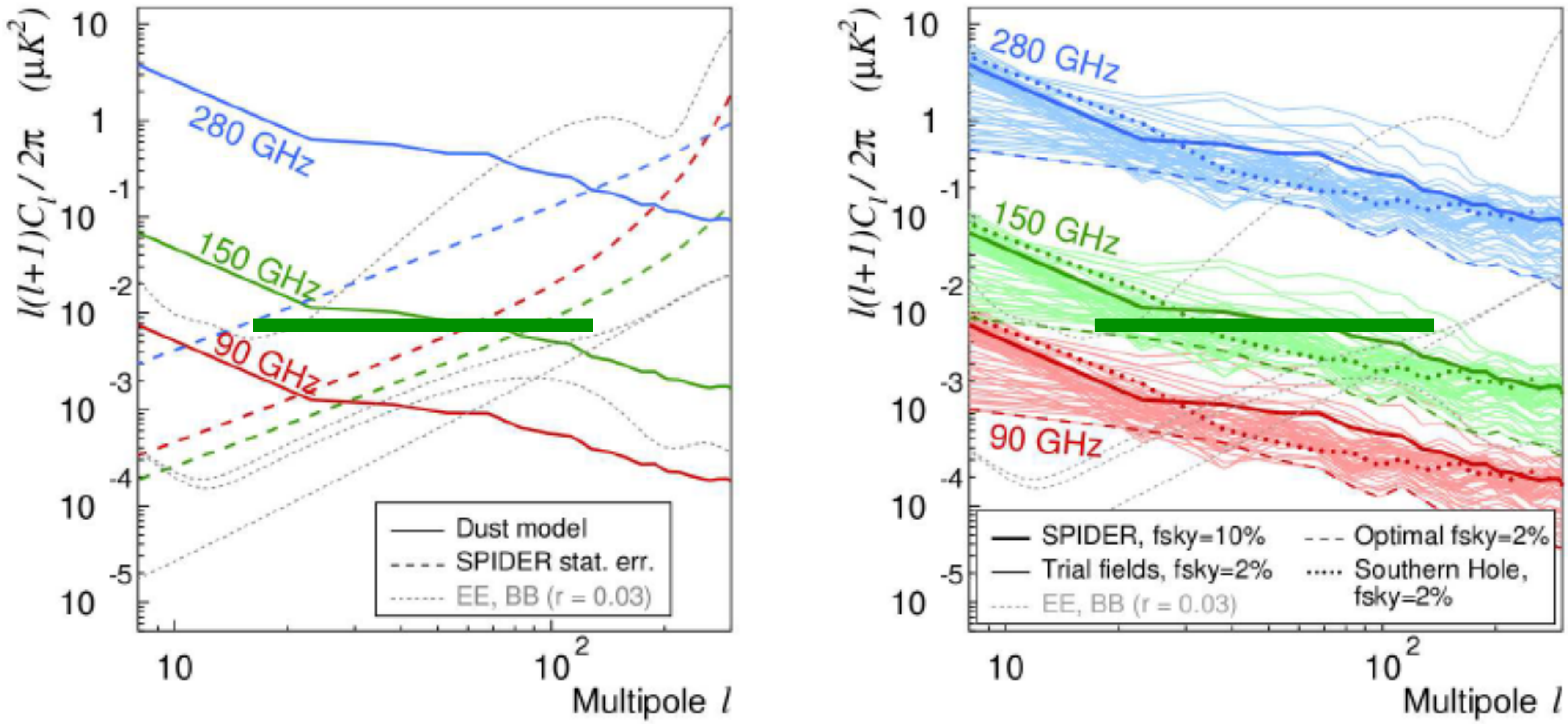
