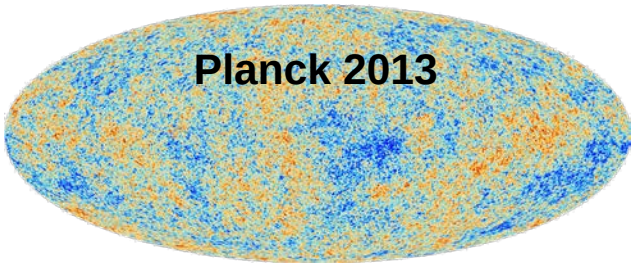
Lorenzo Moncelsi

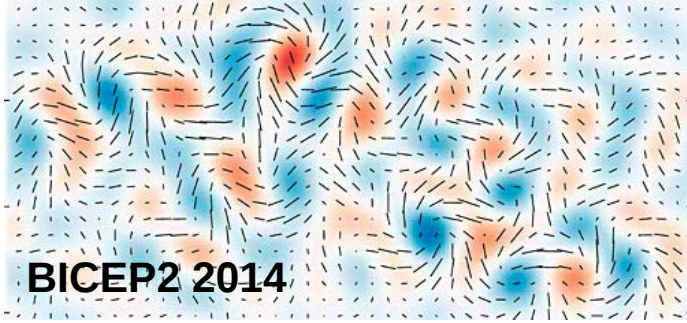
Jet Propulsion Laboratory
California Institute of Technology

SPIDER

Probing The Dawn Of Time From Above The Clouds

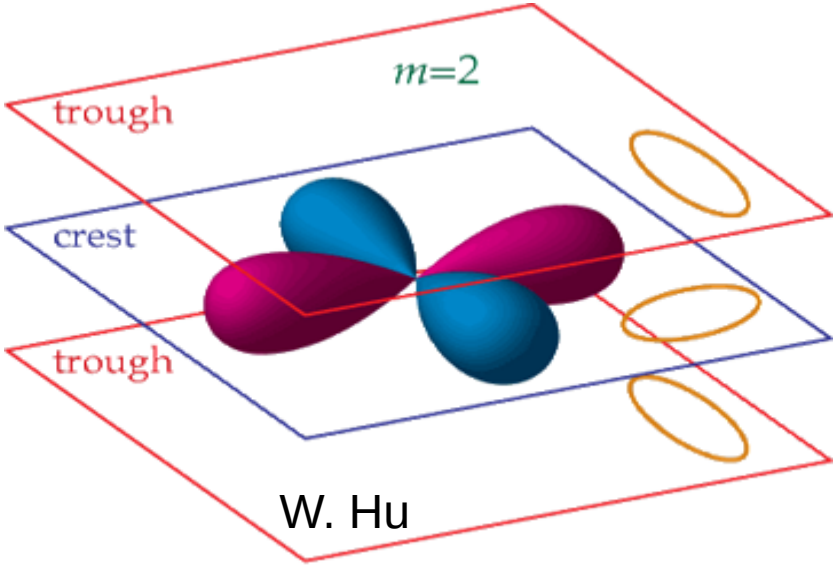


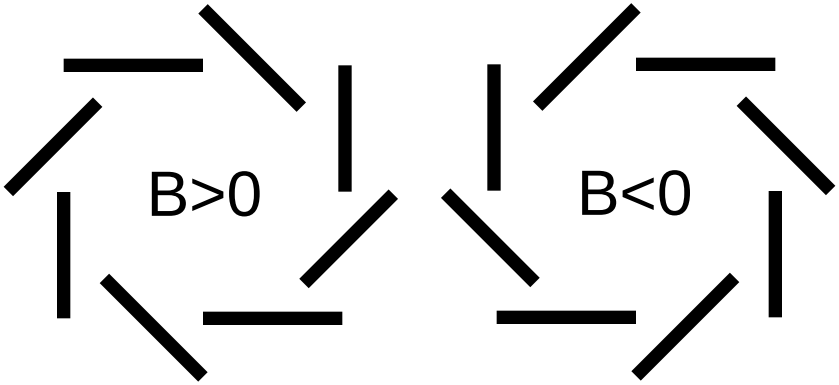
B-modes



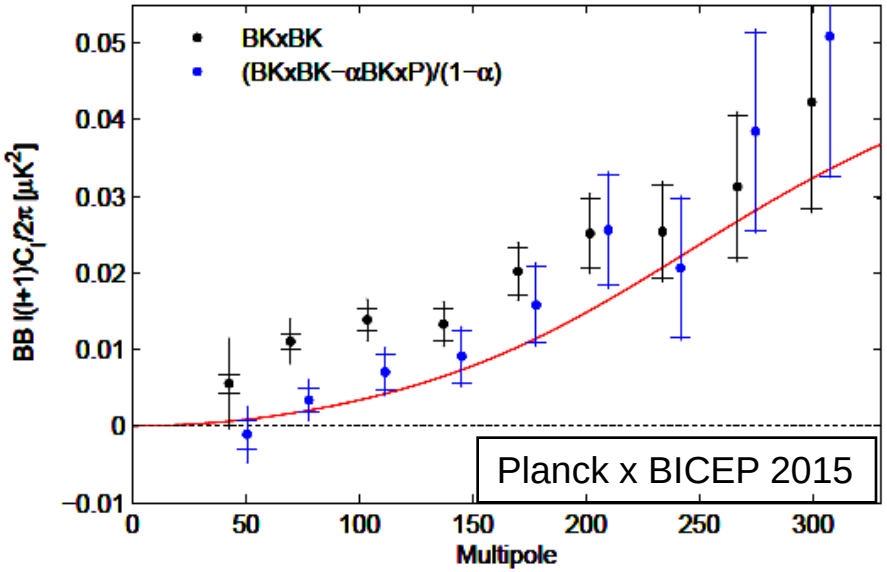
- Thomson scattering within local quadrupole anisotropies generates linear polarization
- Scalar modes → T, E
- Tensor modes → T, E, B
- Ratio $r = \Delta_T / \Delta_S$
- Gravitational waves at LSS create B-mode polarization
- Probes Lyth bound in Inflation and indirectly proves that gravity is quantized
- Ekpyrotic models → r = 0

Tensor modes – gravitational waves

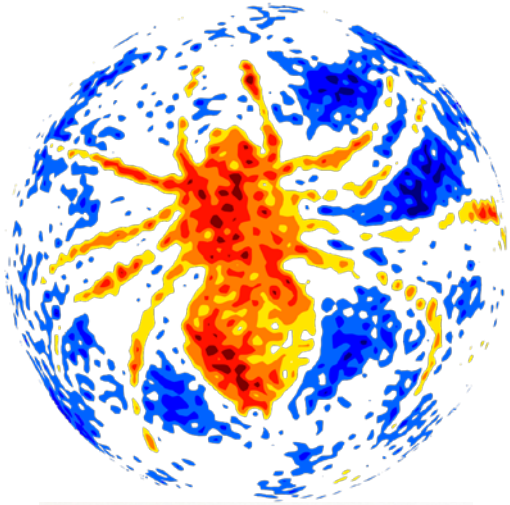




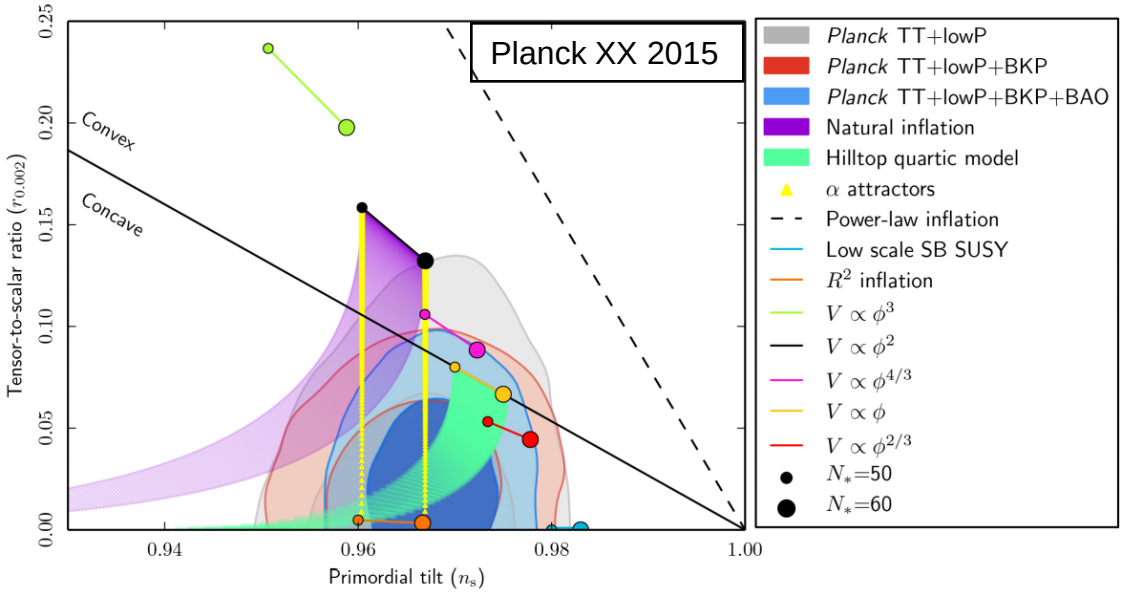
The quest for (primordial) B-modes

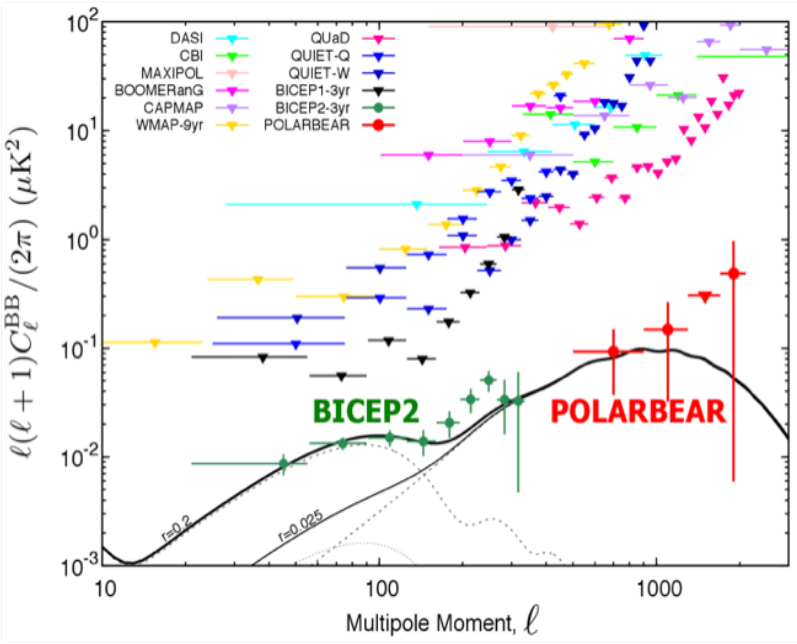


?



