Particle response of antenna-coupled TES arrays

Ben Osherson, University of Illinois at Urbana-Champaign

R.V. Gramillano, J. Fu, R. Gualtieri, J.P. Filippini,
the JPL detector team and the SPIDER collaboration

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photo cred: Sam Burrell

Detectors in space

Planck glitch experience

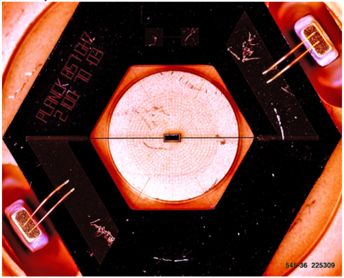
Planck HFI saw frequent ($\sim 1/s/det$) 'glitches' in data. The Planck team conclusioned:

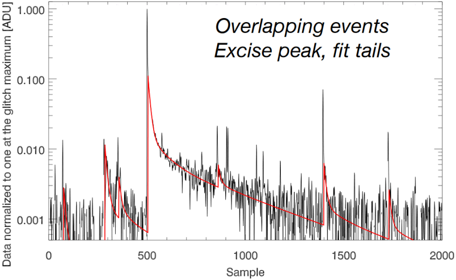
- Glitches were caused by particle interactions with some of **the surrounding assembly**, not just the bolometer.
- Some glitches have **long recovery times ($\sim$ 1s)**.

Cleaning data required careful template fitting and subtraction and some excision.

A. Catalano et al. 2014

JPL/Planck's 545 GHz spider-web bolometer

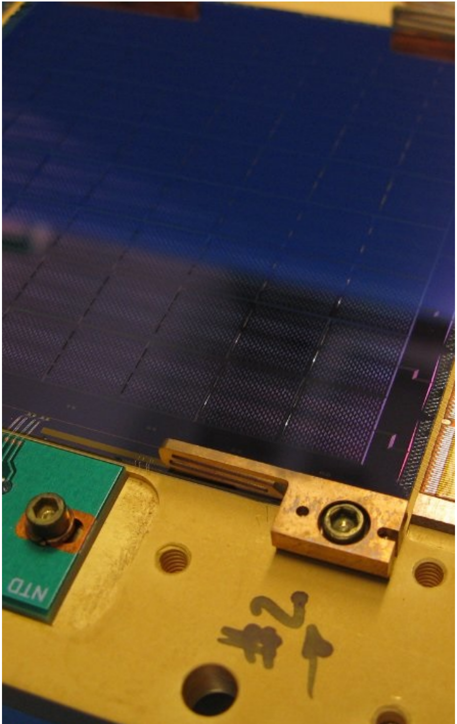




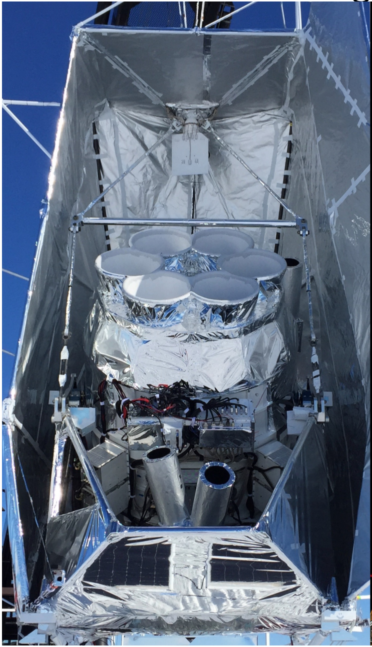
TES arrays in space

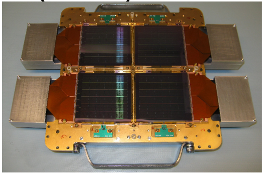
Future space missions (PICO, LiteBIRD, SPICA, OST and more) will feature **larger and more densely populated** detector arrays.

- These arrays will have a **higher rate of interactions** and those interactions may **couple to many near-by detectors** on the wafer.
- **Multiplexing** may cross-talk glitches across channels.