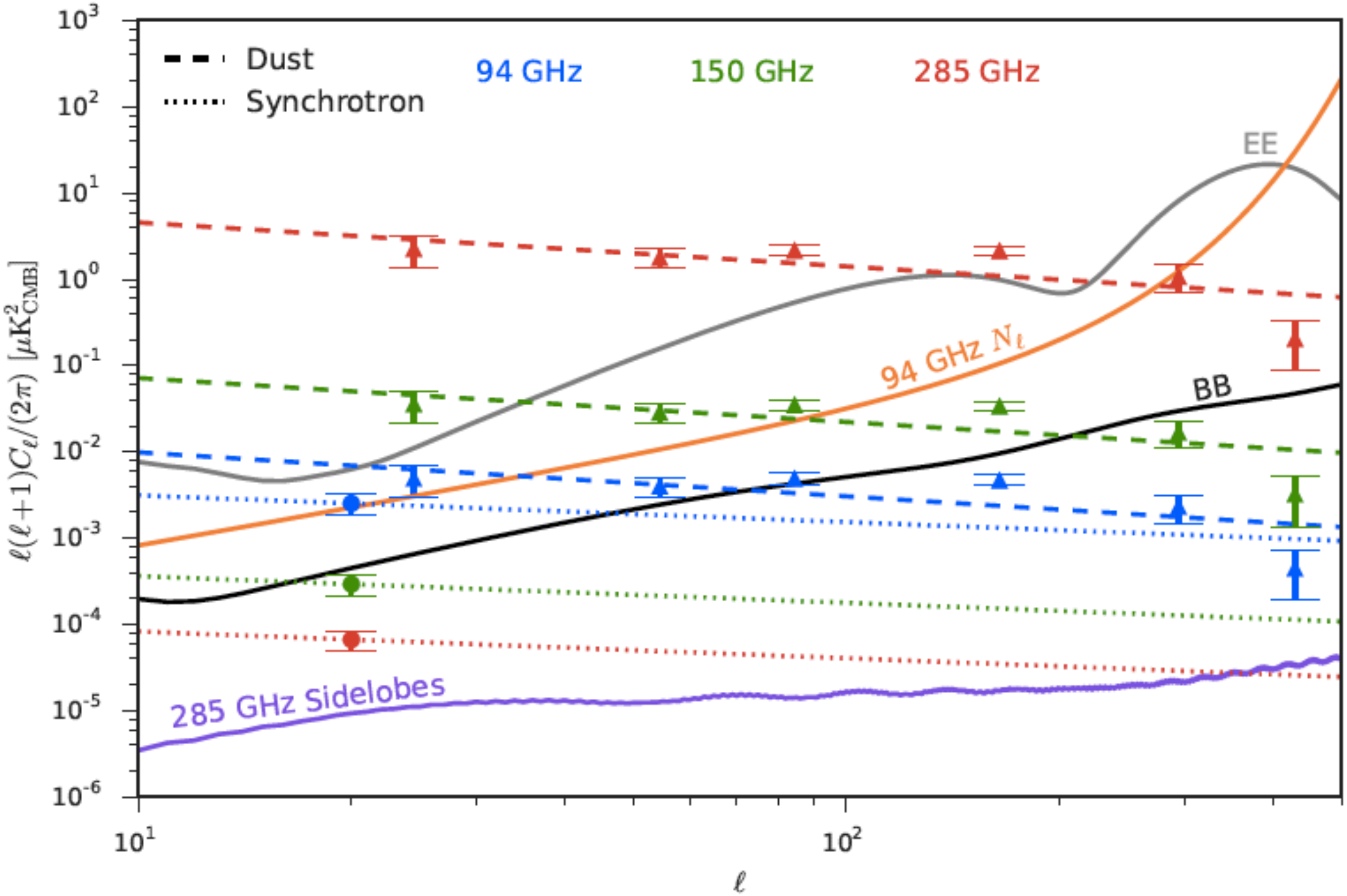