SPIDER





SPIDER: science goals

Measure cosmological B-modes on degree angular scales *in the presence of foregrounds*

1) Verify angular spectrum
   (many uncorrelated bins out to large scales)

2) Verify statistical isotropy
   (large sky to check sub-regions)

3) Verify frequency spectrum
   (multiple frequencies needed to separate foregrounds)

Platform summary

perfect

difficult

data quality

technical challenge

limited

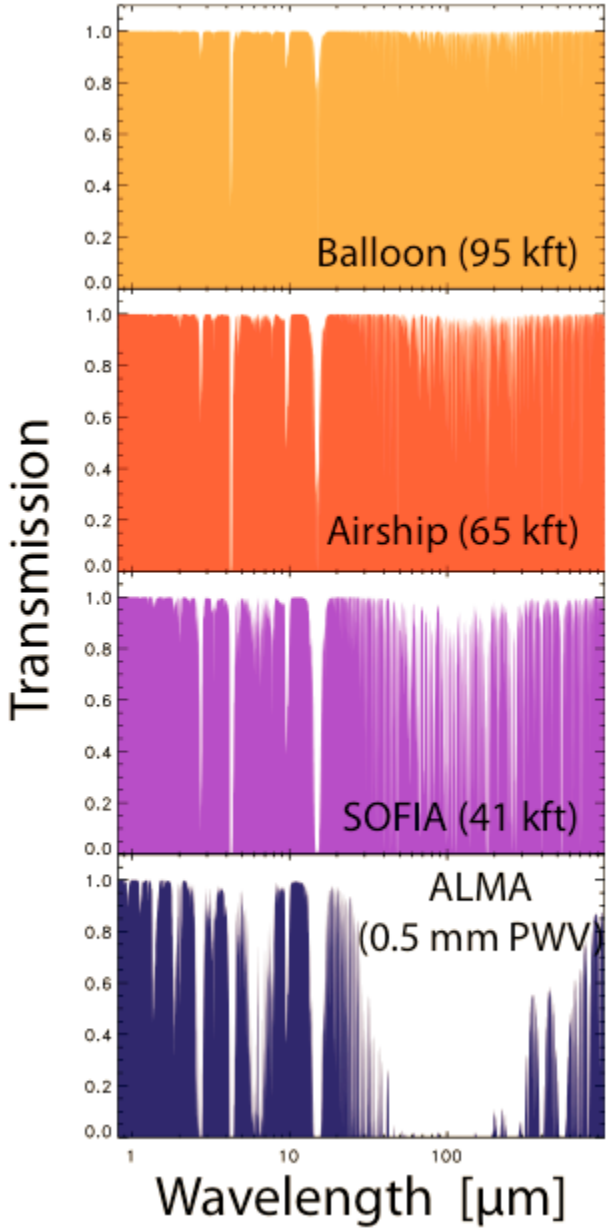
easy

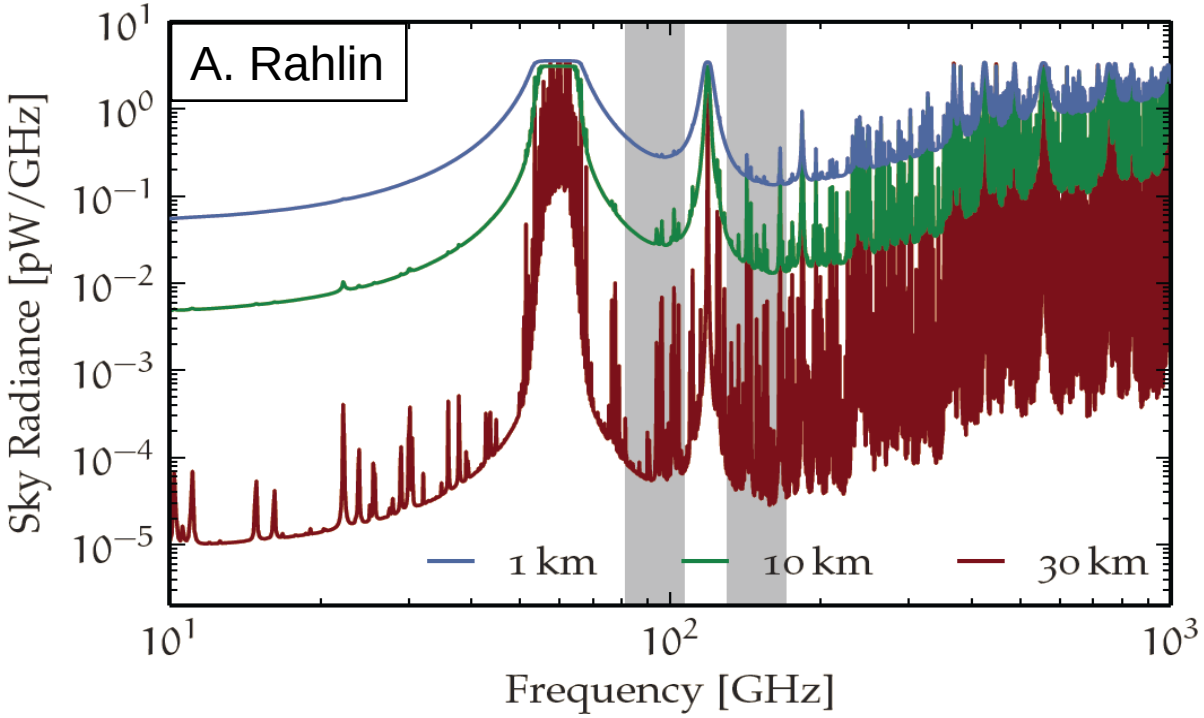
Platform summary

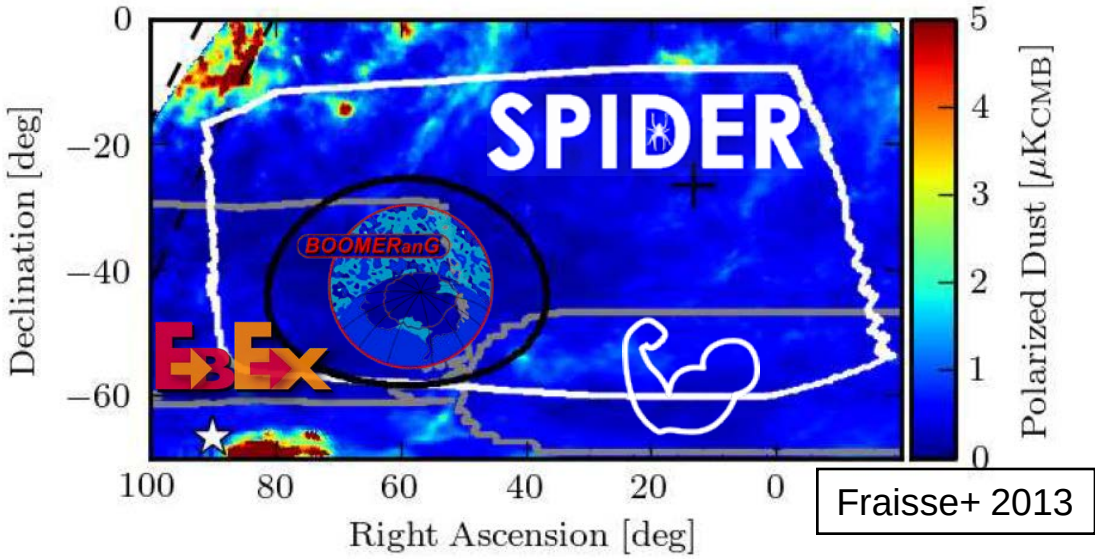
	Space	Balloon	Ground
Cost	>10-100x	1.5x	1x
Max Mirror	~8m	~2.8m	>100m
Max Payload		3 tons	
Integration Time	Years	Weeks	Indefinite
Chance to fix/ refly	~0	70% (in 1-2 years)	100% (quickly)
Platform Reliability	90%	85%	~100%
Atmosphere	None	~None	Can add noise
FunFactor	0.24	2.28	1.00
New Technology	needs SQ	careful, can bite but can SQ	easy

B. Netterfield

Why ballooning?







