SPIDER 2015 Flight Systematics

B-mode from space workshop | Berkeley | Dec. 5, 2017

Edward Young
Princeton University

Deployment 2014-2015

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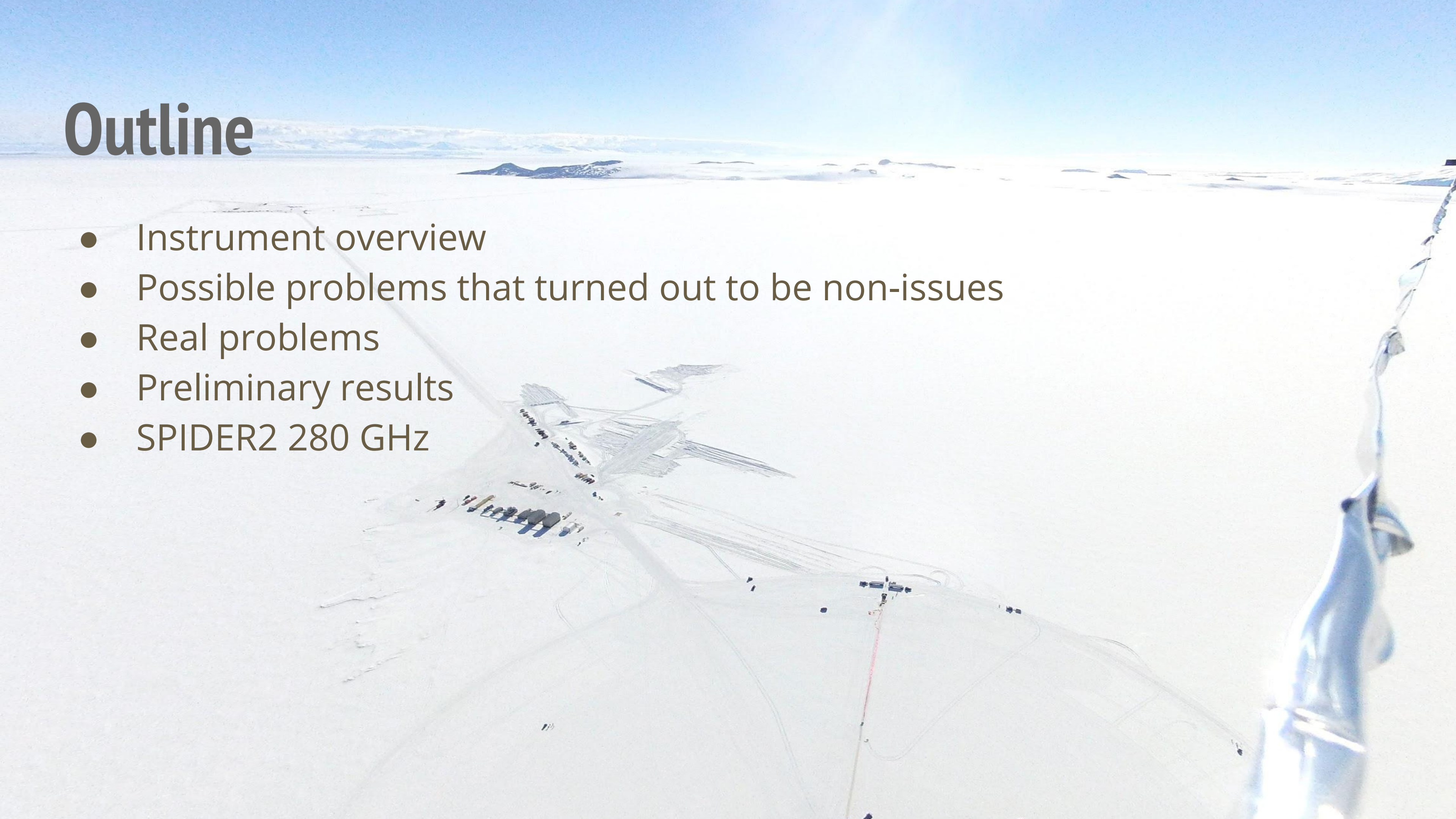
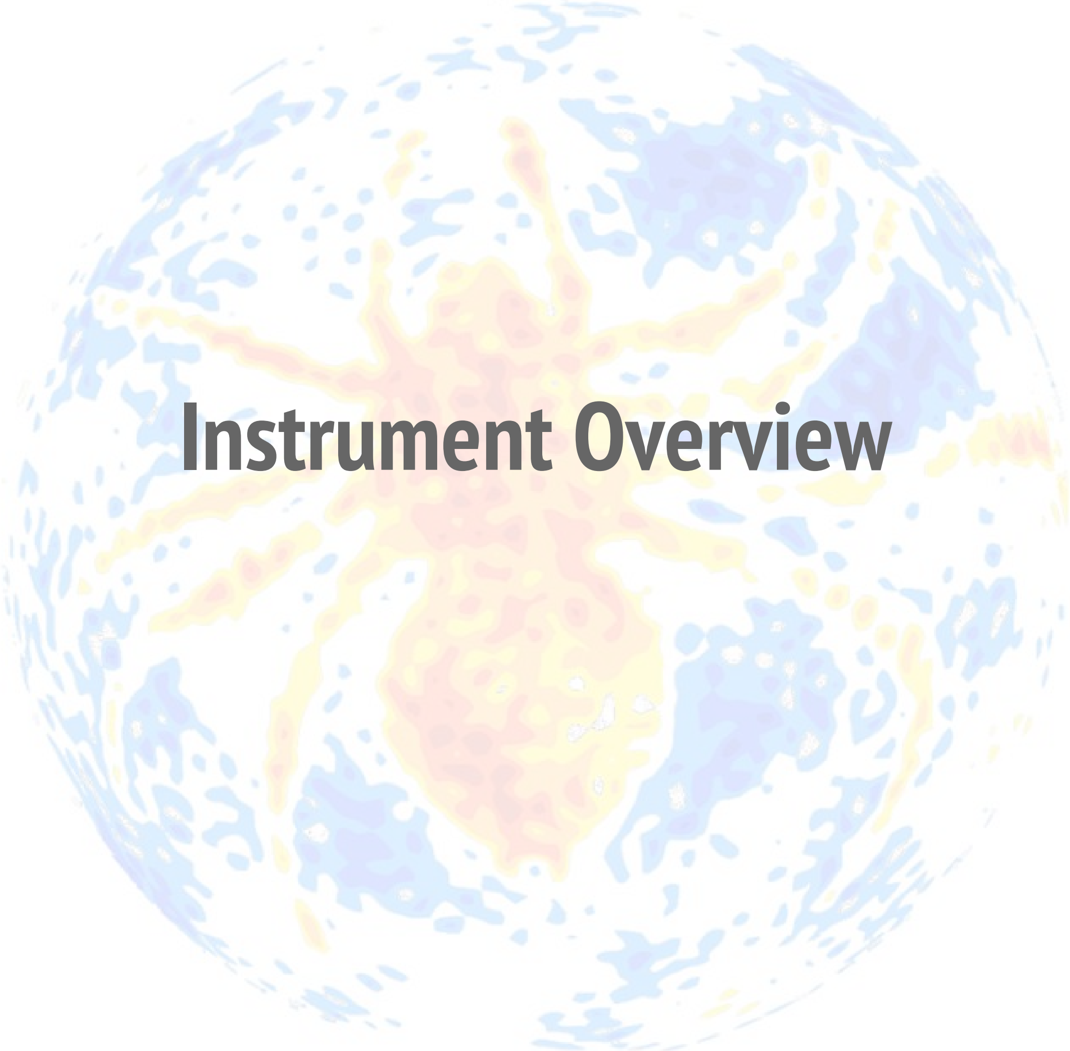
Outline



- Instrument overview
- Possible problems that turned out to be non-issues
- Real problems
- Preliminary results
- SPIDER2 280 GHz

Instrument Overview



Instrument overview

- Balloon-borne polarimeter
- Mapped approximately 10% of the sky in a 16.5 day flight
- Lightweight carbon fiber gondola
- 6 independent telescopes in a single cryogenic and vacuum system
  - 3 at 95 GHz, 3 at 150 GHz
- Custom control electronics

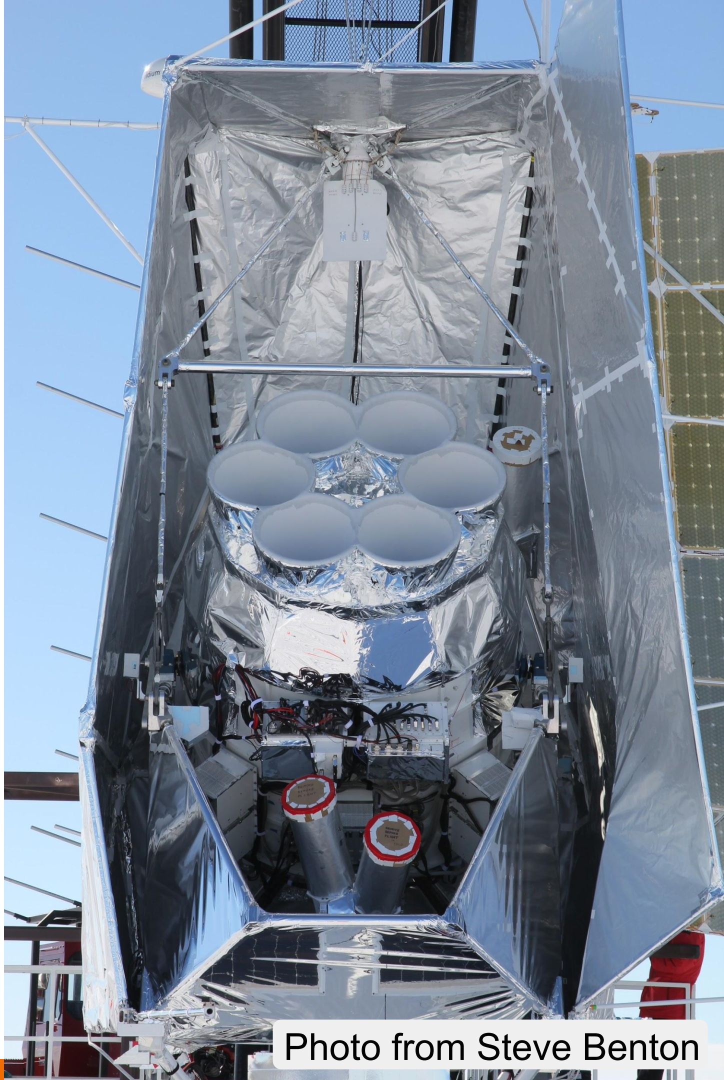


Photo from Steve Benton

Cryogenic system

- 1300 Liter LHe4 cryostat
- Two vapor-cooled shields
- Capillary-fed 12 Liter superfluid tank
- Closed-cycle He3 adsorption fridge per telescope