SPIDER Antarctic Long Duration Balloon (LDB) mission





Modern arrays:

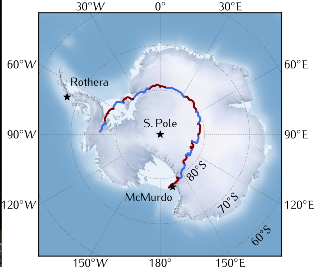
Three telescopes observing at 90GHz and three telescopes observing at 150GHz, totaling more than 2400 TESs.

Multiplexed:

NIST SQUID readout chain and multiplexed by time-division Multi Channel Electronics (MCE) from UBC.

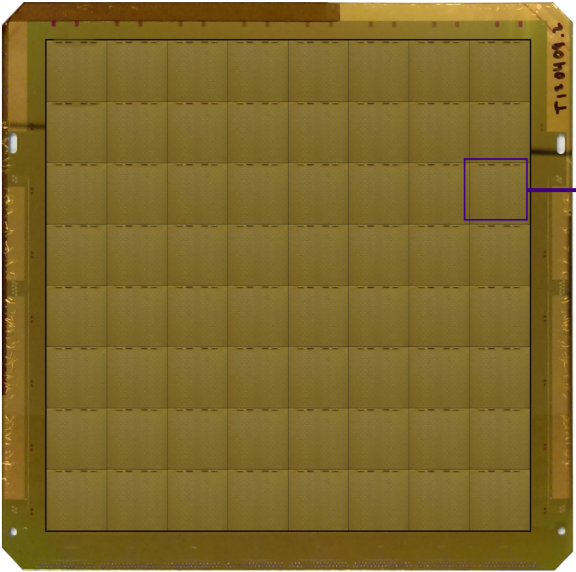
Space-like environment:

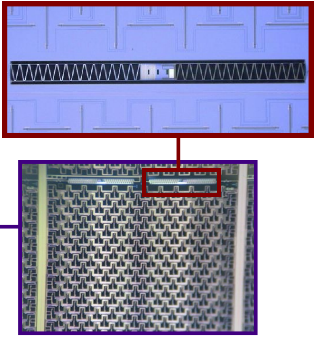
16 days floating at ~40km.



SPIDER TES arrays by JPL

Dense wafers, interleaved phased antenna arrays and TES islands



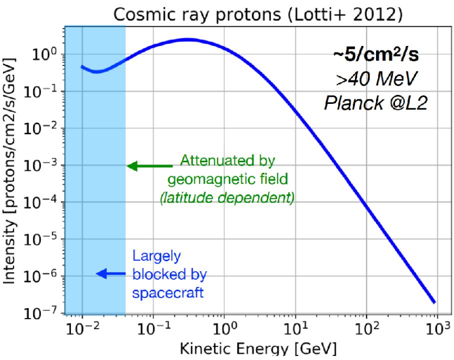


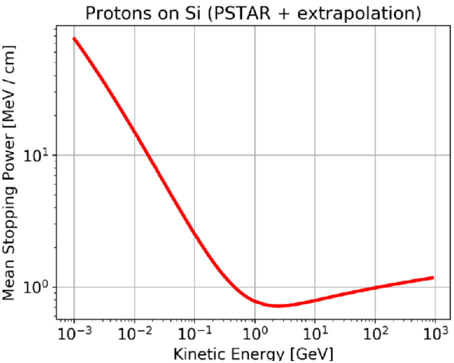
Each grid-square has **two interleaved phased antenna array sets** of orthogonal polarizations.