Fraisse+ 2013

SPIDER Overview

- Instrument: balloon-borne microwave polarimeter
- Goals: Primordial B-modes, foreground characterization
- The good:
  - Frequency coverage
  - Sky coverage
  - Pol angle coverage
- The bad:
  - Mass/power constraints
  - One shot at quality data
  - Recovery
- The ugly:
  - Government shutdowns…

Frequencies	94 / 150 GHz (+ 280)
Beam FWHM	42 / 31 arcmin
Visible sky	10%
Flight 1	Dec. ~~2013~~ 2014, McMurdo Station
Observation time	10-20 days
Pol modulation	Stepped HWP
# detectors	2400, 85% yield
NET/det	100 – 140 uK-rts
Map depth	12 / 10 uK-arcmin

BICEP2: 5 uK-arcmin (+Keck = 3.4)

SPIDER

Princeton University
W. Jones
A. Fraisse
Z. Kermish
M. Hasselfield
A.S. Rahlin
J. Gudmundsson
A. Gambrel
E. Young

Case Western Reserve Univesity
J. Ruhl
S. Bryan
J. Nagy
S. Wen
R. Bihary

UKZN
C. Chiang

University of Toronto
C.B. Netterfield
J.R. Bond
S. Benton
M. Farhang
L. Fissel
N. Gandillo
J. Hartley
I. Padilla
J. Soler
J. Shariff

University of British Columnbia
M. Halpern
M. Amiri
D. Wiebe

Caltech/JPL
J. J. Bock
B. P. Crill
O. Doré
J. P. Filippini
S. Golwala
W. Holmes
V. V. Hristov
R. O'Brient
P. V. Mason
L. Moncelsi
T. A. Morford
M. C. Runyan
A. Trangsrud
R. S. Tucker
A. D. Turner

APC
K. Ganga

Cardiff University
P. Ade
E. Pascale
C. Tucker

Imperial College
C. Contaldi
C. Clark

Cambridge
C. MacTavich

Stanford
K.D. Irwin
C.L. Kuo

NIST
Carl Reintsema
George Hilton

SPIDER: the instrument

• Lightweight, carbon fiber gondola frame and sun shields

• Largest cryogenic vessel on a balloon payload

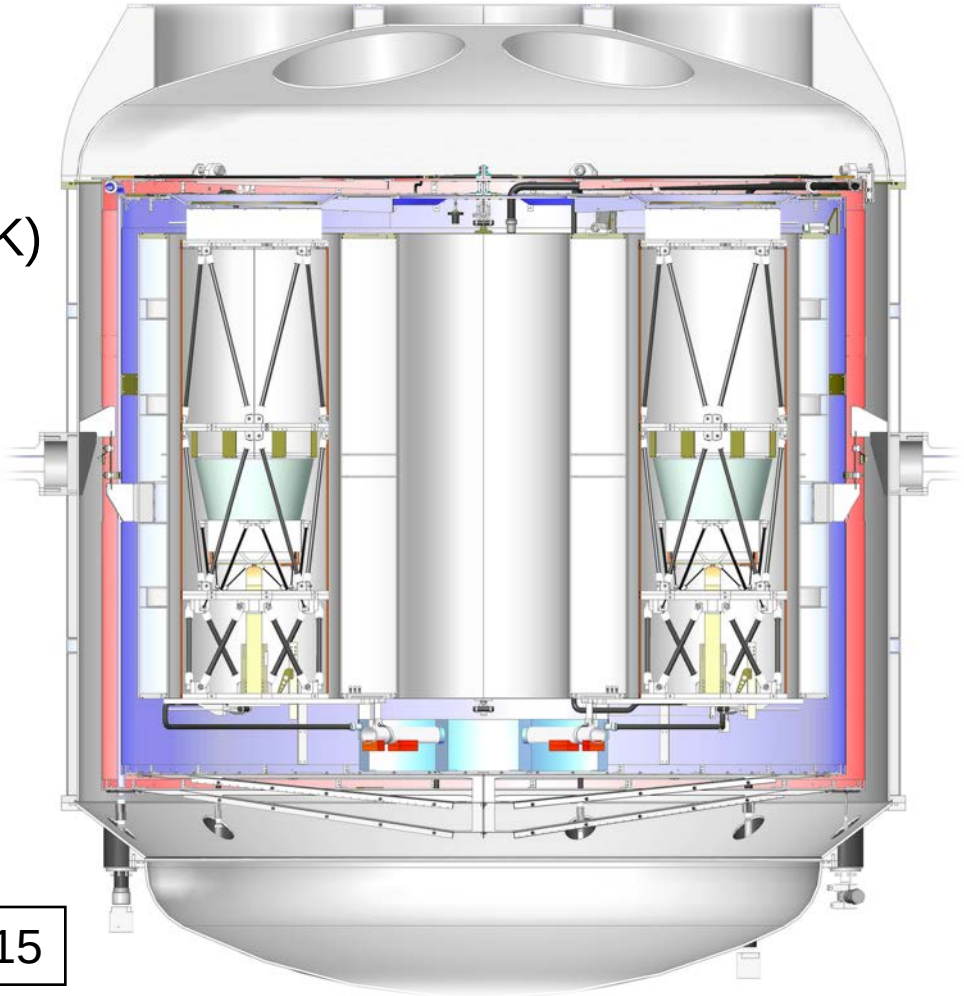
• Reaction wheel + pivot for fast Az scanning

• Redundant pointing sensors for in-flight and post-flight reconstruction
- star cameras
- ~~dGPS~~
- gyroscopes
- pinhole sun sensors
- magnetometer