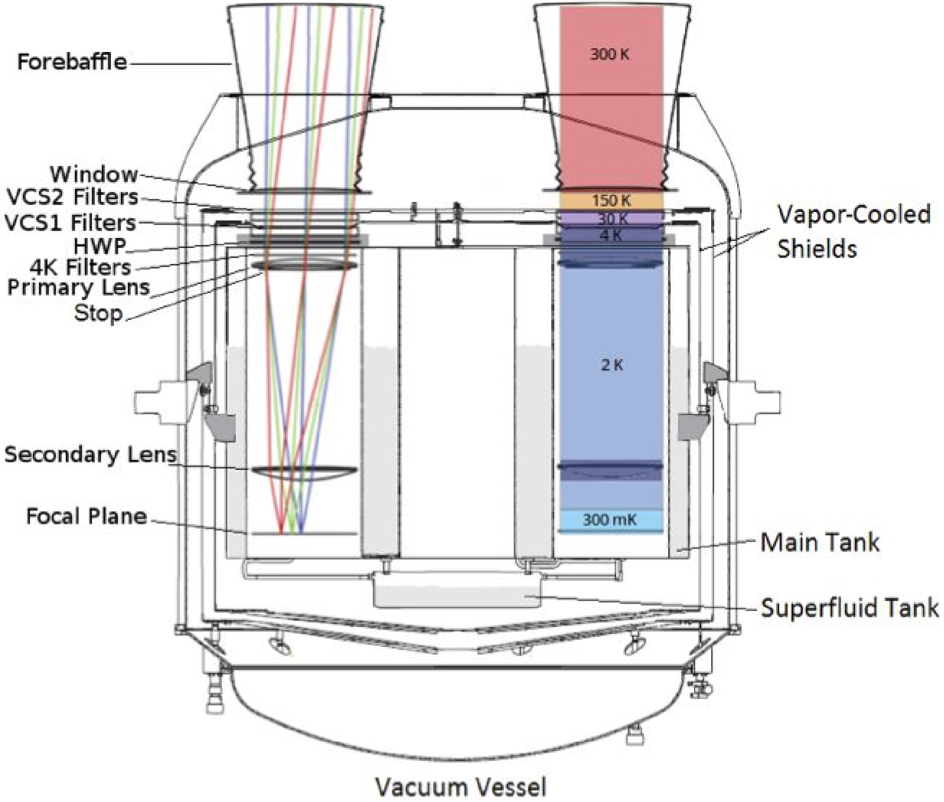
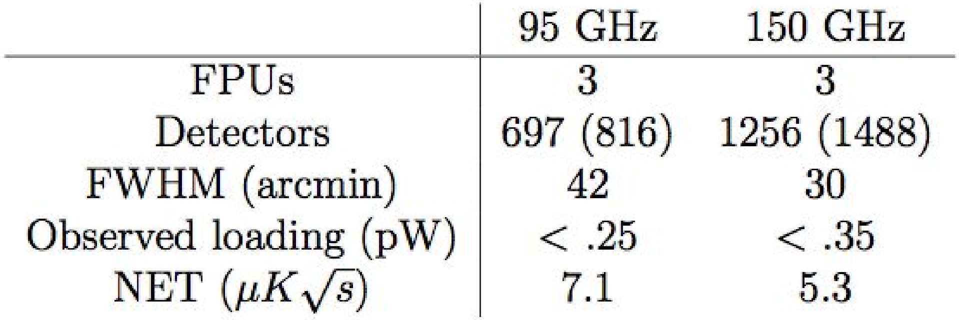


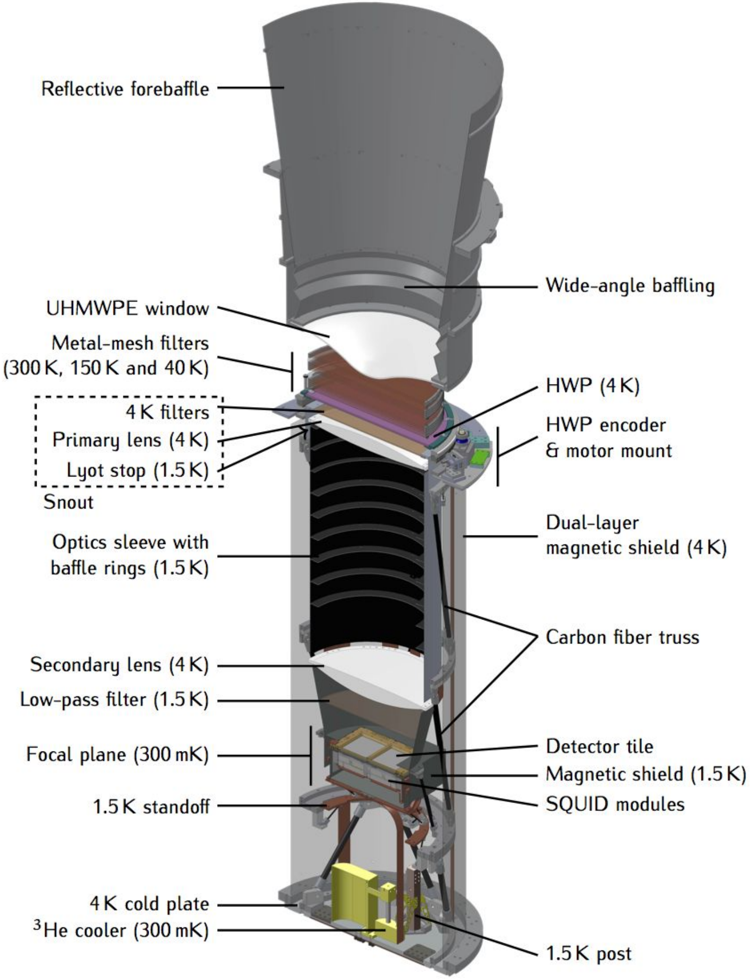
Figure from Johanna Nagy

Telescope and detectors

- Part of the BICEP/Keck/SPIDER heritage
- Almost all optical filtering using reflective filters (one Nylon filter at 4 K)
- Internal baffles at 1.5 K



	95 GHz	150 GHz
FPUs	3	3
Detectors	697 (816)	1256 (1488)
FWHM (arcmin)	42	30
Observed loading (pW)	< .25	< .35
NET ($\mu K\sqrt{s}$)	7.1	5.3



Half-wave plate

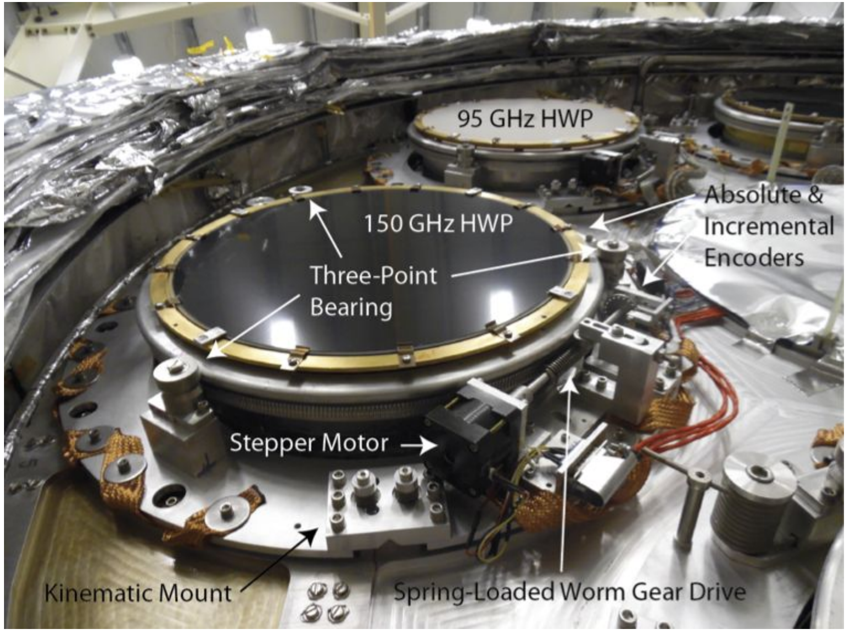


Photo from Johanna Nagy

- Birefringent single-crystal sapphire with anti-reflection coating
- Mounted at 4 K
- Rotated twice a day - full Q/U coverage per pixel every 2 days

Power

- Array 2200 W (peak), 1440 W (average)
- Two independent systems
- 35 V for switched mode DC power supply
- Charges 2 40 Ah/12 V lead acid battery

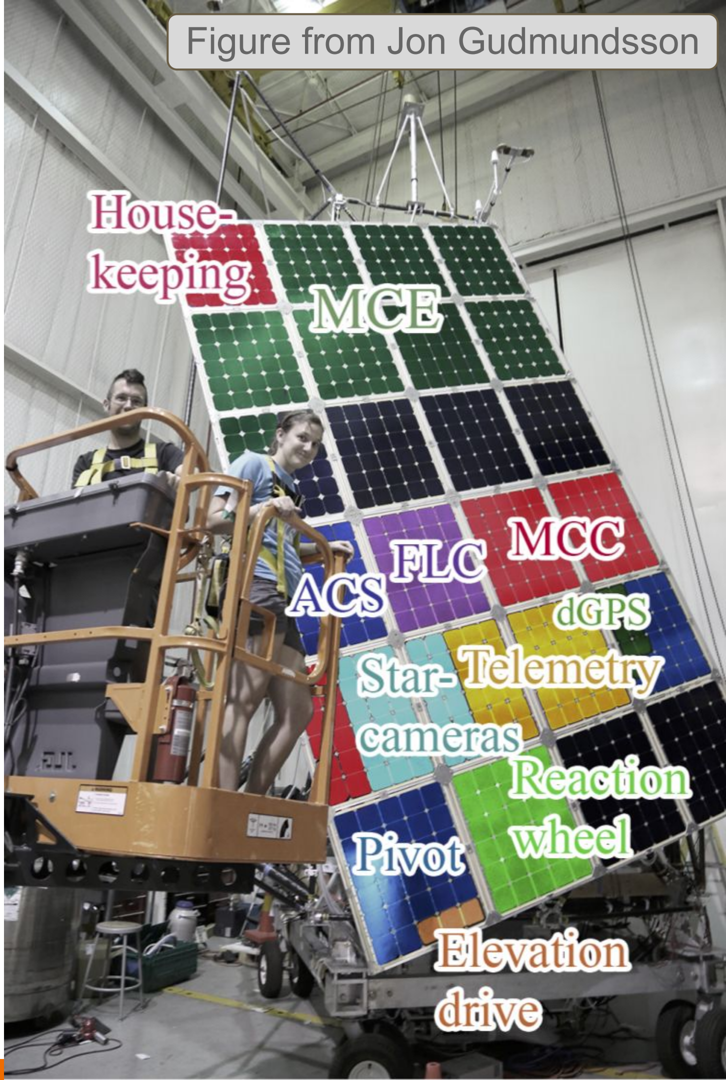
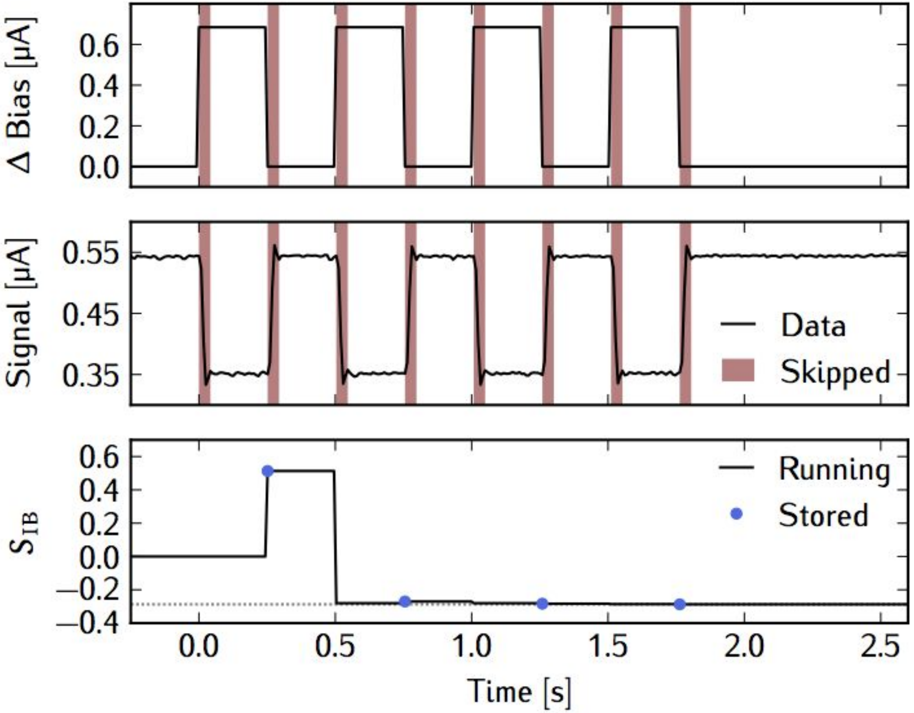