Detector NEP 2-4 x 10^{-17} W/rtHz

Photoshop mosaic

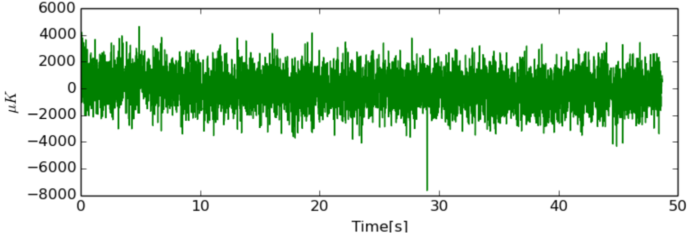
Flight expectations

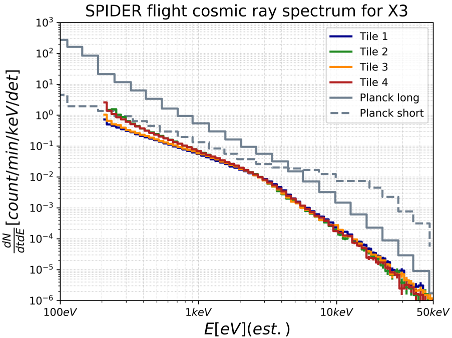




	dimensions	rate	deposition
TES island	$300\mu m \times 150\mu m \times 1\mu m$	$\sim 1/10min$	250 eV
Wafer	$70mm \times 70mm \times 0.5mm$	$\sim 250/s$	50 keV

Flight results





- Glitch rate: $\sim 1/3min/det$.
- Each glitch lasts $< 0.1s$.

$\Rightarrow$ **$< 1\%$ of data is excised because of cosmic rays!**

Coincidence rates (averaged)

$N_{events}^{dets>1}/N_{events}$	$N_{events}^{dets=2}/N_{events}^{dets>1}$
5.3%	$\sim 90\%$

Coincidence pattern

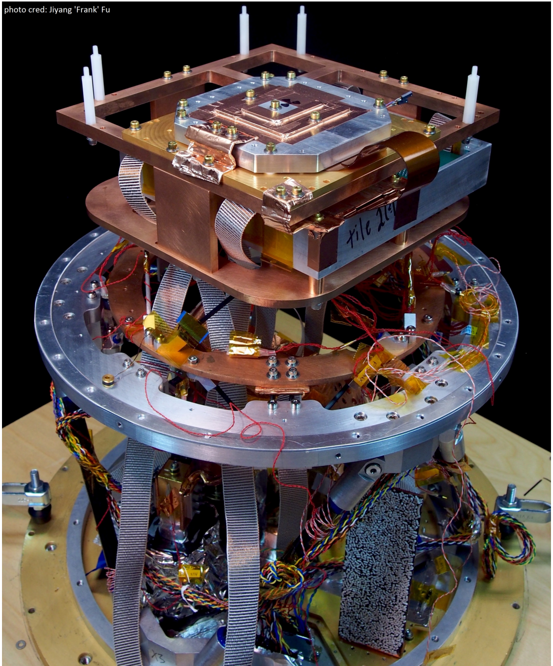
	Expected	Observed
AB partner	$< 0.5\%$	**7.4%**
Adj. mux row	$< 0.5\%$	0.6%

Lab setup

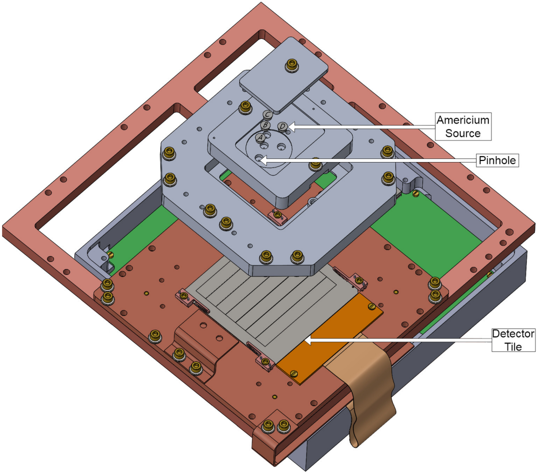
Constructed and run at UIUC

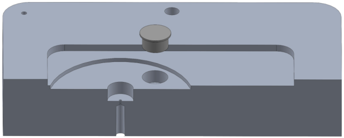
Custom FPU built from all flight systems:

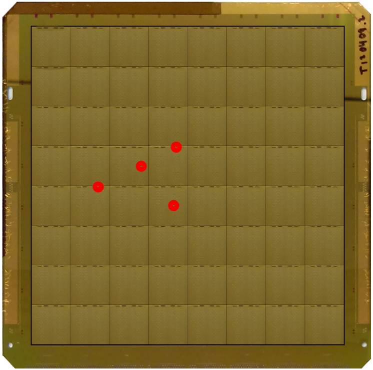
- A recovered SPIDER flight TES wafer
- Recovered SPIDER flight SQUIDs
- A recovered SPIDER flight telescope base
    - incl. the sub-kelvin fridge
- Flight-like multiplexer