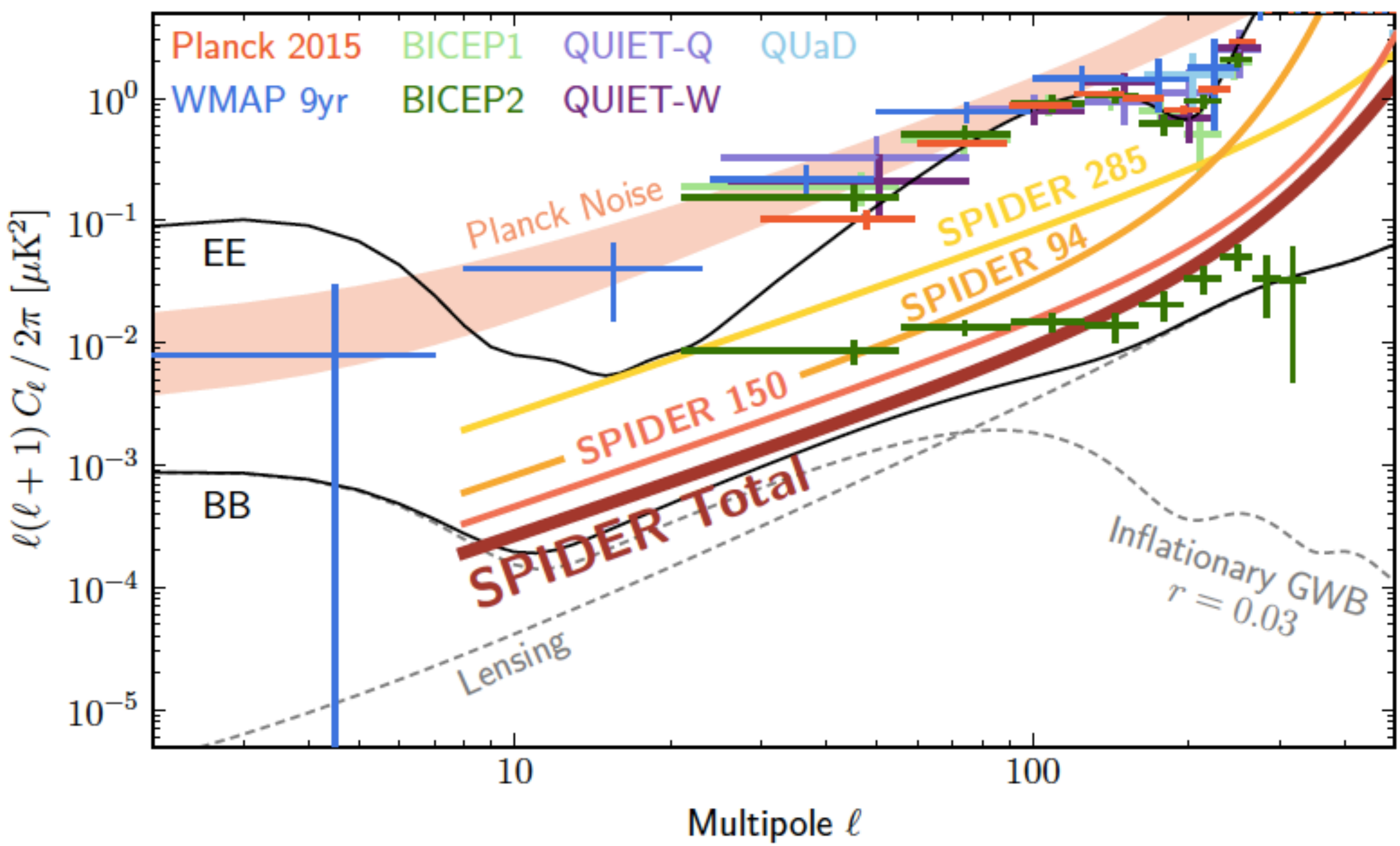