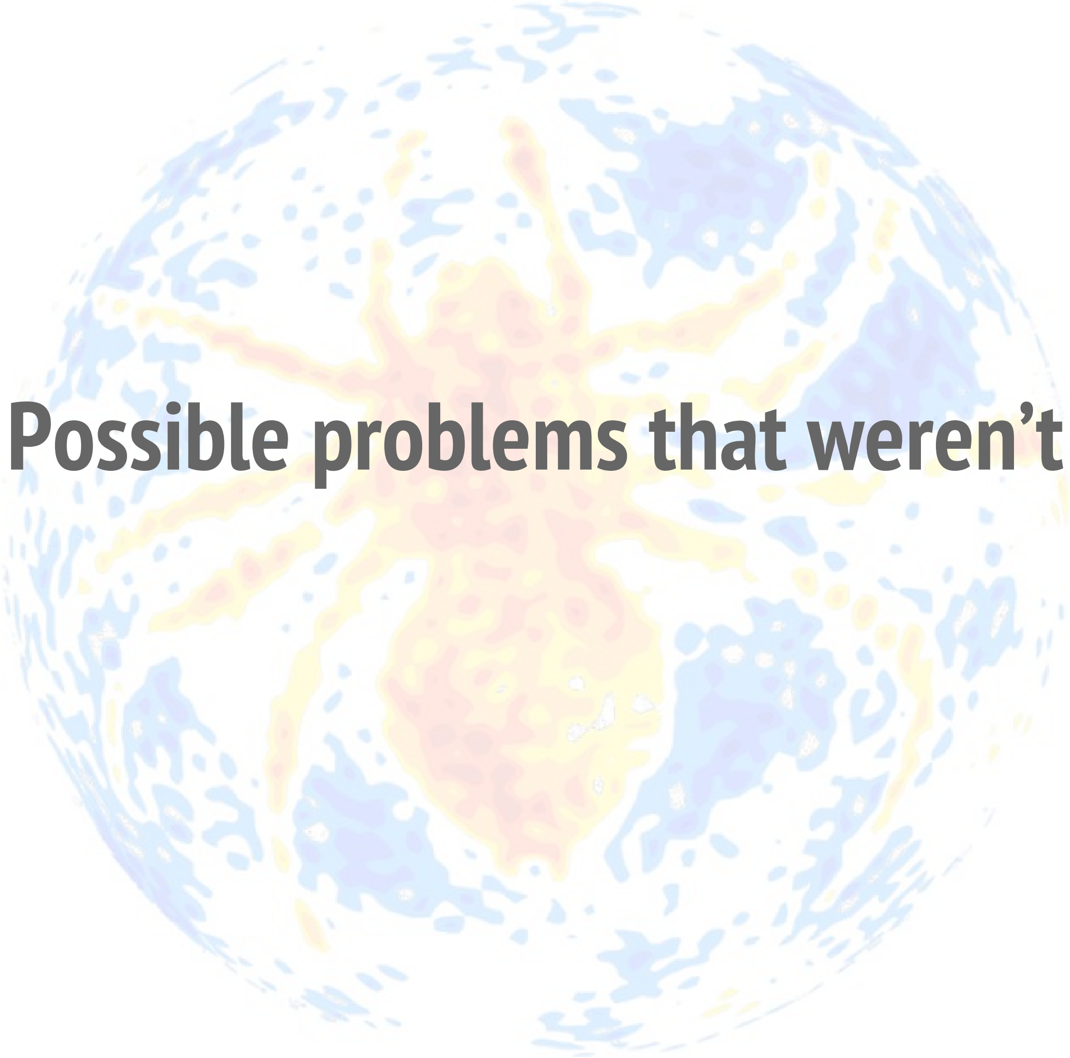
Figure from Jon Gudmundsson

Autonomous detector operations

- SQUID tuning
  - Retuned after every fridge cycle
  - Compares to preflight templates and adjusts parameters as needed
  - ~5 minutes
- Detector responsivity
  - Electrical bias step as a proxy for gain
  - 2 seconds to run for .1% uncertainty on gain
  - Monitors and readjusts bias automatically during flight
- Fully automated
  - Downlinks minimal set of statistics to verify functionality



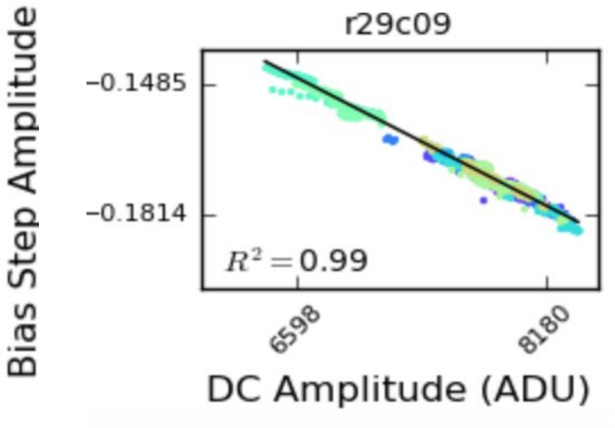
Plot from Sasha Rahlin



Possible problems that weren’t

Possible problems that weren't: Gain drift

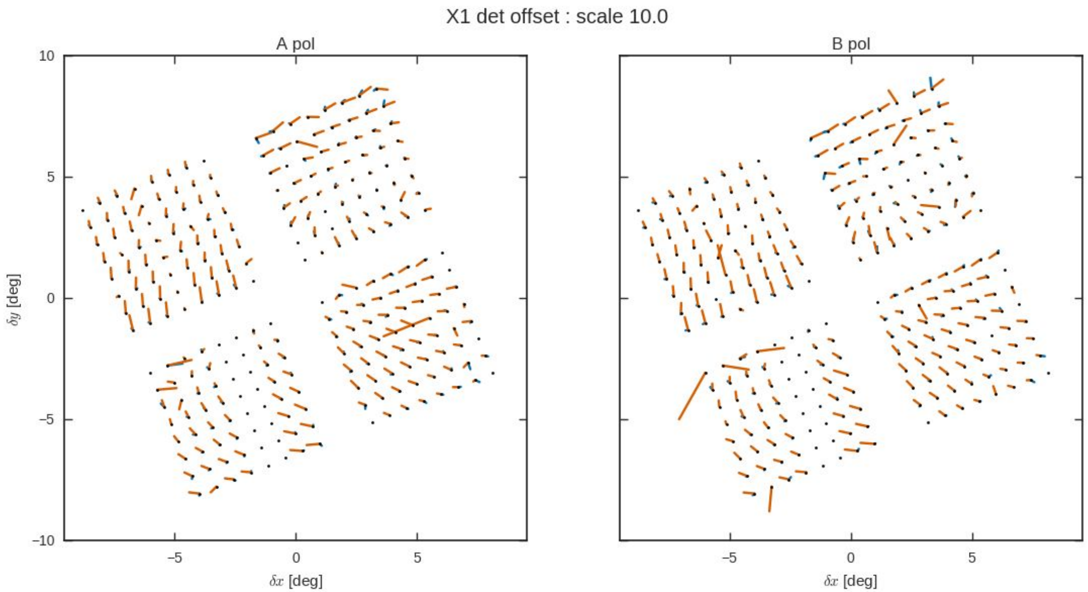
- Bias steps stopped halfway through flight on several FPUs
  - Bias step results were not downlinked during flight
- No rebiasing during this time
- Used detector DC level as a proxy for gain
- Turns out we were rebiasing too often



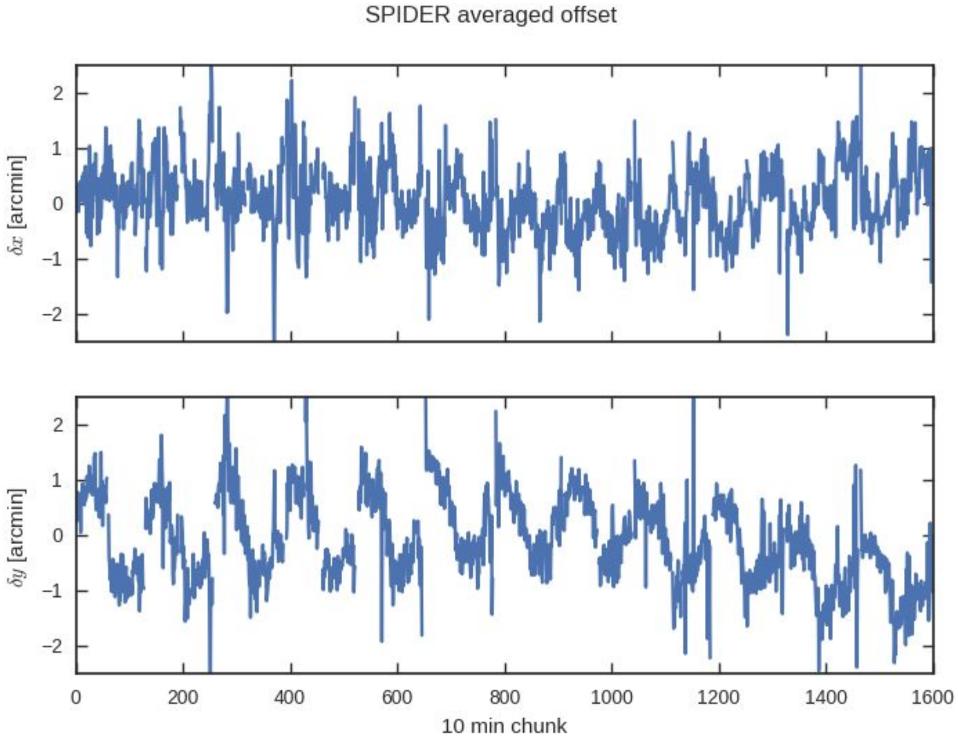
Plot from Anne Gambrel

Possible problems that weren’t: Detector pointing

- Used a deprojection analysis with Planck
- Corrections to the plate-scale pointing of each detector

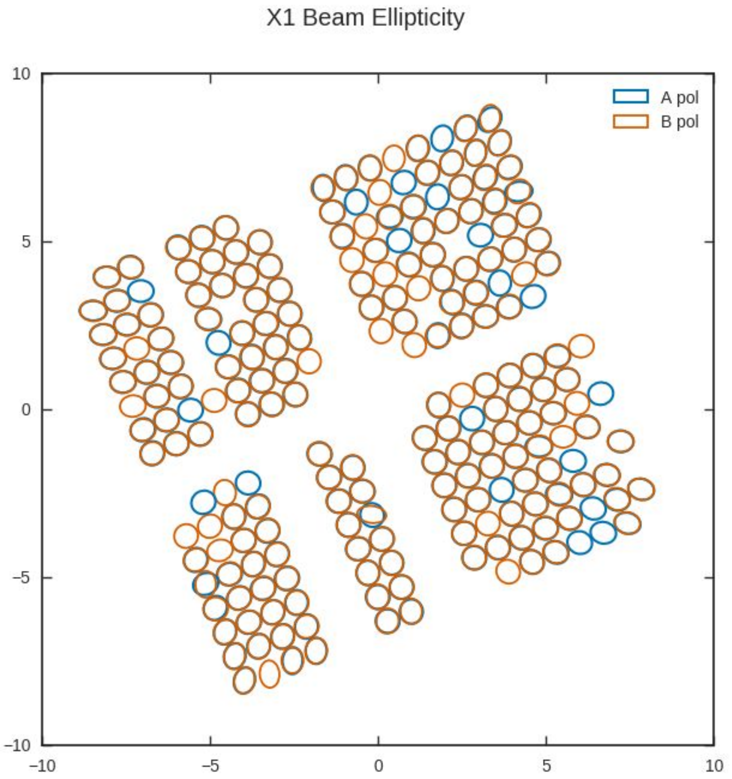


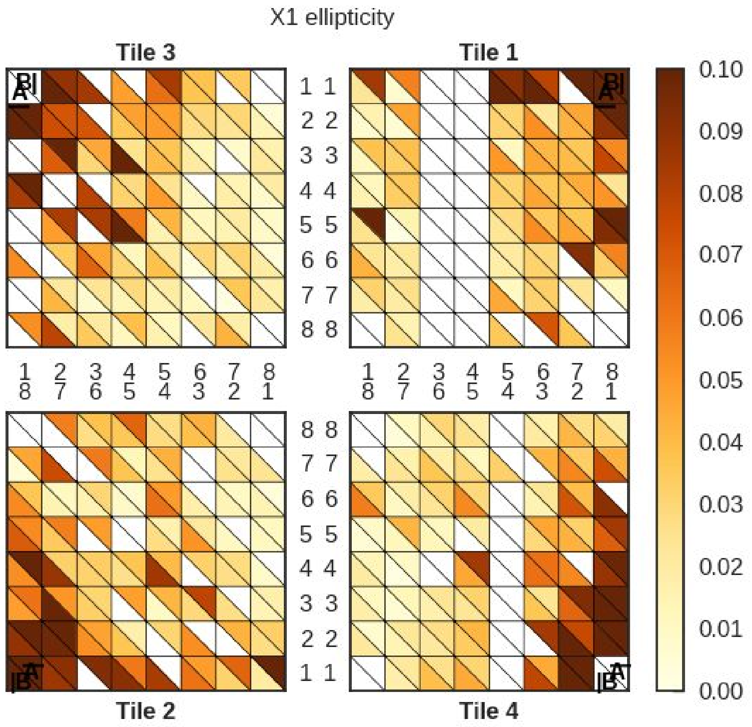
Possible problems that weren't: Boresite pointing