Lab set-up: $5MeV$ αs from ^{241}Am







- Two sources are placed directly over TES islands, we **expect a few α interactions per min, depositing** $100keV$ **to** $1MeV$ **into each islands.**
- Two sources are placed over antenna patches, each providing **hundreds of** $\alpha s/s$ **interactions depositing** $5MeV$ **into the wafer.**

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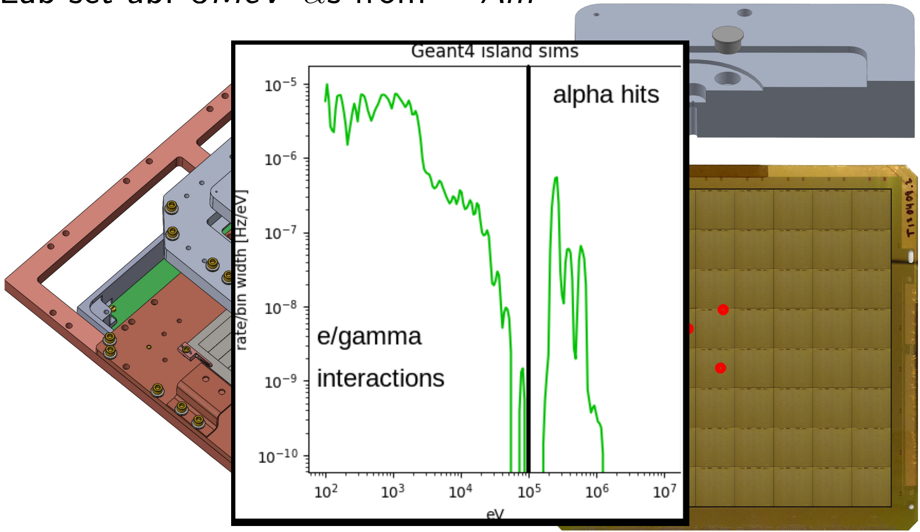

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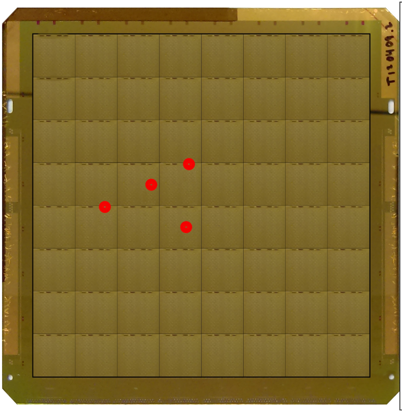
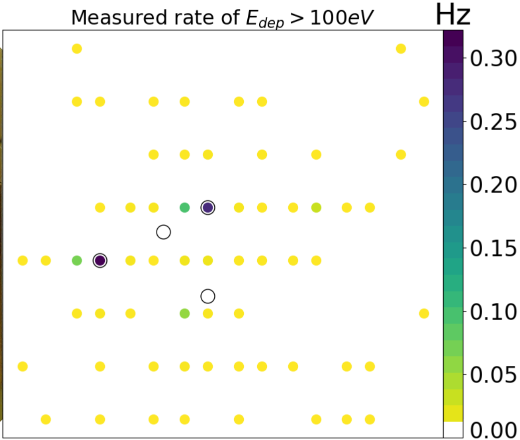
Lab rates





Lab agrees with flight:

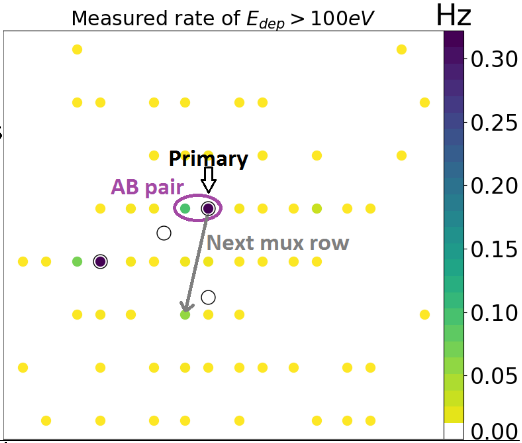
- Detector sensitivity is localized to near the TES island.