• Designed for nearly autonomous observations

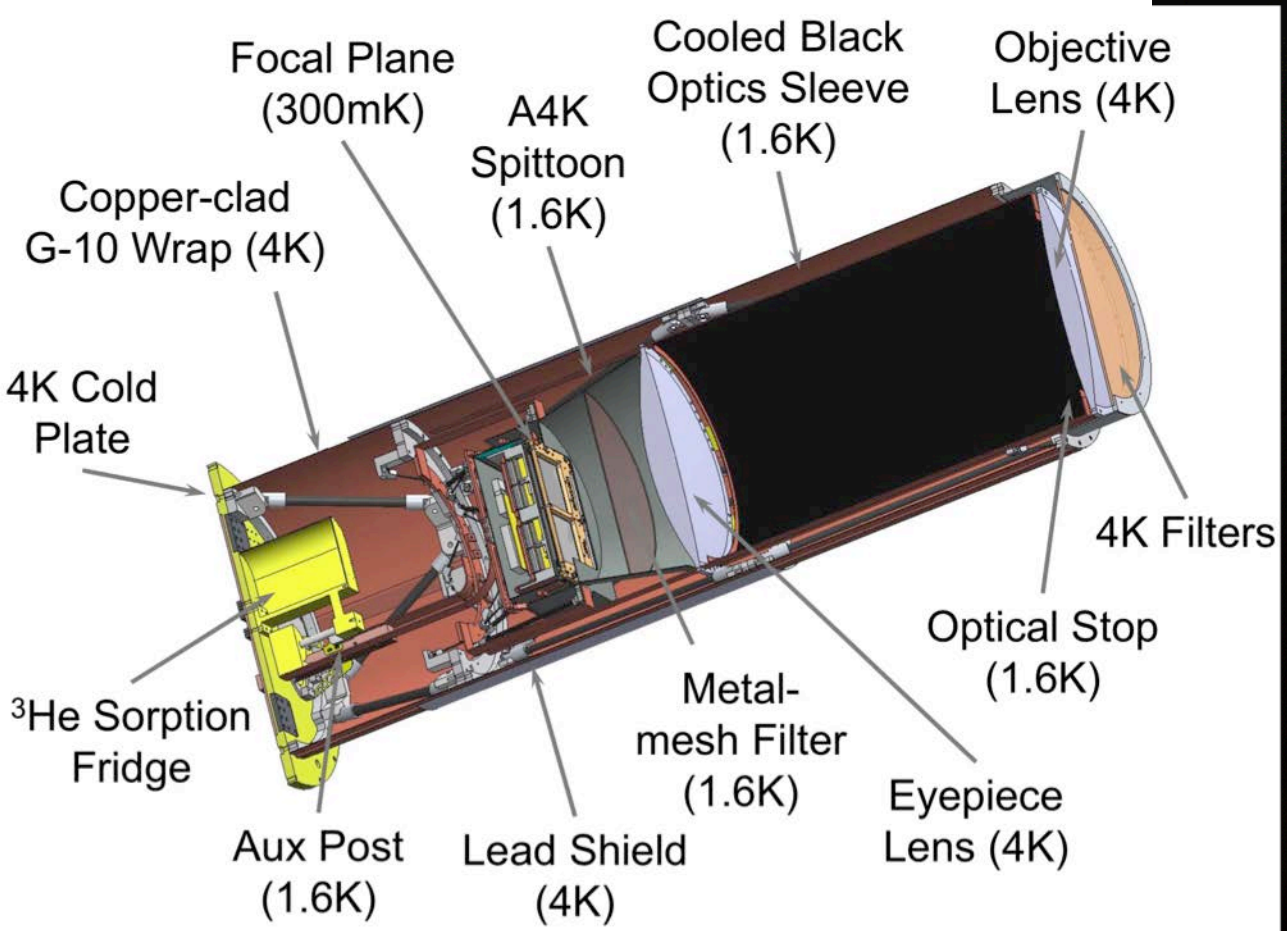
Cryogenic System

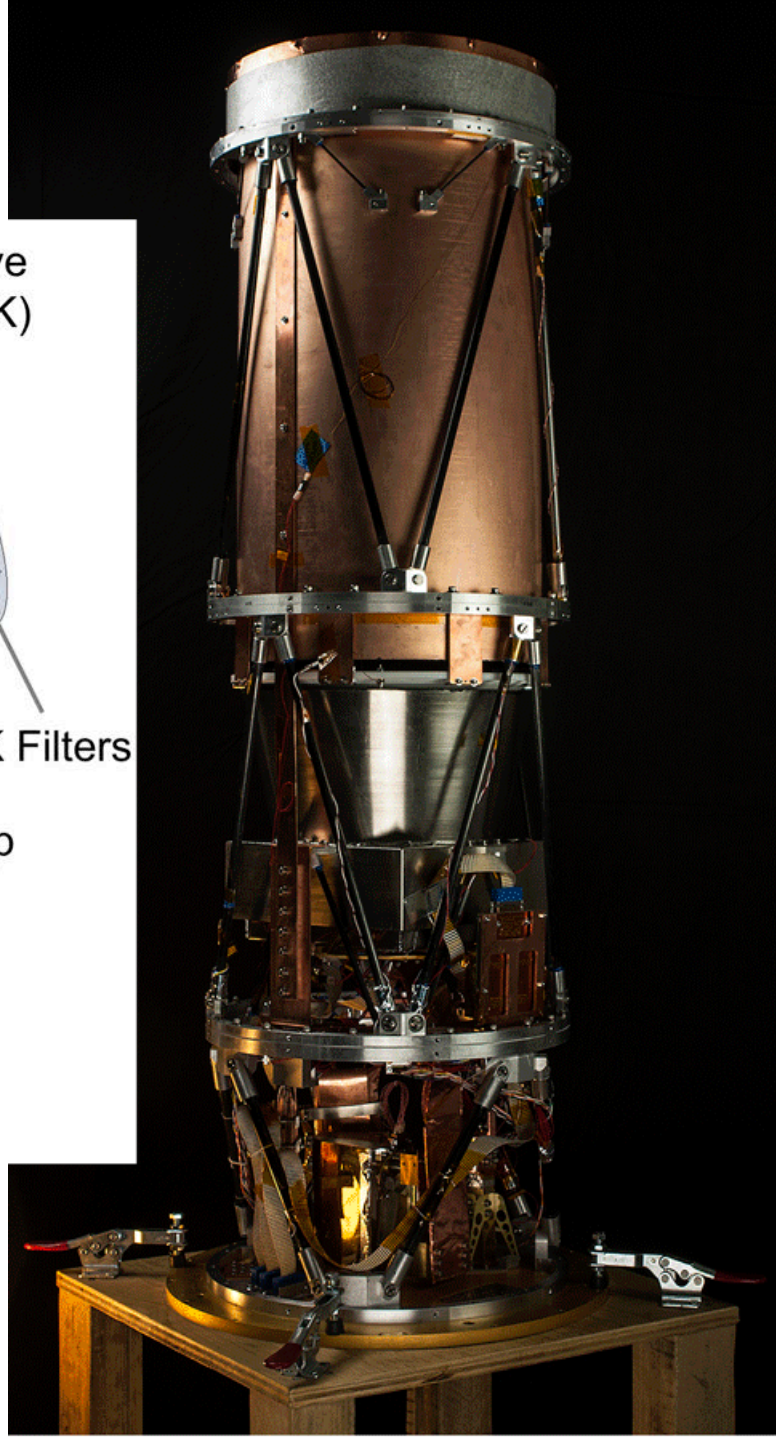
- Lightweight (850 kg)
- 1300-L LHe4-only cryostat (4K)
- Two vapor cooled shields (30K, 120K)
- Capillary-fed 20-L superfluid LHe4 tank (1.5K)
- Closed-cycle He3 adsorption fridge per telescope (300mK)
- Two weeks from close up to cold detectors
- Baselined for 20 day hold time



Gudmundsson+ 2010 & 2015

The Telescope



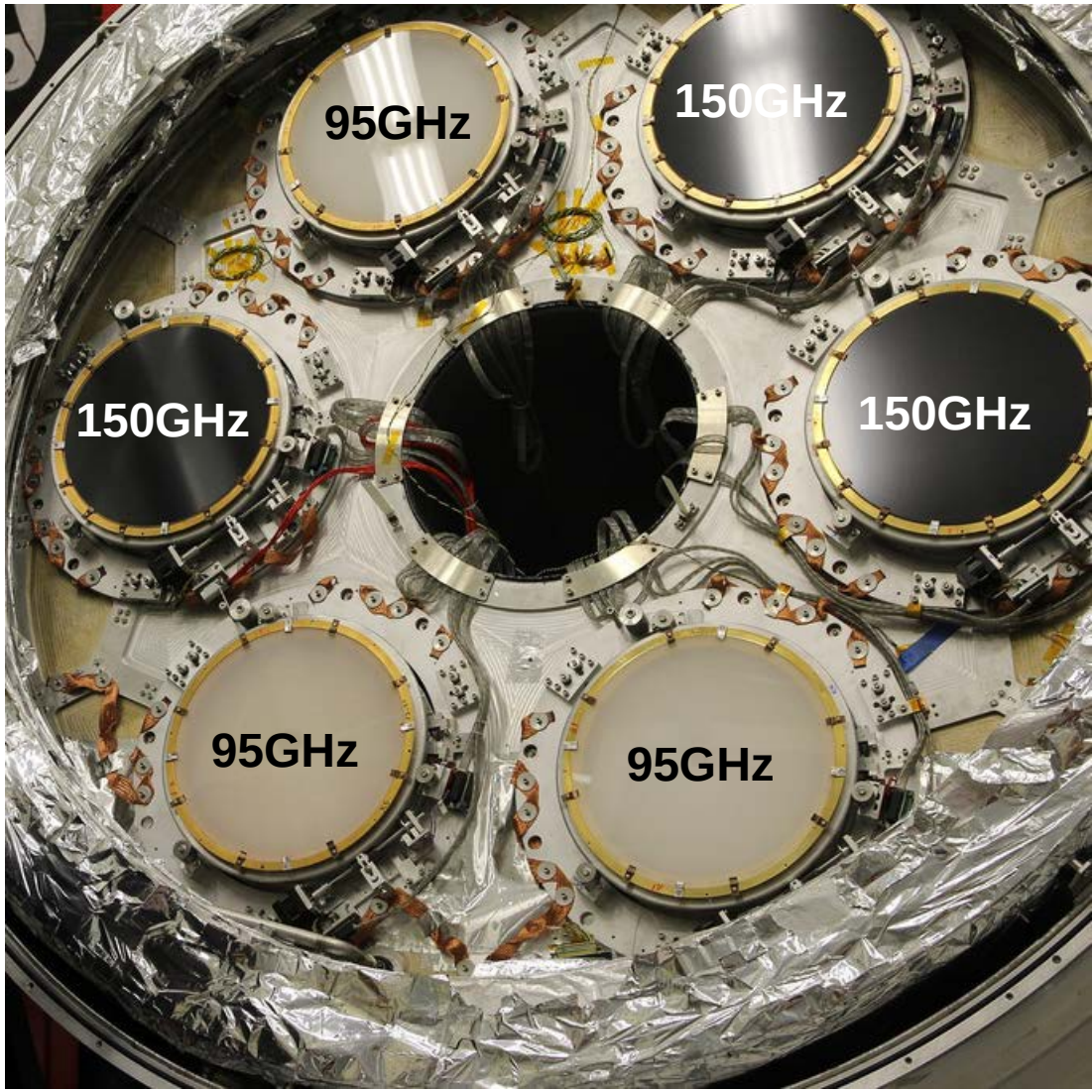


Runyan+ 2010
Filippini+ 2010

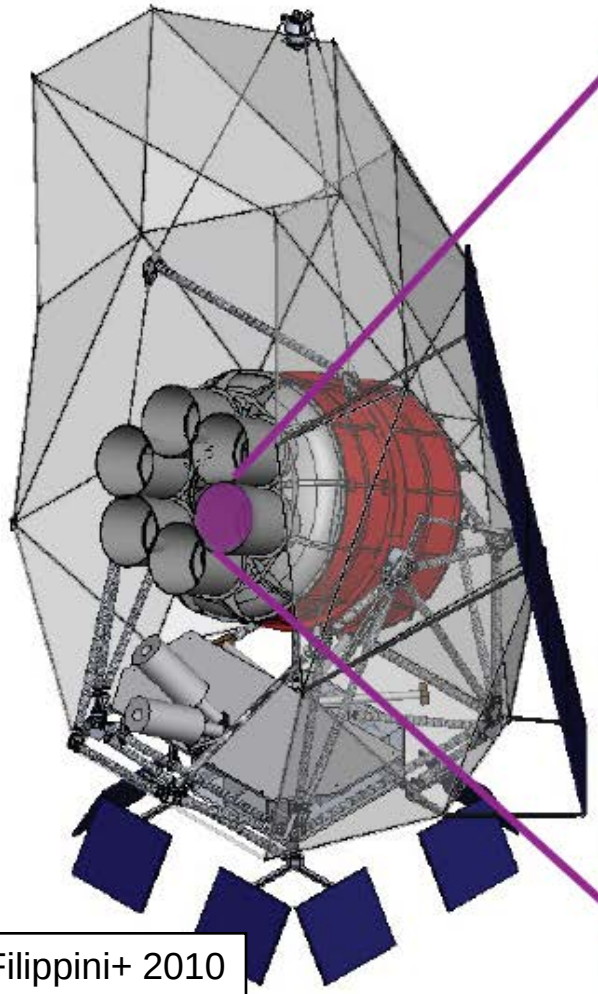
Half-Wave Plates

- Sapphire with quartz (90 GHz) and Cirlex (150 GHz) bonded AR coatings
- Custom worm-gear mechanism turns at 4K
- Stepped twice daily to modulate polarization
- Custom absolute and relative encoders to reconstruct HWP angle to better than 0.1°