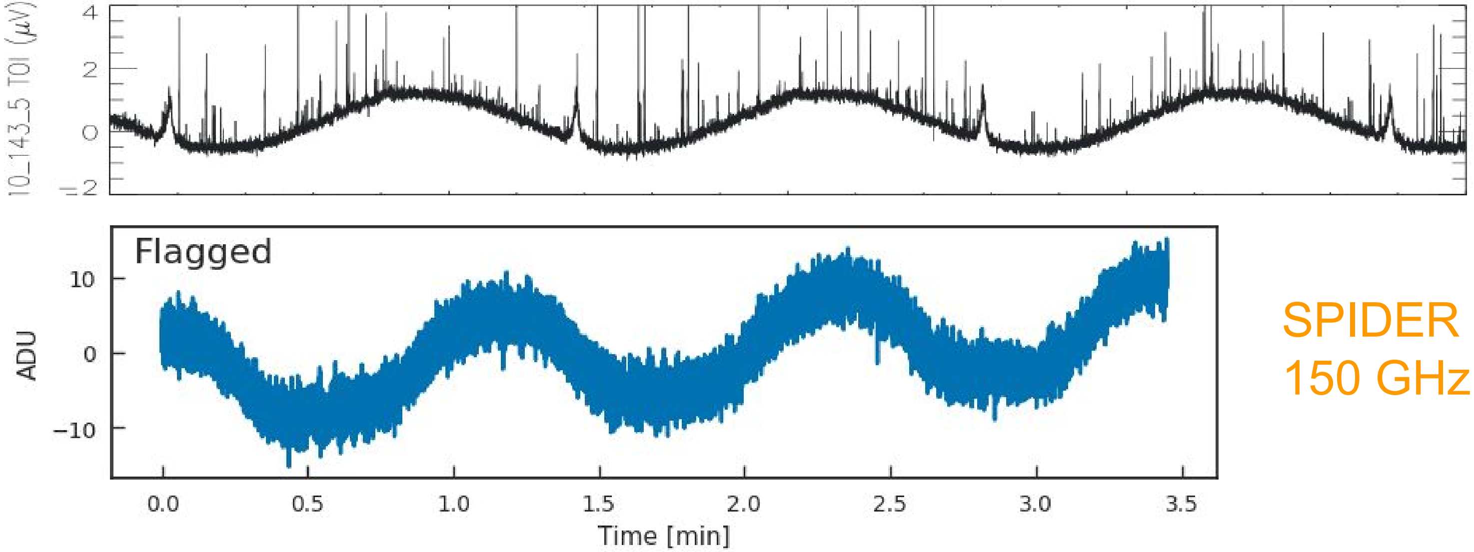
- Corrections relative to dedicated pointing system
- Uses the same sensors to get pointing so don't need to worry about referencing two instruments

Possible problems that weren't: Beam ellipticity





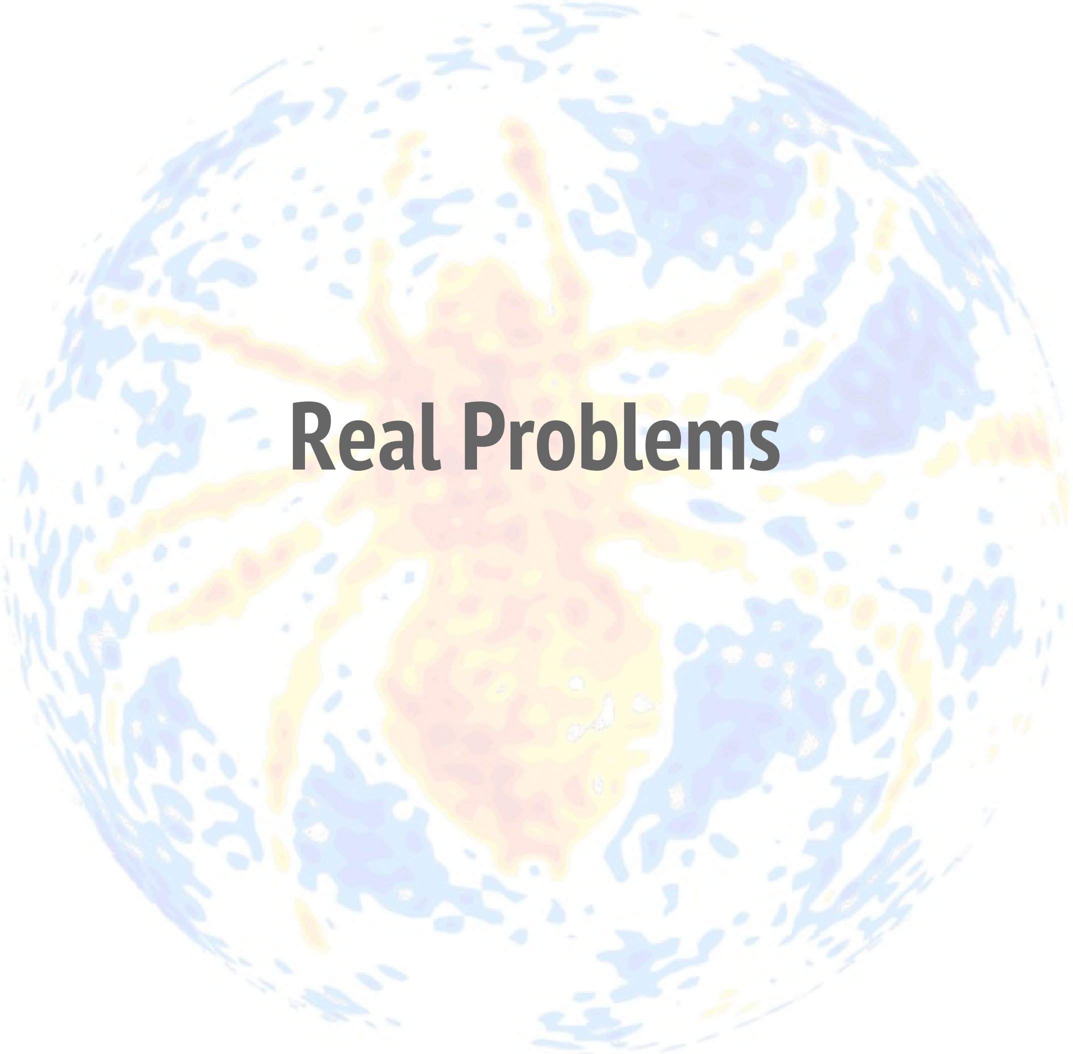
Possible problems that weren’t: Cosmic rays



Planck
143 GHz

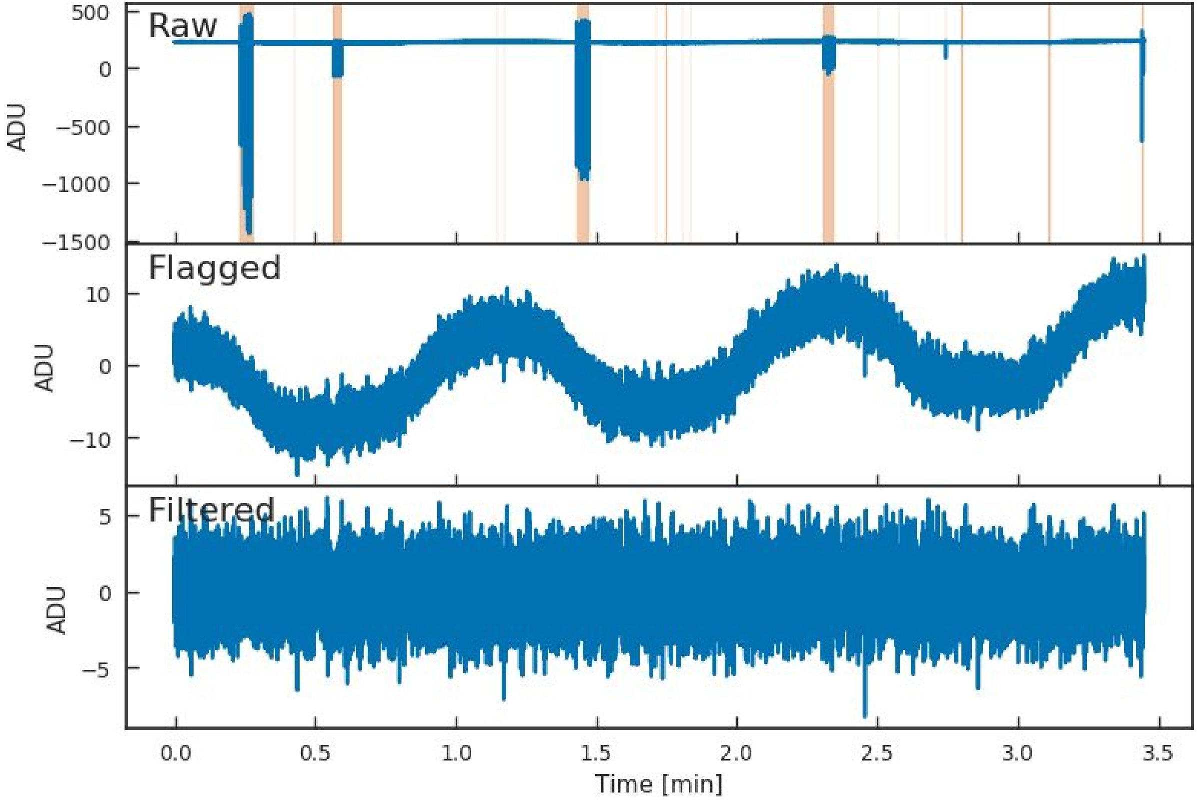
SPIDER
150 GHz

See Jeff Filippini’s talk for more details!