Lab coincidences

For a glitch on **Primary**, what is the probability of a glitch on cross-talkers?

AB partner	9.8%
next mux row	8.8%

Expected Poisson coincidence $< 0.5\%$ in AB pair.



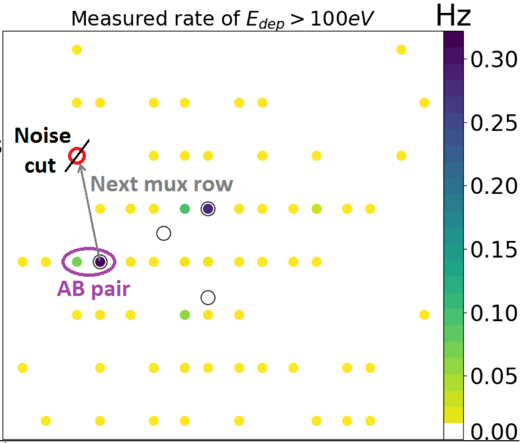
Some cross-talk mechanisms evident:

- AB pair correlated:
  - $\Rightarrow$ Could be either wafer propagation or cross talk.
- Next mux row correlated:
  - Adj. mux row cross-talk visible in lab, not in flight. Possibly because of lab's high energy depositions.

Lab coincidences

For a glitch on **Primary**, what is the probability of a glitch on cross-talkers?

AB partner	13.7%
next mux row	N/A



Some cross-talk mechanisms evident:

- AB pair correlated:
  - ⇒ Could be either wafer propagation or cross-talk.
- Next mux row correlated:
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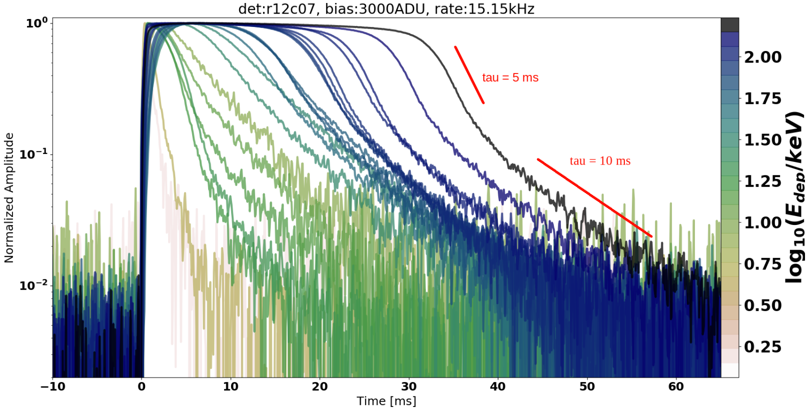
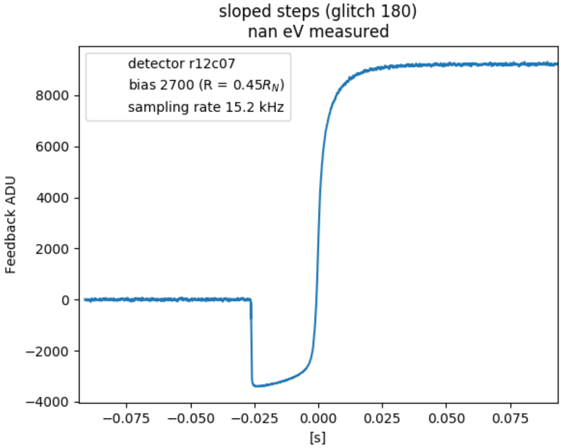
Lab glitch shapes at 15.2kHz



- Some glitches saturate (expected!) at this TES bias.
- Diverse rising and falling time constants (notice trace crossings!).
  - Diverse falling time constant could come from where the energy is deposited in the island or along the legs (modeling work by JPF).
  - Very fast rise and fall times only occur in low energy glitches.