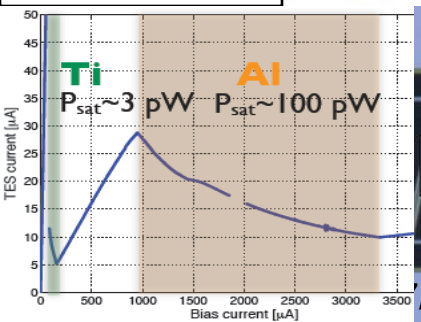
Bryan+ 2010

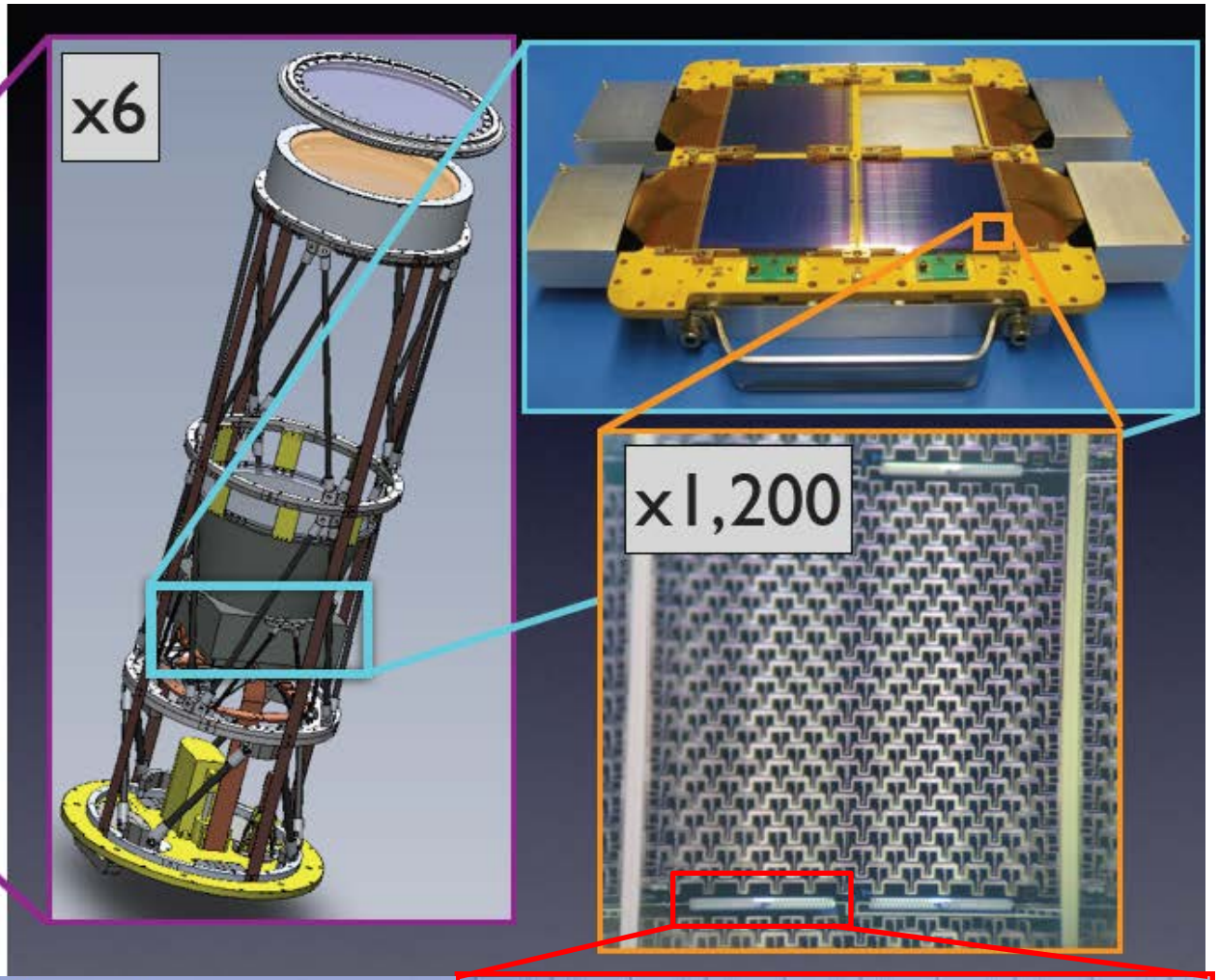


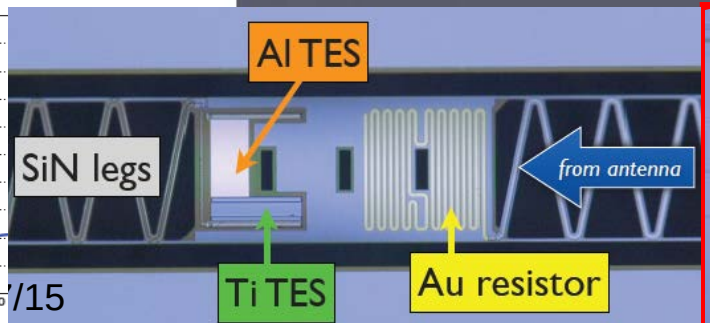
FPU and TES architecture



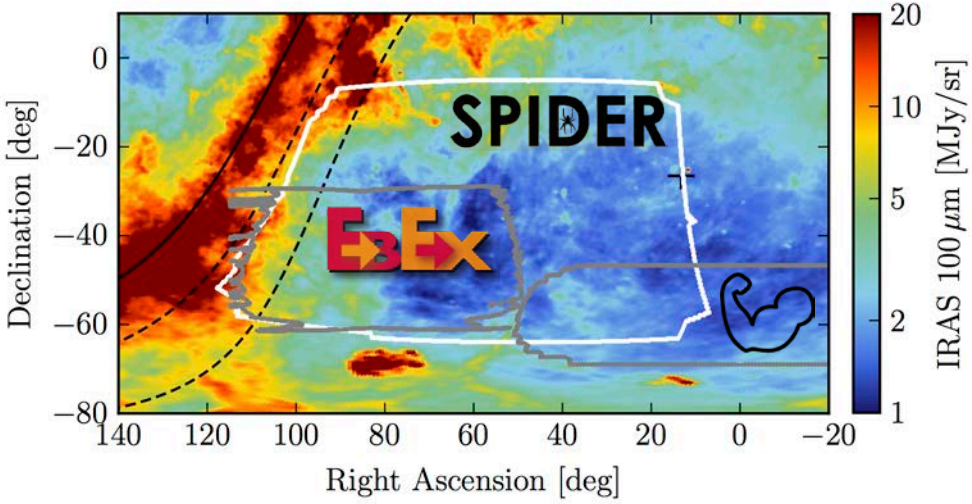
Filippini+ 2010



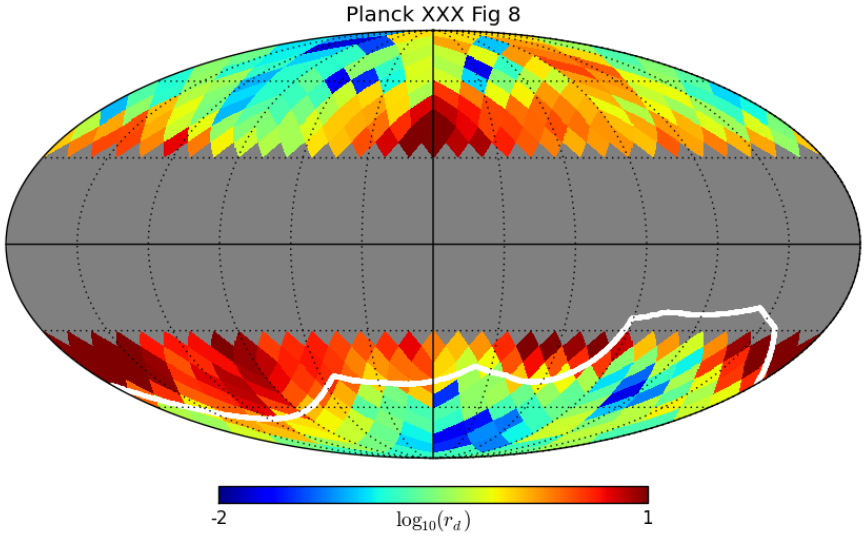




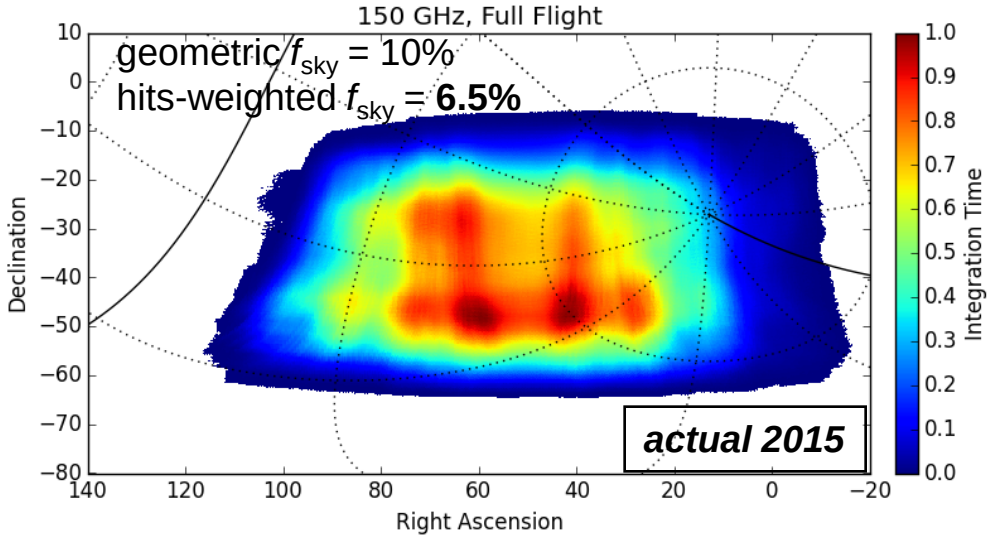
Scan strategy

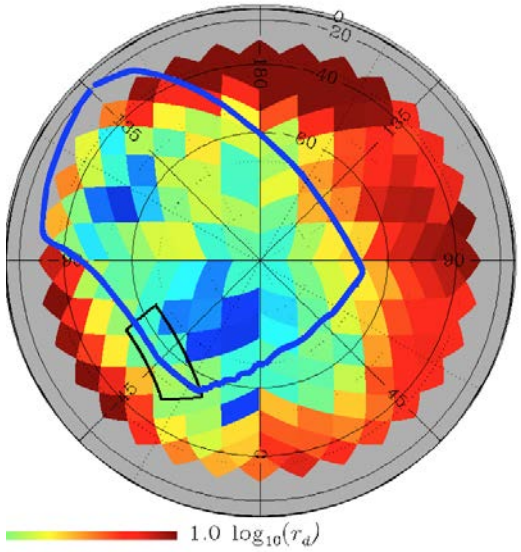


Rahlin+ 2014

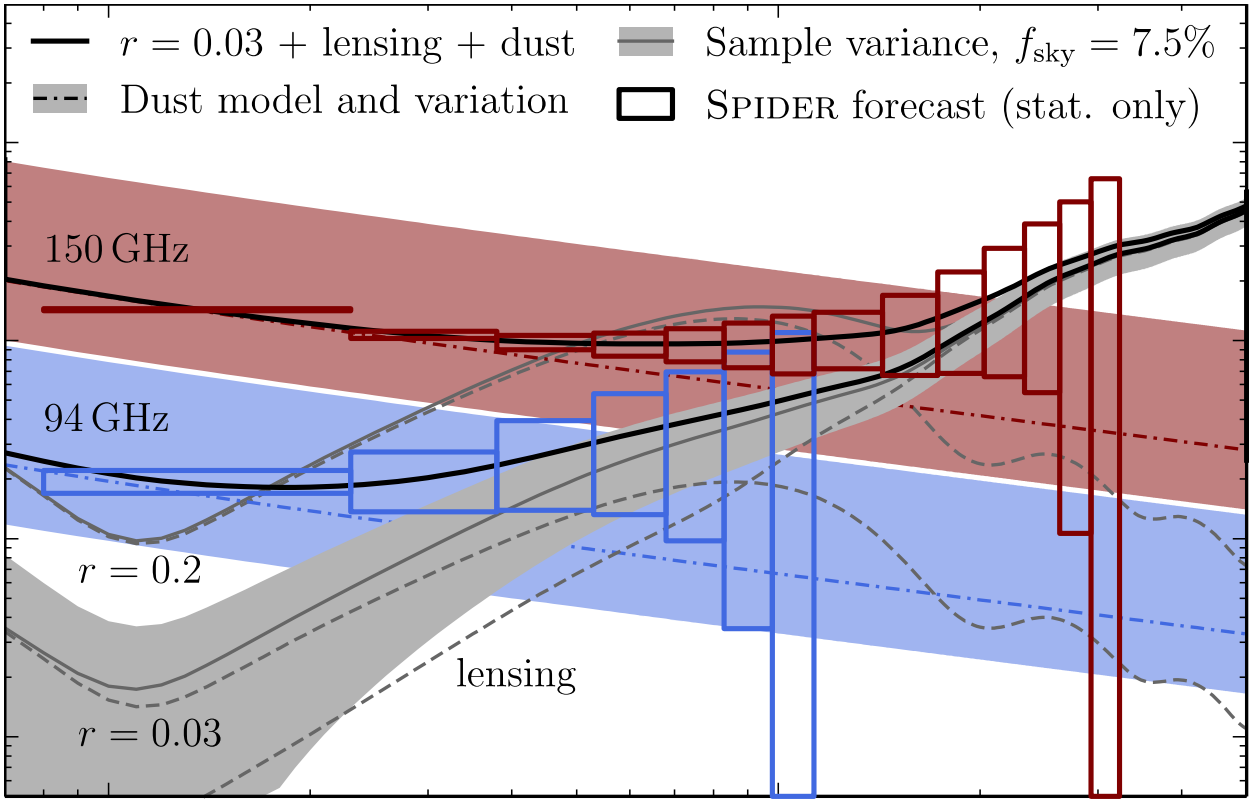