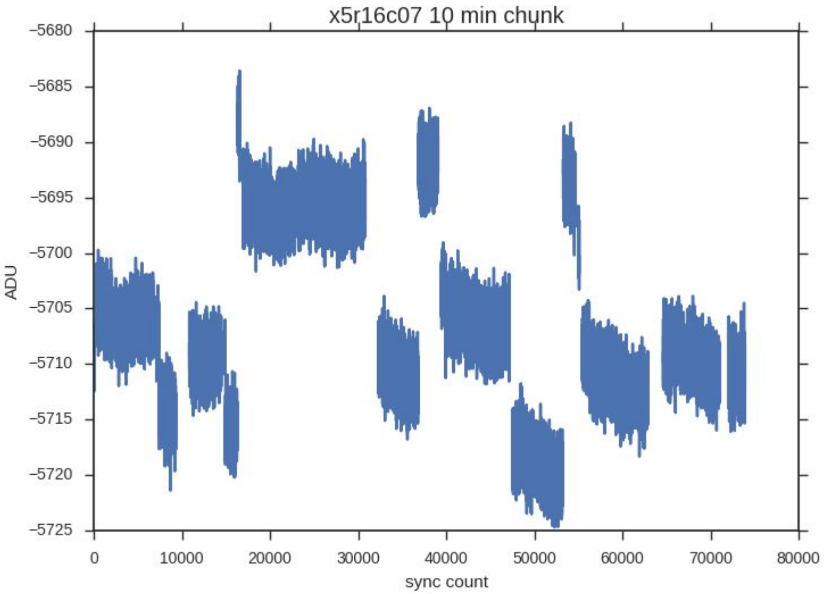
Real Problems

Real problems: RF pickup



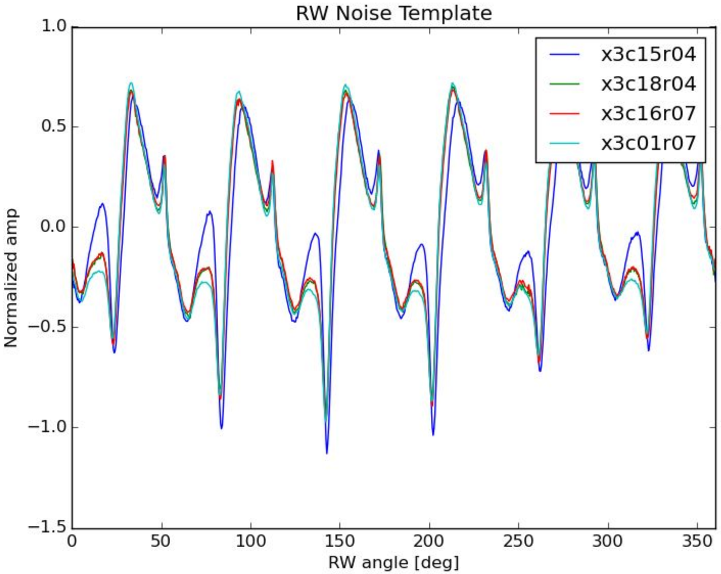
- Loss of ~10% of data on good channels
- Transmitters handshake every ~minute

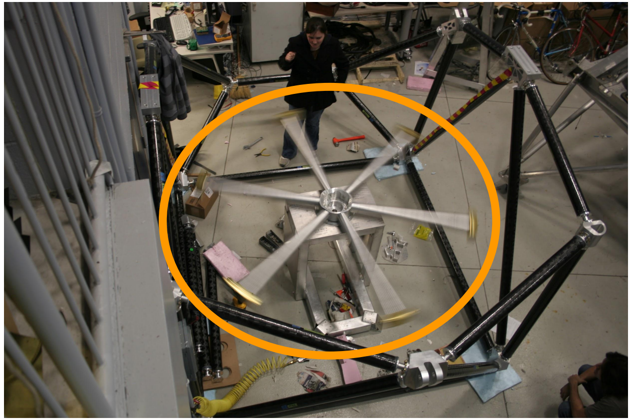
Real problems: RF pickup



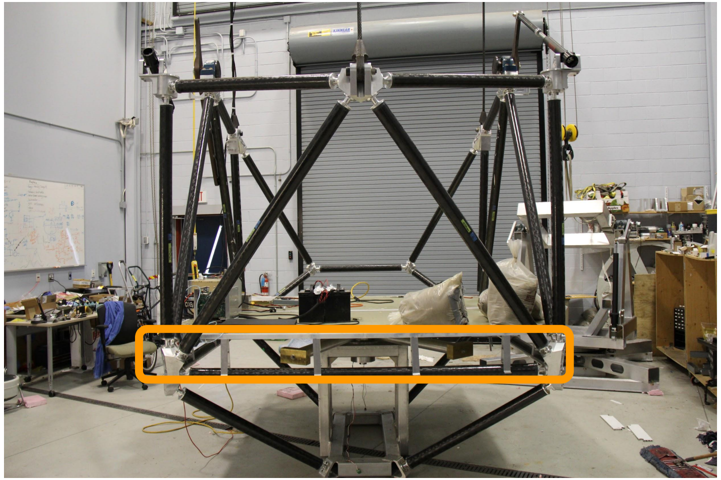
- Loss of DC level
- Difficult to reestablish DC level because it is caused by transmitter pulses, which simultaneously cause a loss of data
- Often flux jumps in one detector will cause a small DC level step in another detector in column