Flux slips

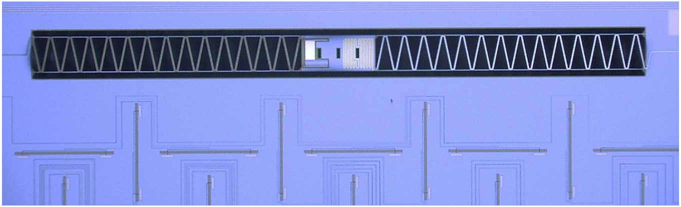
15kHz ^{241}Am lab data



Step properties

- There are **flux slips** on the rising edges of **very big glitches**. Causing the readout system to recover **one SQUID flux period away** from where it should.
  - At SPIDER 1's sampling rate, these shapes have no information about the underlying glitch.
- In SPIDER these happen about $1/hour/det$.

Take-aways and looking forward



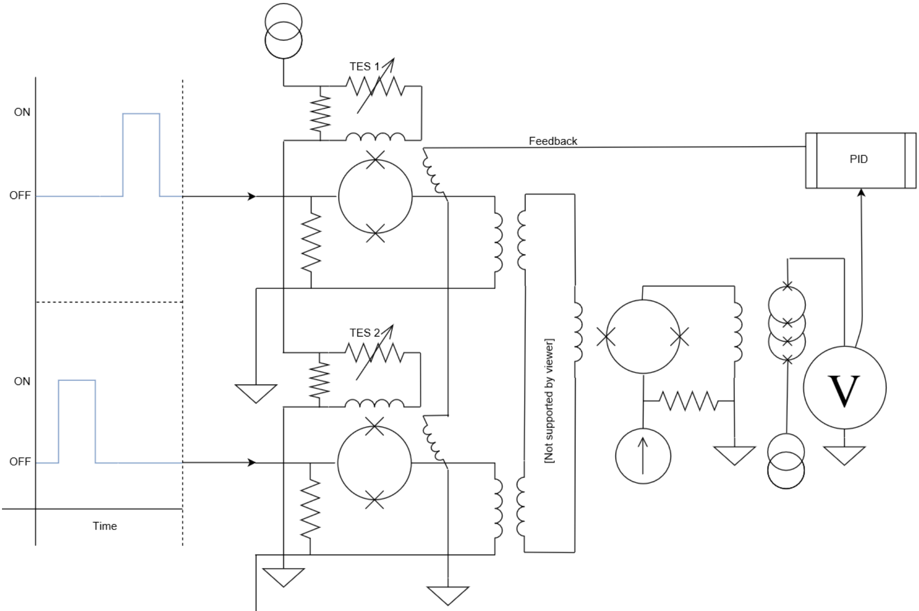
- The detectors are **not sensitive to large areas** of the wafer, sparing them of a significant analysis glitch impact.
  - The detectors are **probably sensitive to depositions on the legs**, increasing the area of sensitivity and causing 'rounded' glitch shapes.
- Multiplexing is responsible for some cross-talk, but we now know **SQUID periodicity is responsible for converting big glitches into flux-slips**.

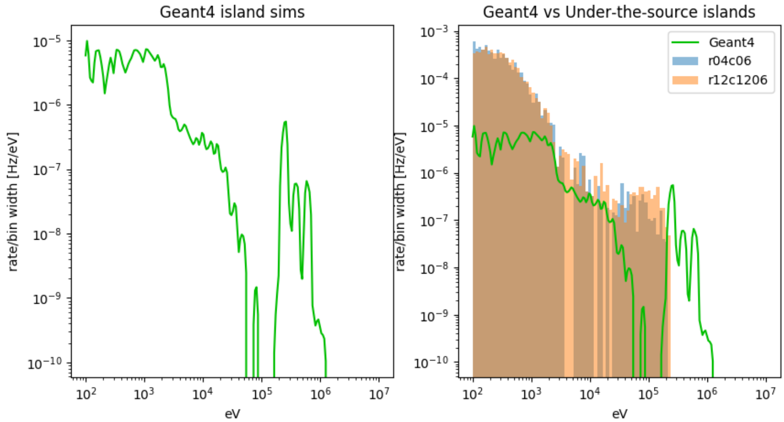
- Repeating the tests at $100mK$.
- Further modeling work:
  - flux-slip mitigation.
  - particle-leg interactions.
  - energy calibrating non-linear / non-ideal glitches.