Planck XXX 2014





Expected Sensitivity

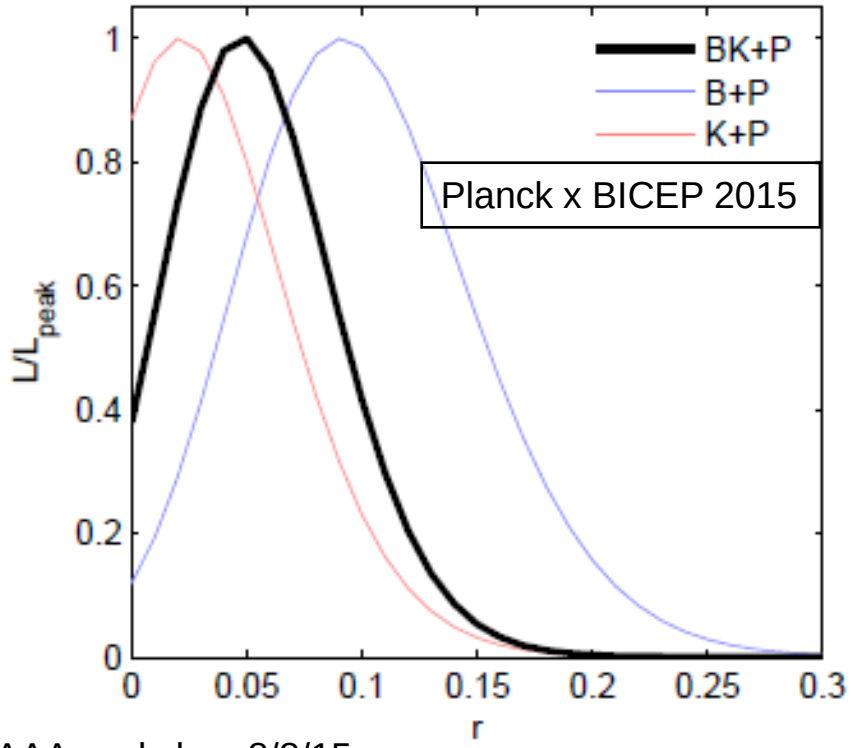


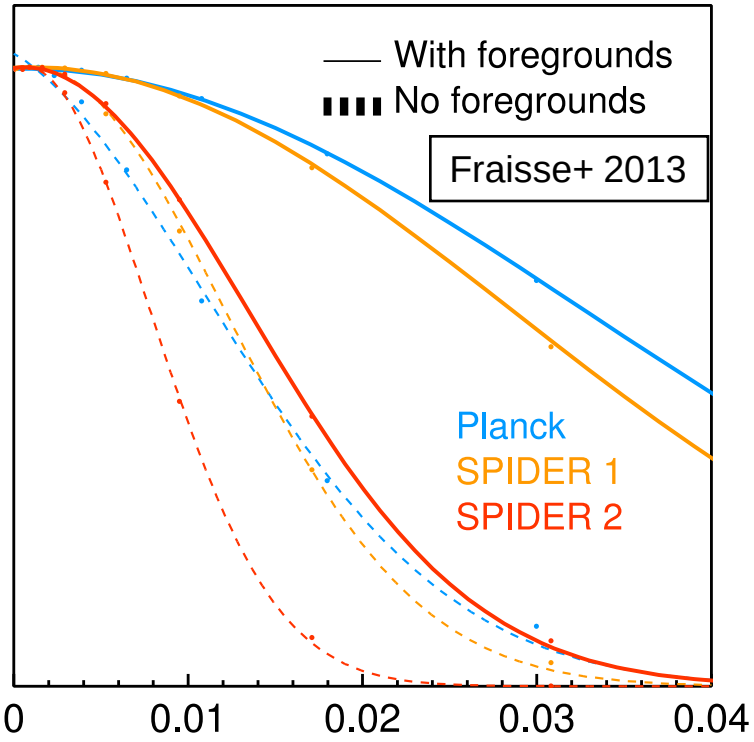
Rahlin+ 2014

20-day flight

Expected Sensitivity

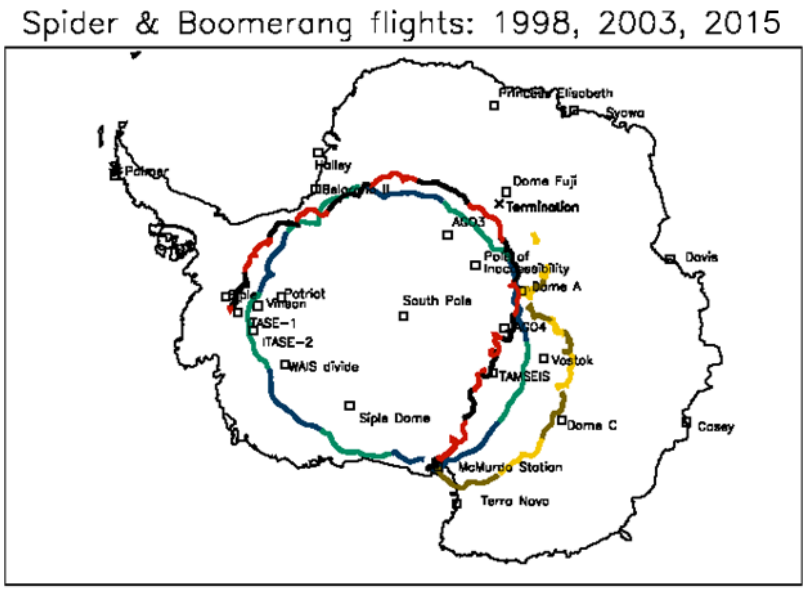
- Dec 2014: 3x (90 GHz, 150 GHz)
  - r<0.03 (99%CL) without FG for a 20-day flight
- Dec 2017: 2x (90 GHz, 150 GHz, 280 GHz)
  - r<0.02 (99%CL) without FG, r<0.03 (99%CL) with FG