Real problems: RF pickup

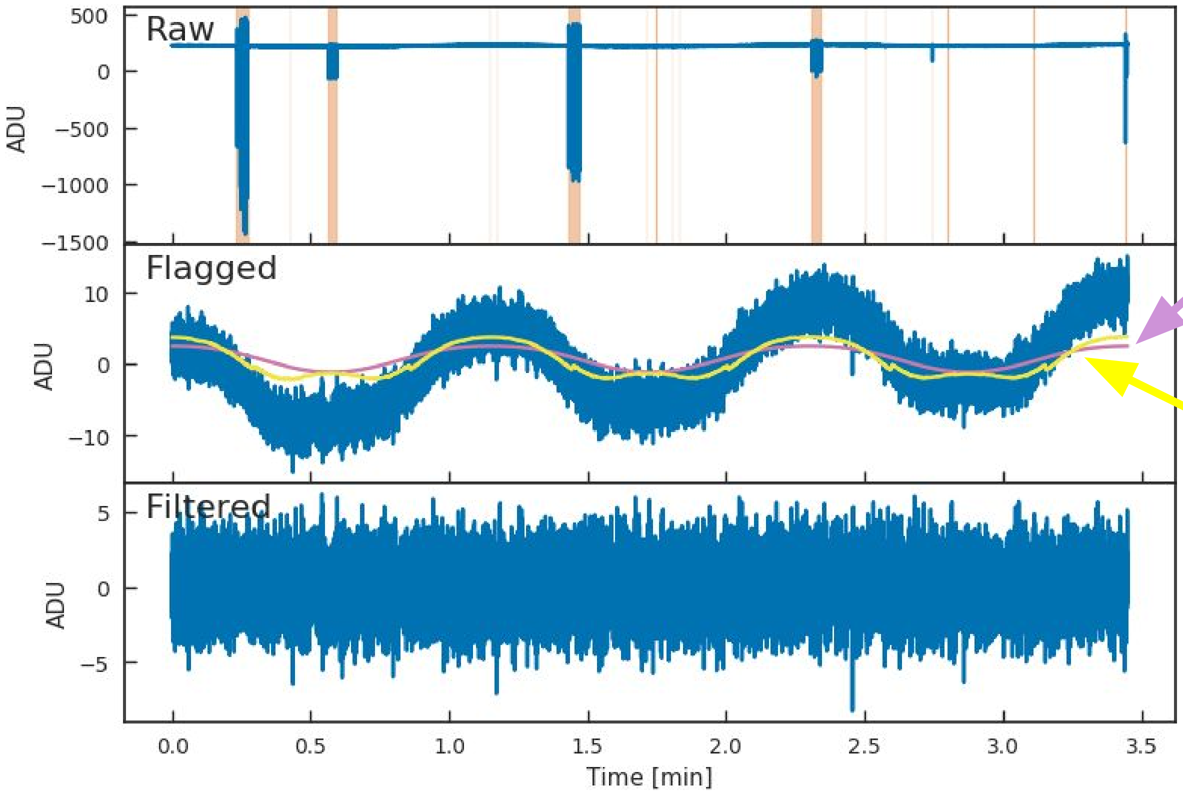




Reaction Wheel



Real problems: Scan-synchronous noise

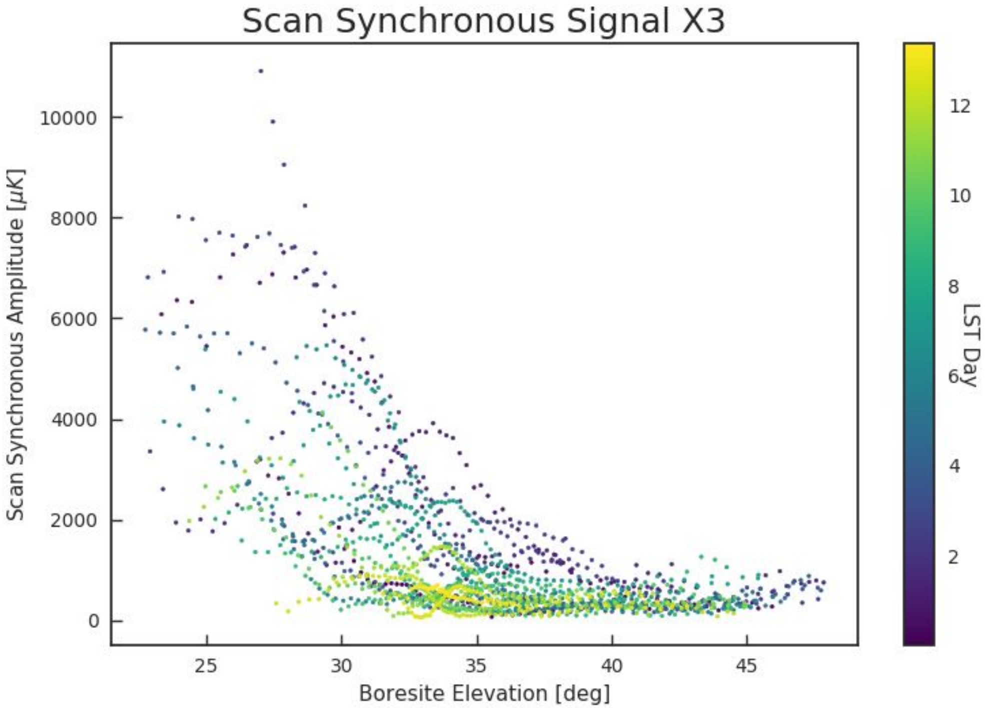


Dipole

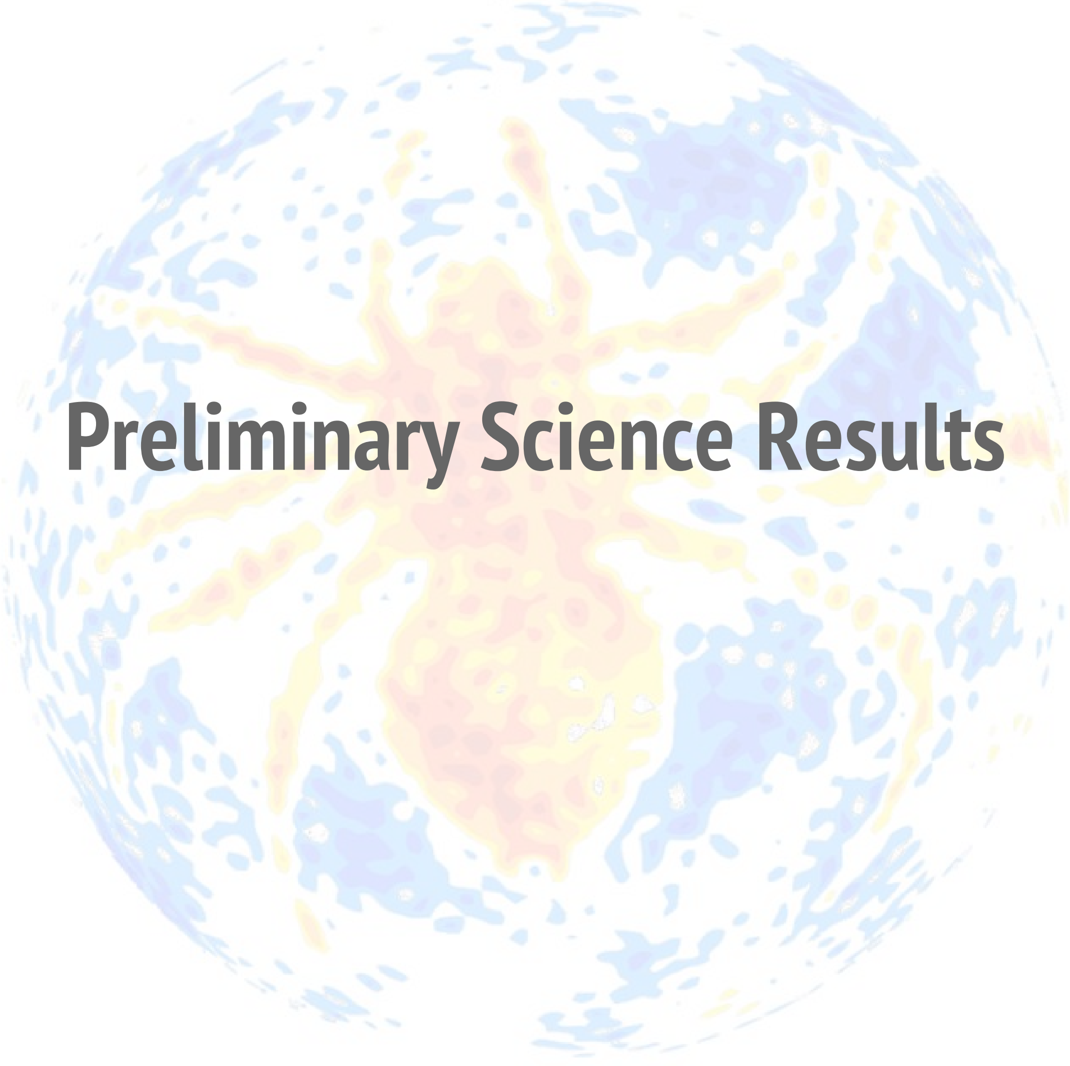
Scan-synchronous noise

Real problems: Scan-synchronous noise

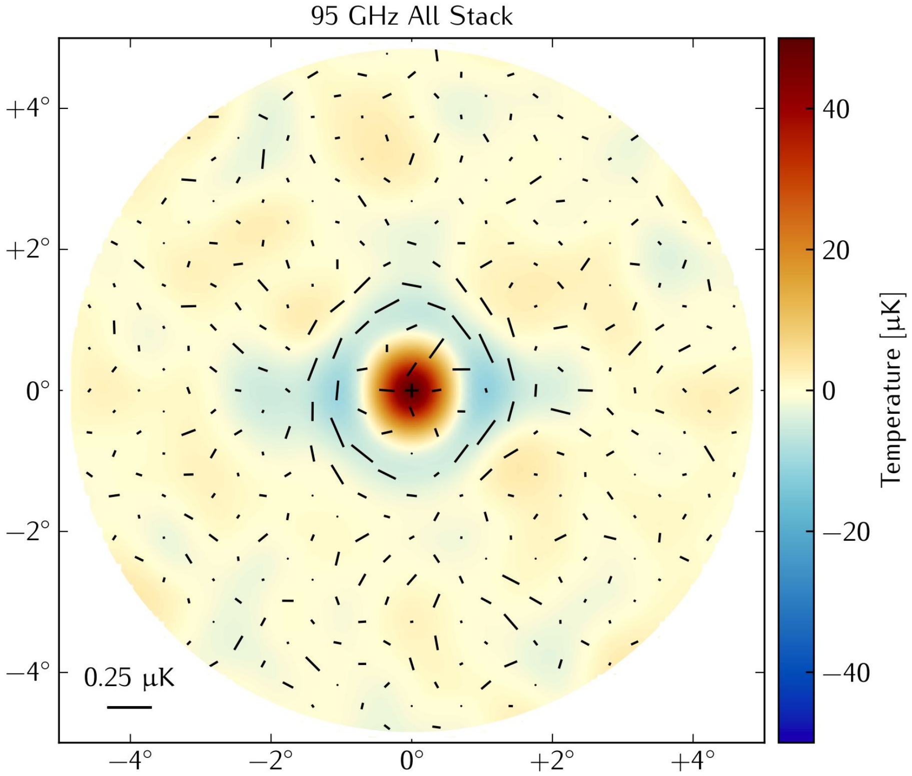
- Boresite elevation dependent
- Requires heavy filtering to remove
    - Poly-5 removed per detector per half-scan
    - Terrible for filter function
    - Working on alternatives to poly-5 removal (SVD, template fitting, etc.)

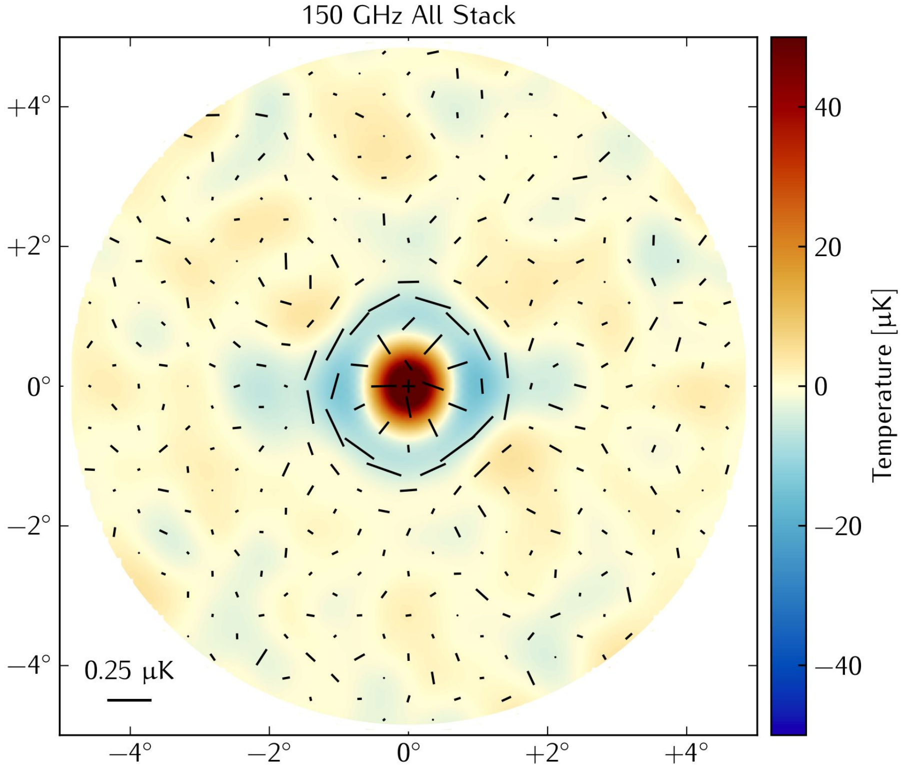


Preliminary Science Results



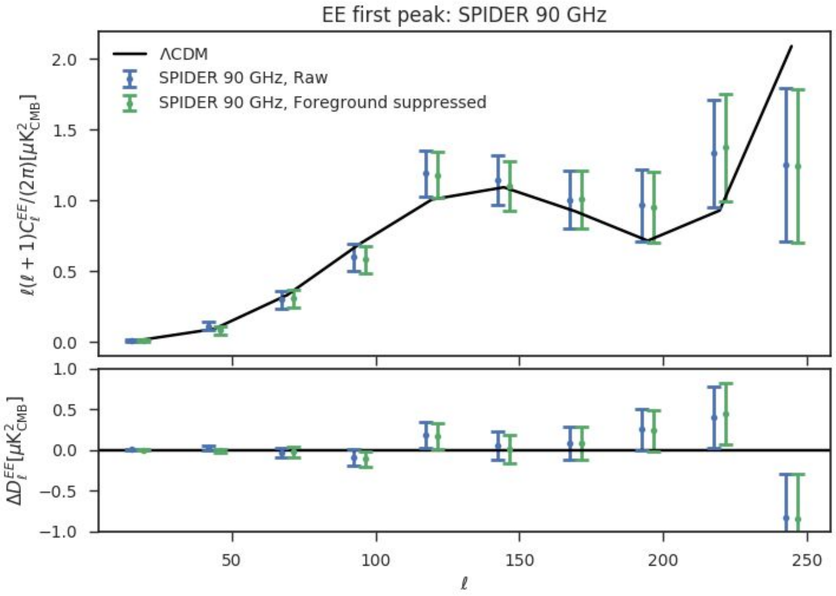
Beam stacks

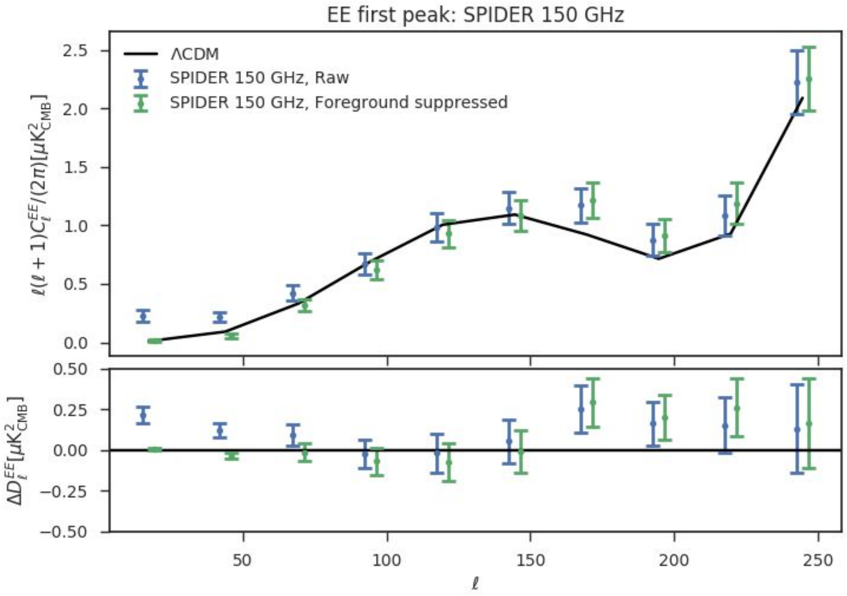

95 GHz All Stack


150 GHz All Stack

Spectra

PRELIMINARY!





SPIDER 2

- 280 GHz FPUs (3)
- Launch December 2018
- Overlap with ground experiments for foreground rejection