exhibit significantly less polarized dust emission. This study suggests that without component separation, degree-scale polarized dust emission will limit the constraints of *any* experiment at or above the level of $r \sim 0.03$, *even in the portions of the southern sky most free of Galactic dust emission.*

Spider 2015: Foreground Estimates (thermal dust and synchrotron)



Spider 2015: flight performance



SPIDER: Probing the early Universe with a suborbital polarimeter

Fraisse, et al. (2011)
arxiv: 1106.3087

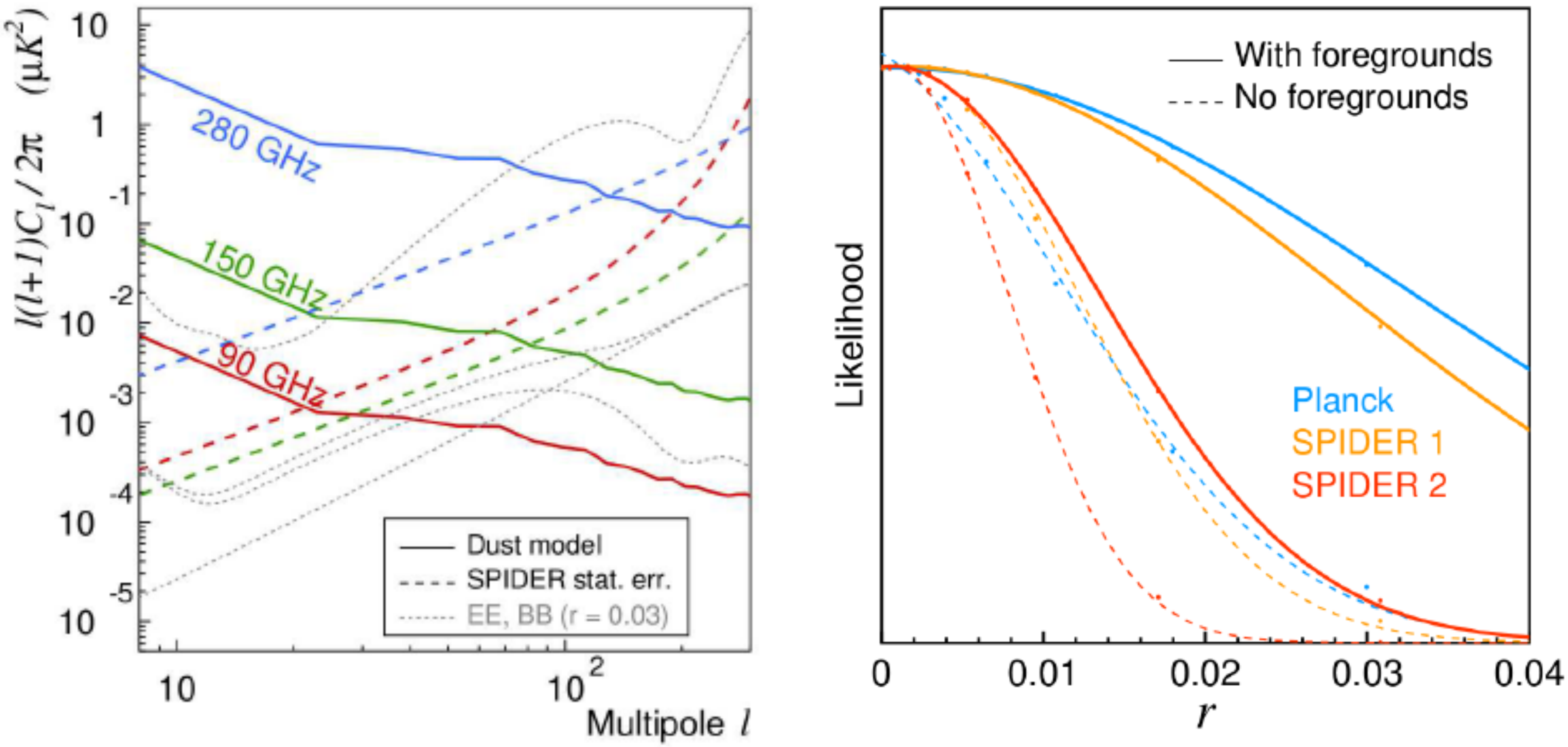


exhibit significantly less polarized dust emission. This study suggests that without component separation, degree-scale polarized dust emission will limit the constraints of *any* experiment at or above the level of $r \sim 0.03$, *even in the portions of the southern sky most free of Galactic dust emission.*