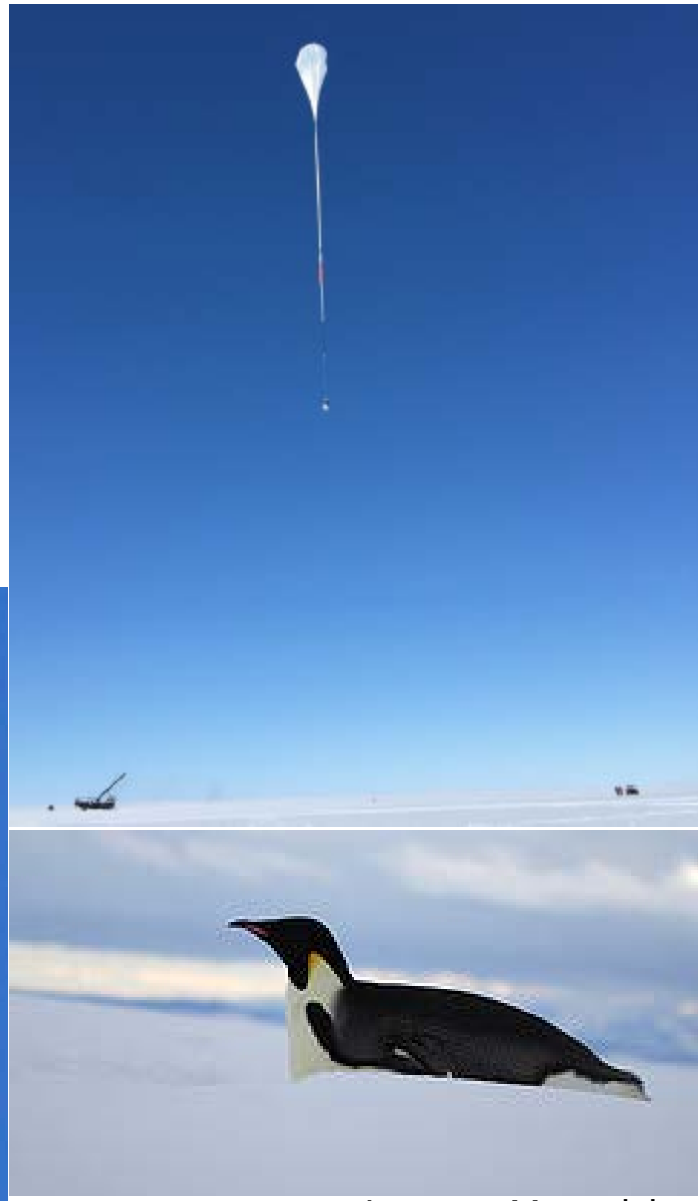




SPIDER: flight summary

- launched on 1/1/15
- all systems operational! (except dGPS)
- 16 days of science data
- f_{sky} = geometric 10%, hits-weighted **6.5%**
- **1.5 TB** of data (analysis ongoing)

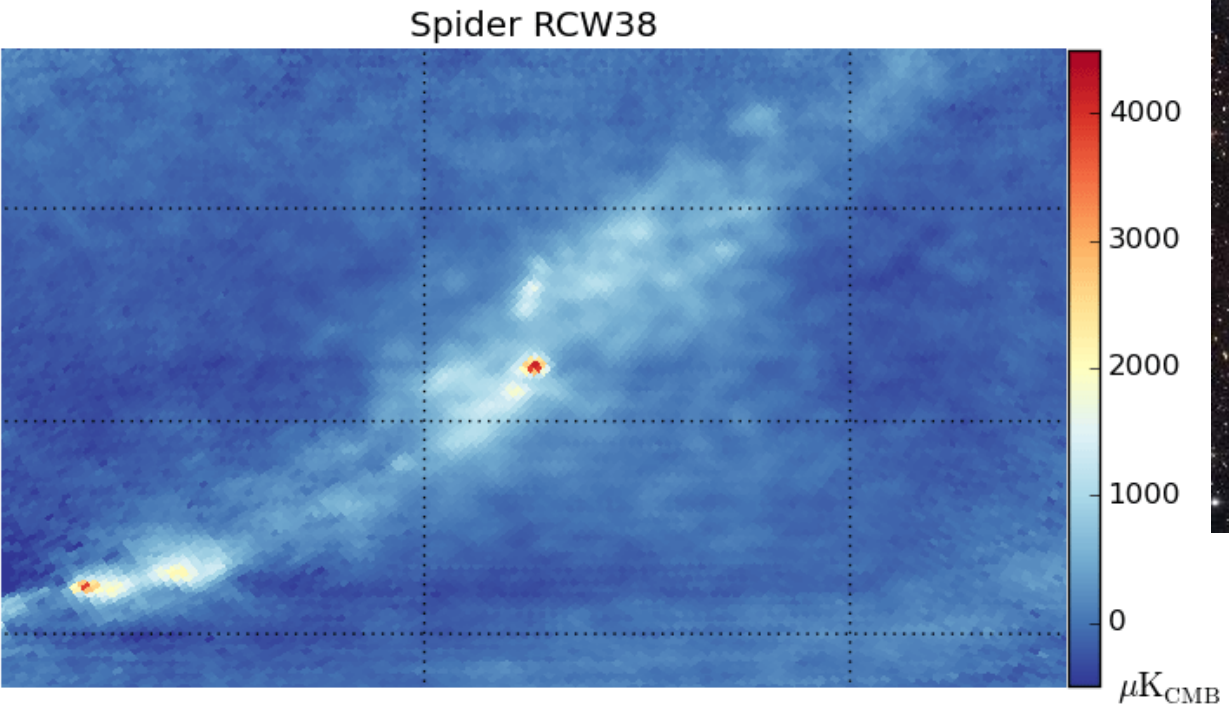




SPIDER: in-flight performance

Preliminary map of RCW38 (bright embedded star cluster 5500 LY away)

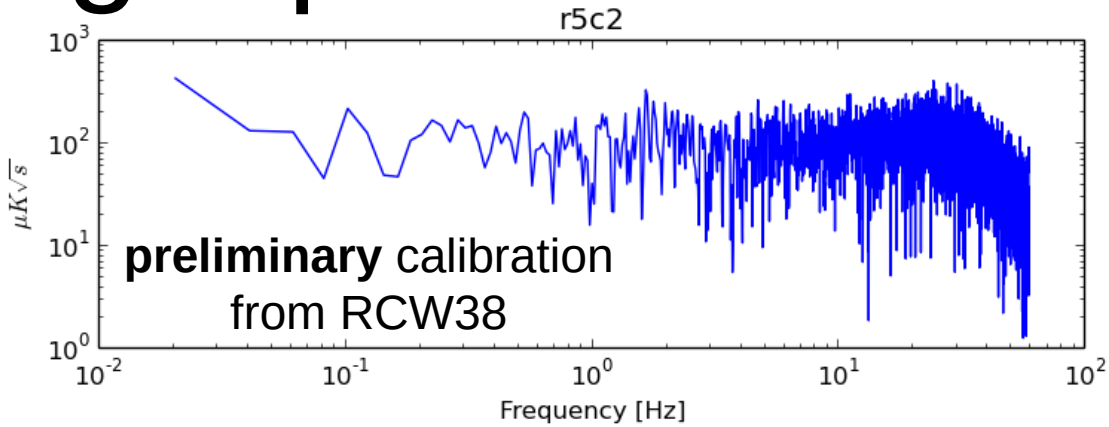
- one of four 60-minute observations for in-flight pointing check
- one 150 GHz telescope shown, simple filtering
- compared to Planck map filtered to match

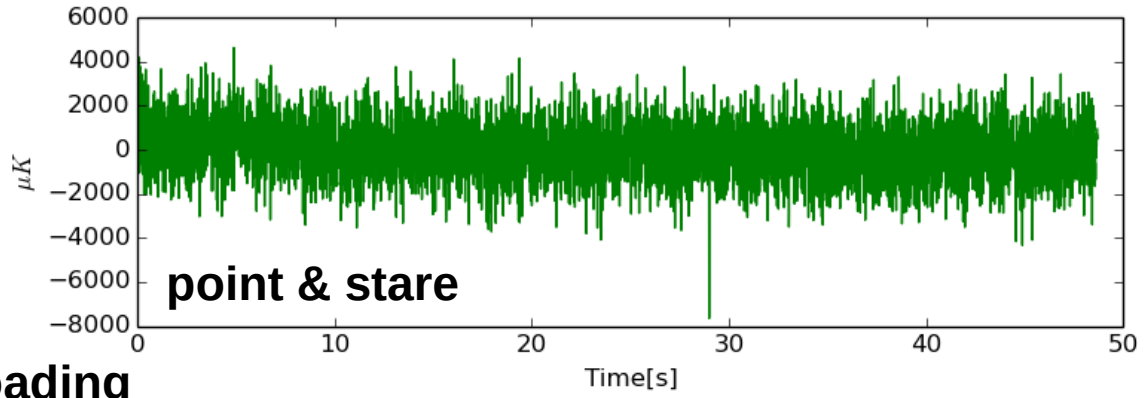


Chandra/Spitzer/2MASS

SPIDER: in-flight performance

- NETs in line with expectations
- cosmic rays are not an issue
- no obvious magnetic pick-up
- pointing reconstruction <1’
- <10% total flagging expected