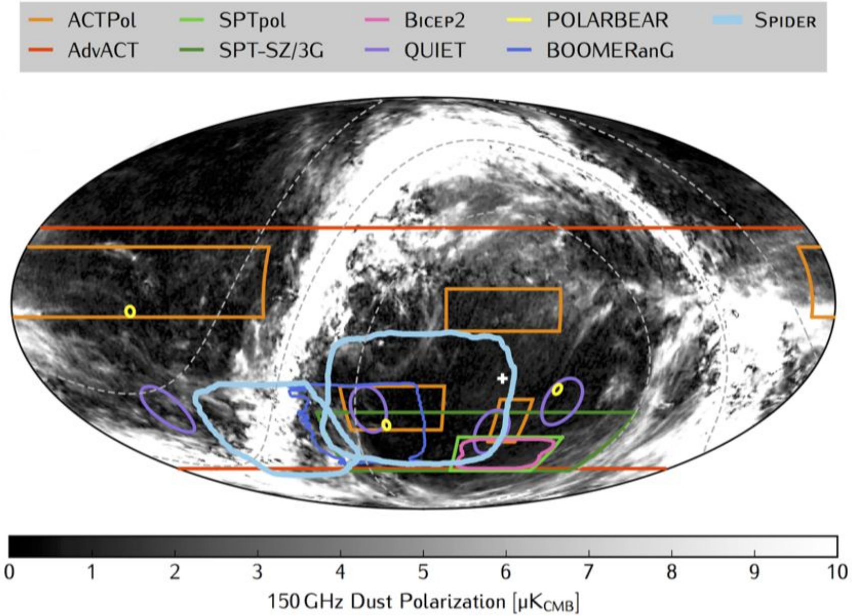


Figure from Sasha Rahlin

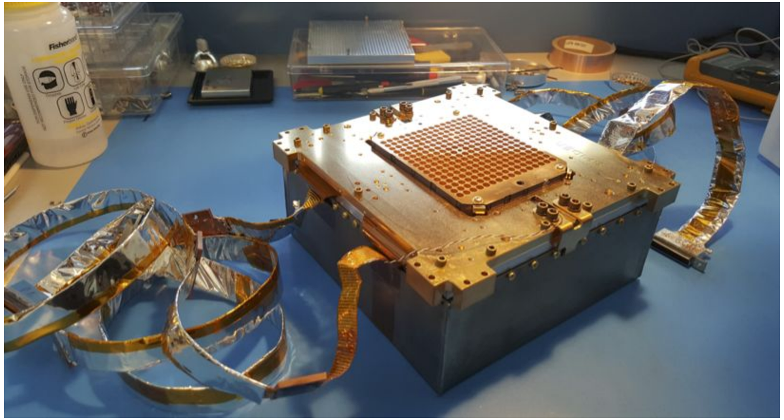
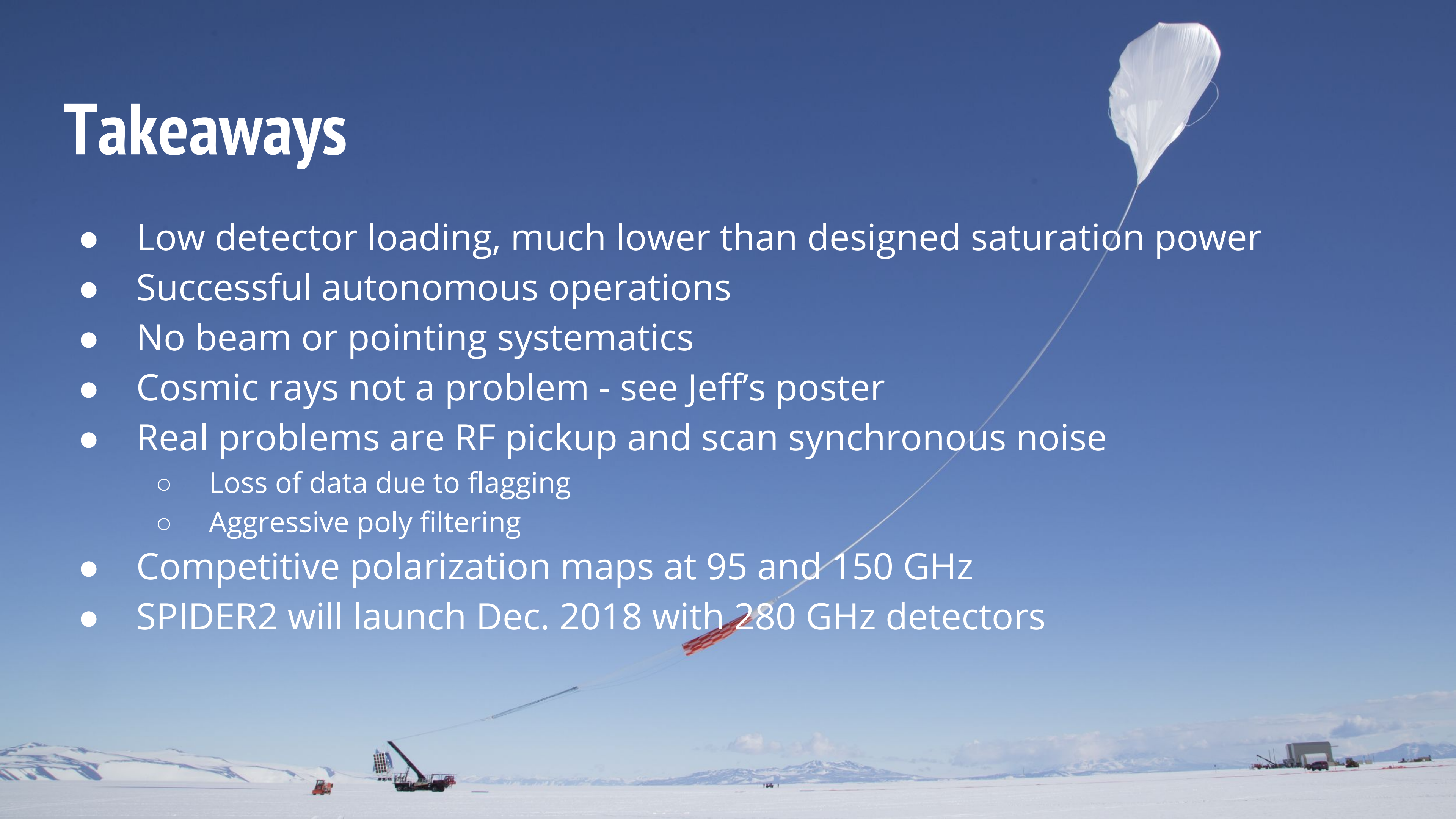
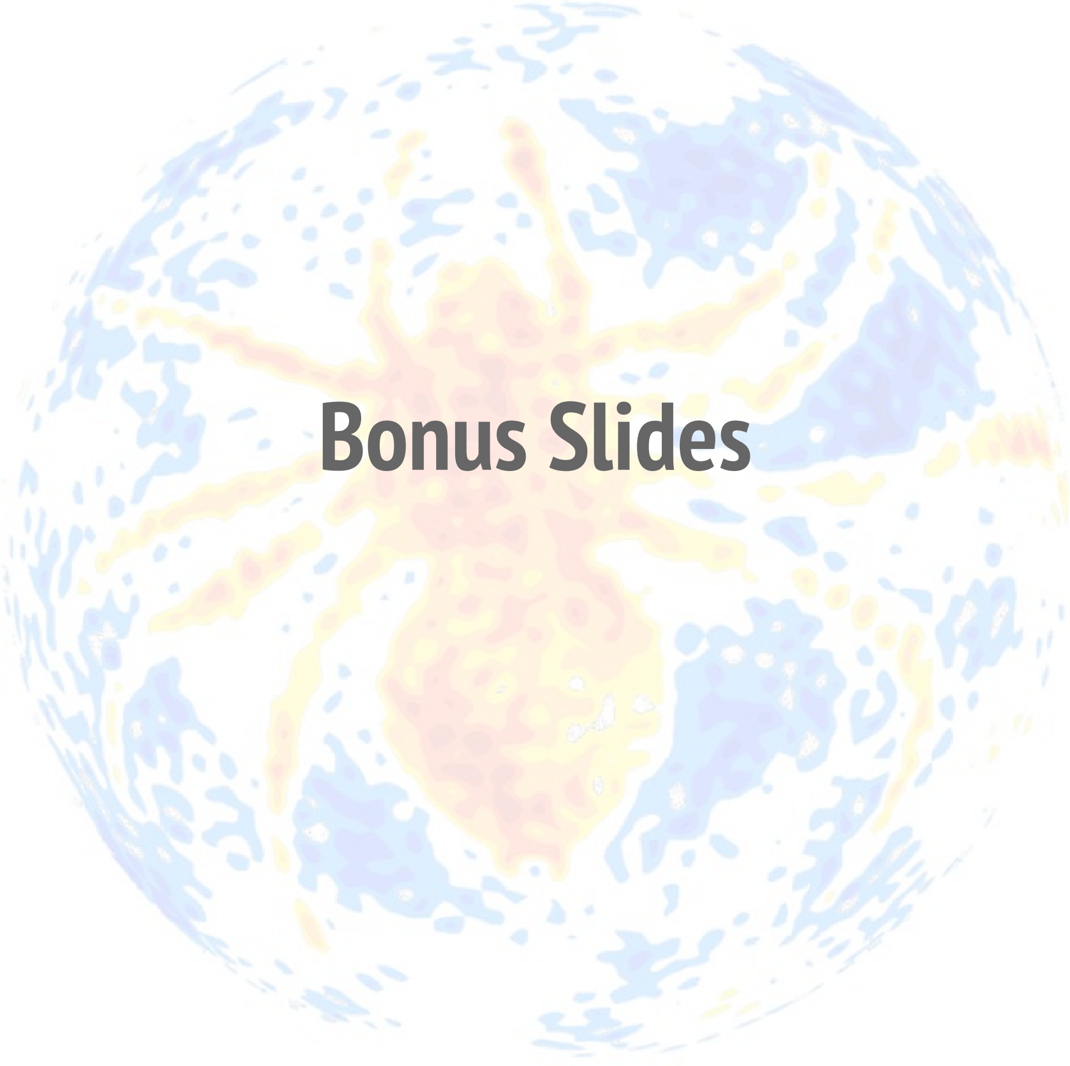


Photo from Stevie Bergman



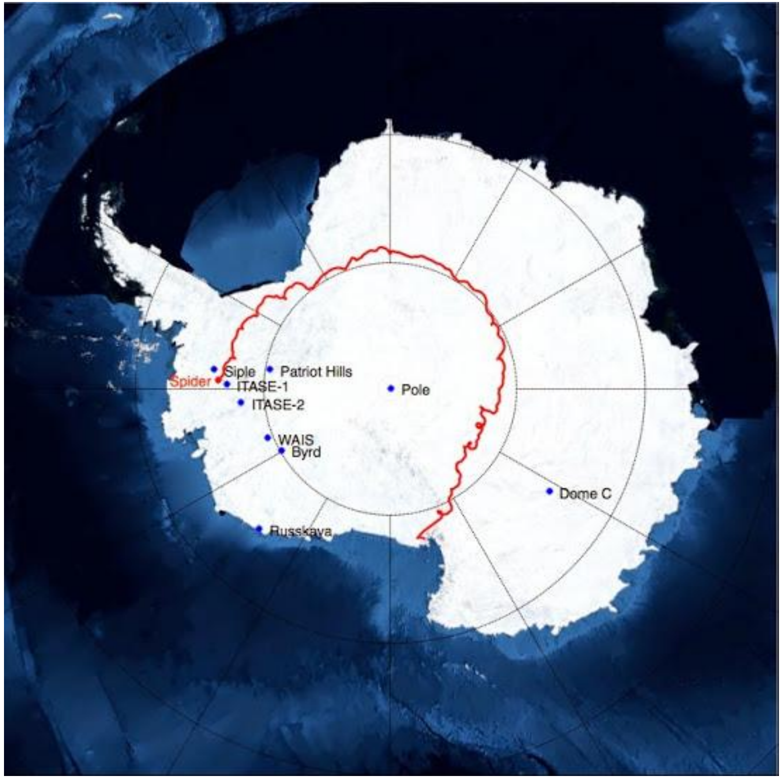
Takeaways

- Low detector loading, much lower than designed saturation power
- Successful autonomous operations
- No beam or pointing systematics
- Cosmic rays not a problem - see Jeff’s poster
- Real problems are RF pickup and scan synchronous noise
  - Loss of data due to flagging
  - Aggressive poly filtering
- Competitive polarization maps at 95 and 150 GHz
- SPIDER2 will launch Dec. 2018 with 280 GHz detectors



Bonus Slides

Flight

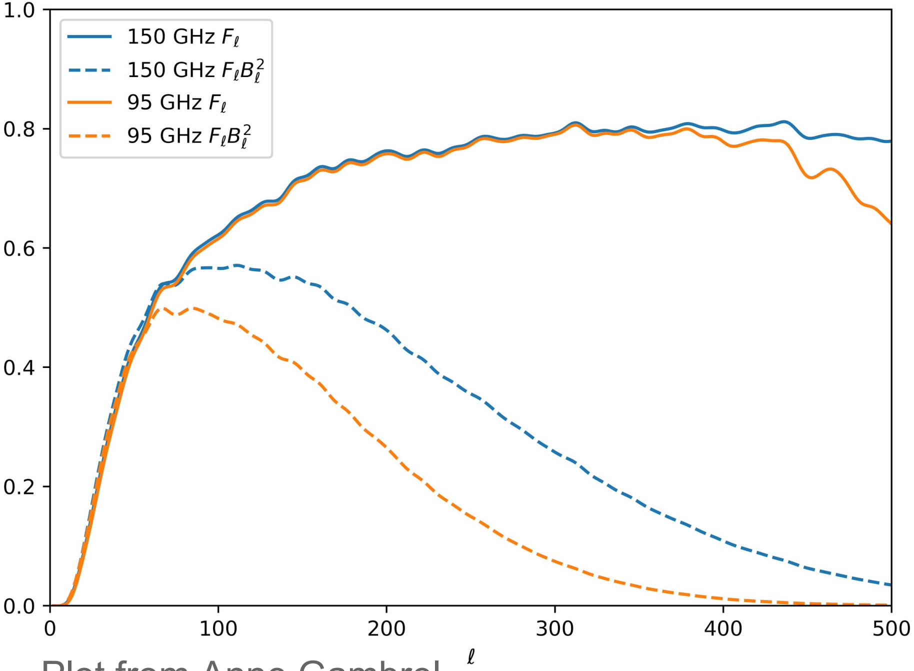

Siple
Patriot Hills
Spider
ITASE-1
ITASE-2
Pole
WAIS
Byrd
Dome C
Russkaya

Telemetry

- TDRSS
- LOS
- DGPS
- Iridium

Photo: Steve Benton

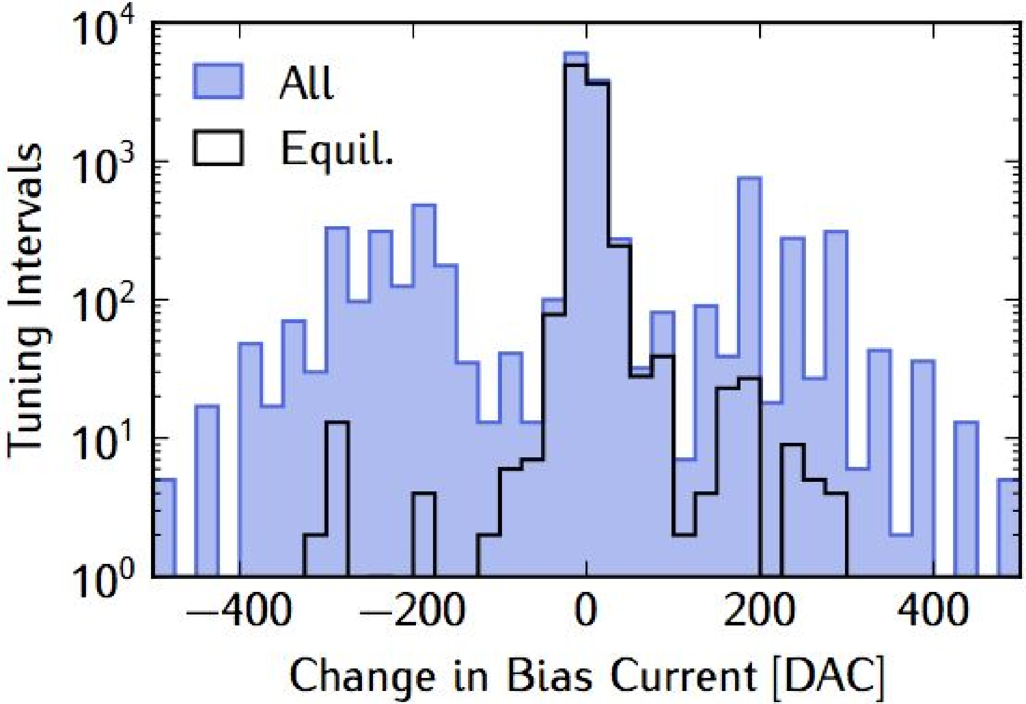
Filter function



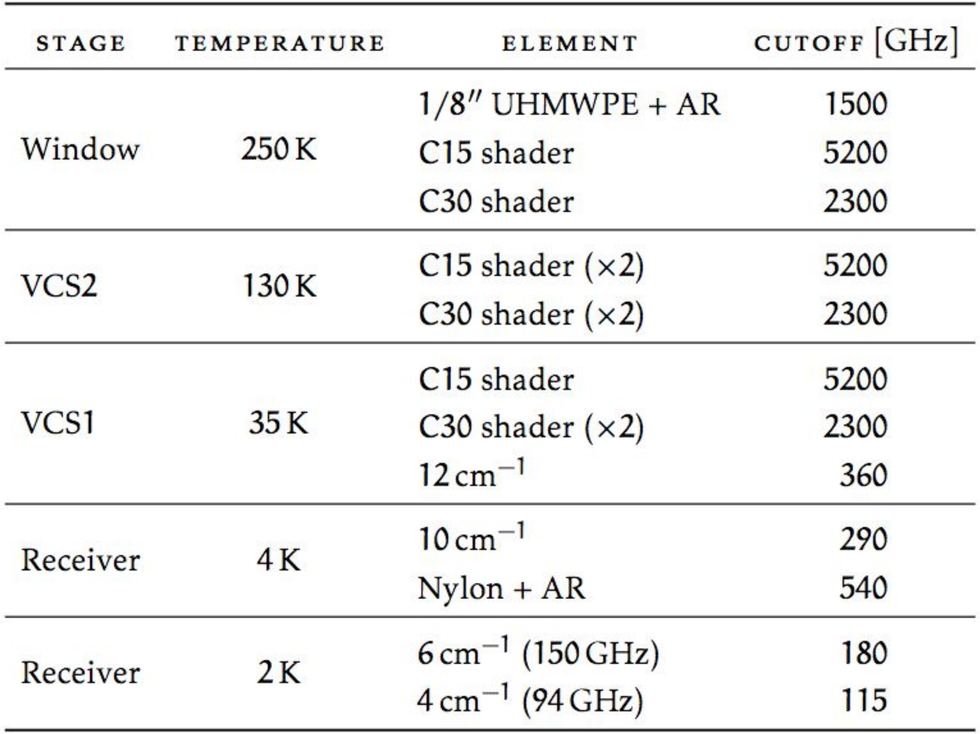
Plot from Anne Gambrel

- Poly 5 per half scan

Rebias amplitudes

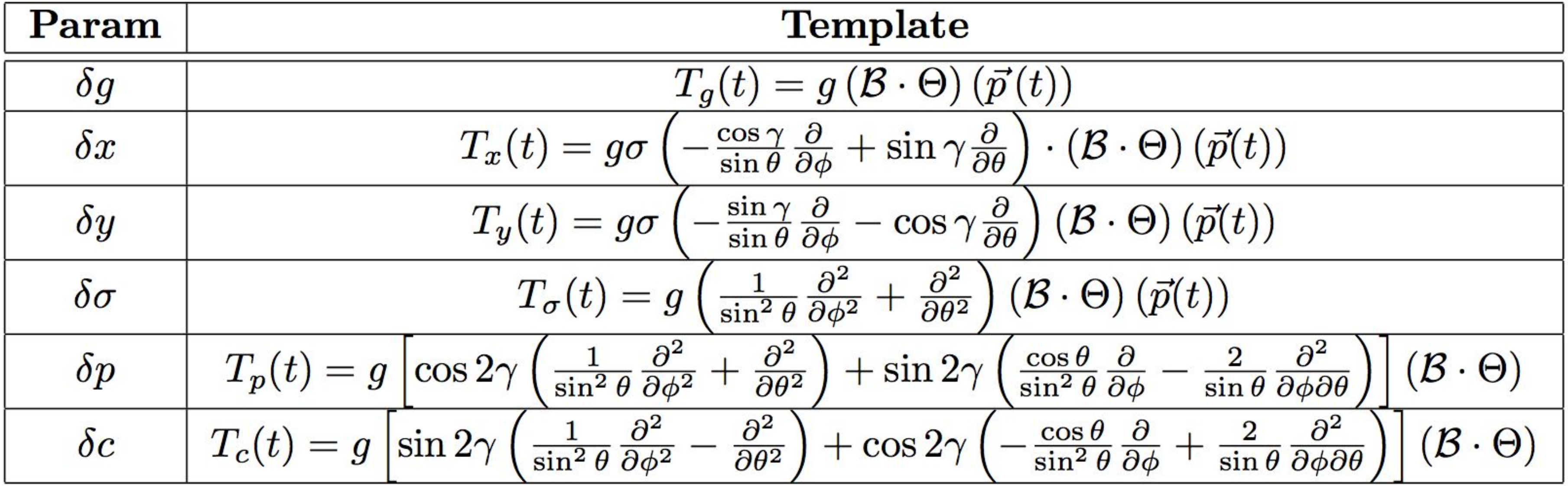


Filter stack



Stage	Temperature	Element	Cutoff [GHz]
Window	250 K	1/8″ UHMWPE + AR	1500
		C15 shader	5200
		C30 shader	2300
VCS2	130 K	C15 shader (×2)	5200
		C30 shader (×2)	2300
VCS1	35 K	C15 shader	5200
		C30 shader (×2)	2300
		$12\,\mathrm{cm}^{-1}$	360
Receiver	4 K	$10\,\mathrm{cm}^{-1}$	290
		Nylon + AR	540
Receiver	2 K	$6\,\mathrm{cm}^{-1}$ (150 GHz)	180
		$4\,\mathrm{cm}^{-1}$ (94 GHz)	115

Deprojection Equations

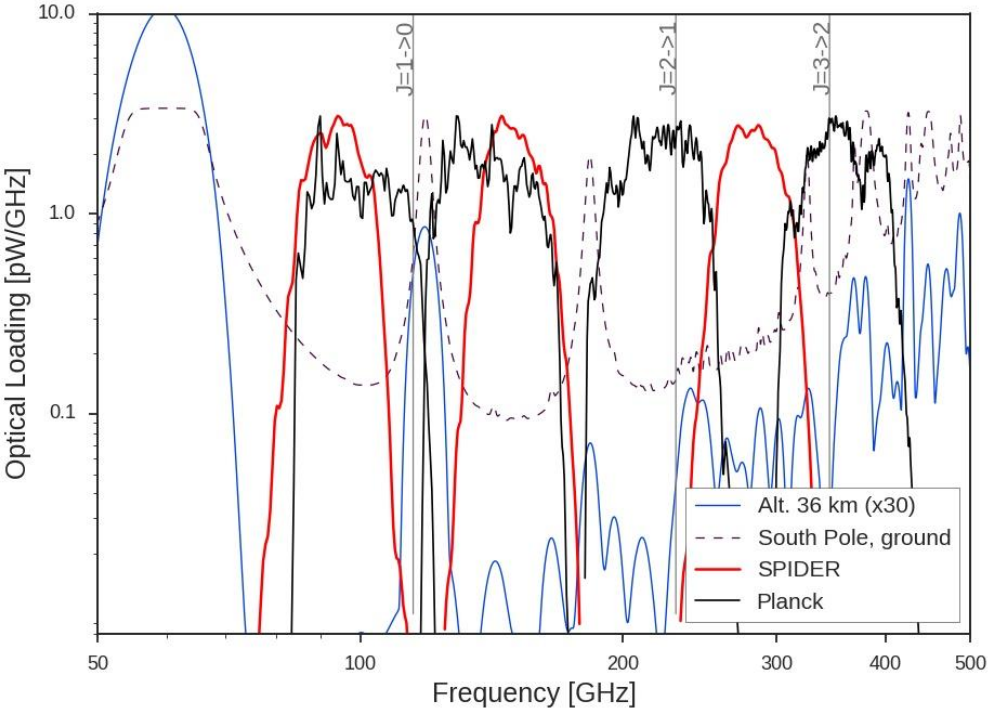


Param	Template
δg	$T_g(t) = g\,(\mathcal{B}\cdot\Theta)\,(\vec{p}(t))$
δx	$T_x(t) = g\sigma\left(-\frac{\cos\gamma}{\sin\theta}\frac{\partial}{\partial\phi} + \sin\gamma\frac{\partial}{\partial\theta}\right)\cdot(\mathcal{B}\cdot\Theta)\,(\vec{p}(t))$
δy	$T_y(t) = g\sigma\left(-\frac{\sin\gamma}{\sin\theta}\frac{\partial}{\partial\phi} - \cos\gamma\frac{\partial}{\partial\theta}\right)(\mathcal{B}\cdot\Theta)\,(\vec{p}(t))$
$\delta\sigma$	$T_\sigma(t) = g\left(\frac{1}{\sin^2\theta}\frac{\partial^2}{\partial\phi^2} + \frac{\partial^2}{\partial\theta^2}\right)(\mathcal{B}\cdot\Theta)\,(\vec{p}(t))$
δp	$T_p(t) = g\left[\cos 2\gamma\left(\frac{1}{\sin^2\theta}\frac{\partial^2}{\partial\phi^2} + \frac{\partial^2}{\partial\theta^2}\right) + \sin 2\gamma\left(\frac{\cos\theta}{\sin^2\theta}\frac{\partial}{\partial\phi} - \frac{2}{\sin\theta}\frac{\partial^2}{\partial\phi\partial\theta}\right)\right](\mathcal{B}\cdot\Theta)$
δc	$T_c(t) = g\left[\sin 2\gamma\left(\frac{1}{\sin^2\theta}\frac{\partial^2}{\partial\phi^2} - \frac{\partial^2}{\partial\theta^2}\right) + \cos 2\gamma\left(-\frac{\cos\theta}{\sin^2\theta}\frac{\partial}{\partial\phi} + \frac{2}{\sin\theta}\frac{\partial^2}{\partial\phi\partial\theta}\right)\right](\mathcal{B}\cdot\Theta)$

Recovery

- Preliminary recovery February 2015
- Full recovery November 2015
- Lead by BAS

Atmosphere



10.0
1.0
0.1
Optical Loading [pW/GHz]
J=1->0
J=2->1
J=3->2
50
100
200
300
400
500
Frequency [GHz]
Alt. 36 km (x30)
South Pole, ground
SPIDER
Planck