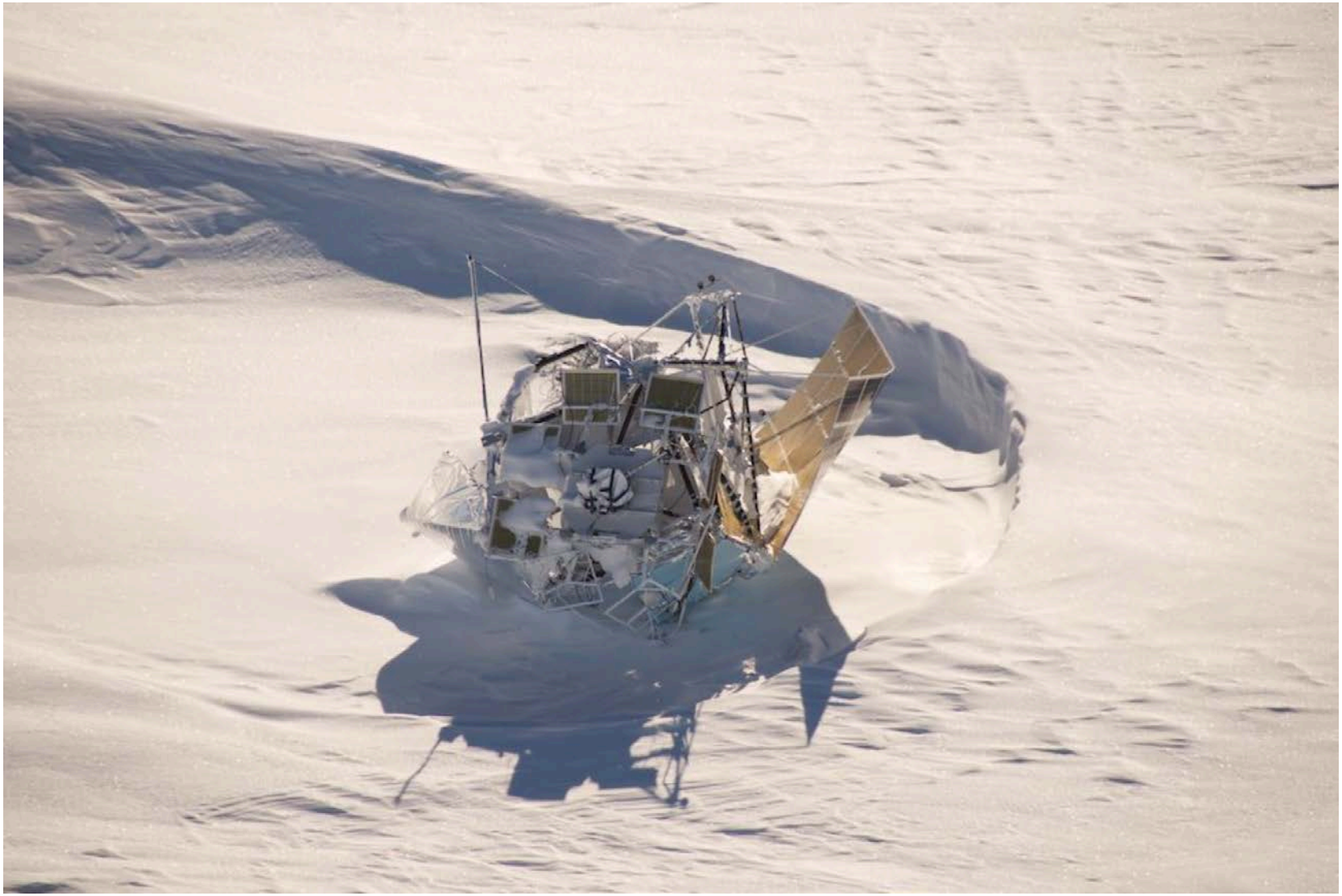
Total in-flight optical loading

instrument	frequency (GHz)	in-band power (pW)
SPIDER	95	0.25
SPIDER	150	0.35
BOOMERanG	150	0.75
BICEP2	150	4.7

corresponding to a warm telescope emissivity of ~0.3%

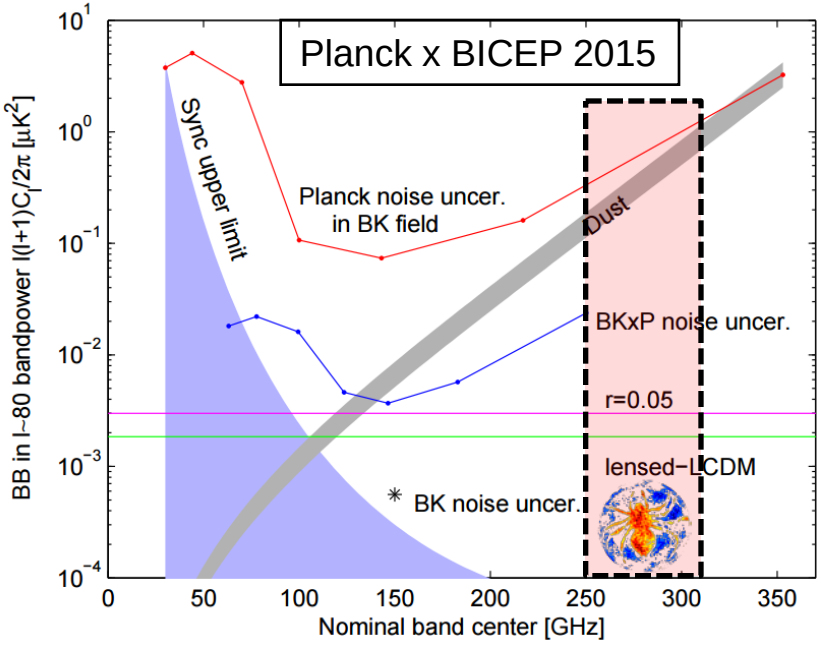
$\varepsilon \approx P_{opt}/kT\Delta\nu$ with T=250K

SPIDER: recovery



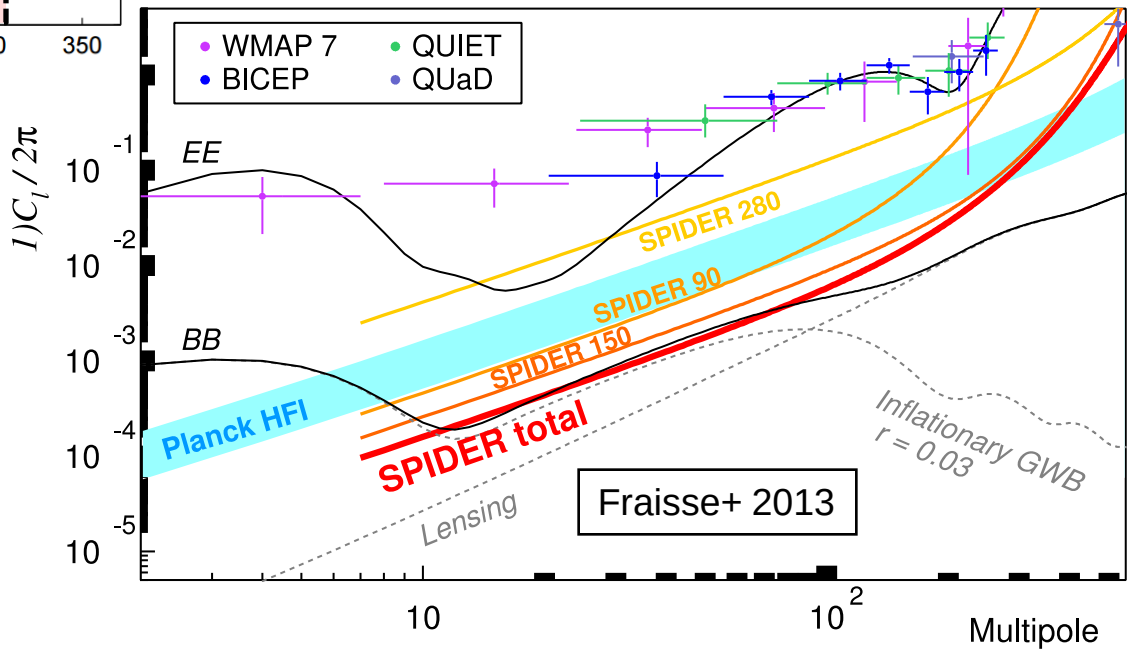
Credits: British Antarctic Survey

SPIDER2



- foreground-optimized channel: **280 GHz**
- very hard to observe from the ground
- r < 0.03 (3σ) with foregrounds
- planning for Dec 2017, pending *recovery*

new cryostat under construction!



QUESTIONS?

SCAR AAA: site testing at mm wavelengths in Northern Hemisphere