This work is supported by NASA Strategic Astrophysics Technology (SAT) program, and the SPIDER collaboration.

Adding multiplexing to readout

Showing time division with SQUID amplifier chain

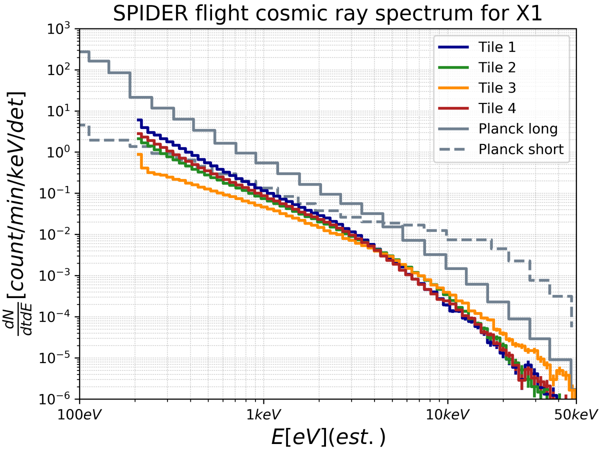




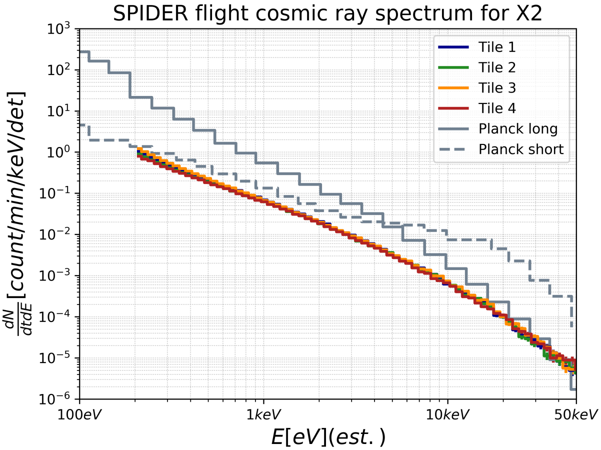
Need to include:

- Fractional transfer of energy from legs.
- Glitch $\rightarrow$ step cut-off.
- Energy calibration for non-linear/non-ideal glitches.

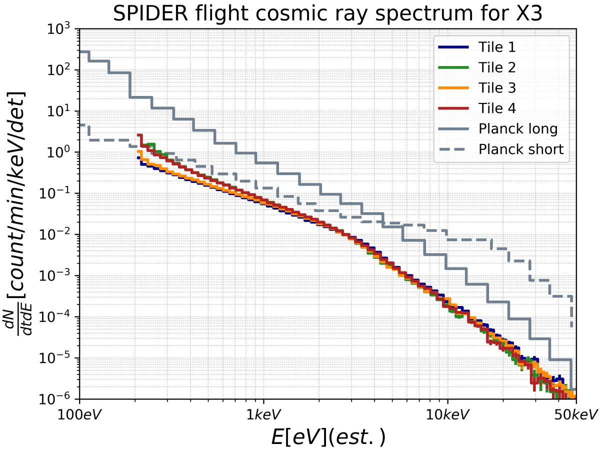
Flight Spectrum 1/6



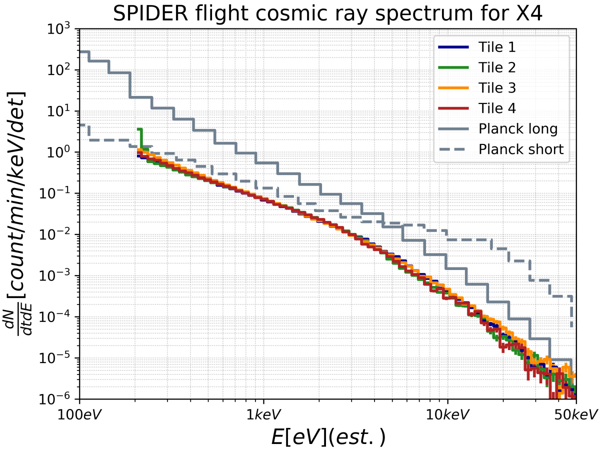
Flight Spectrum 2/6



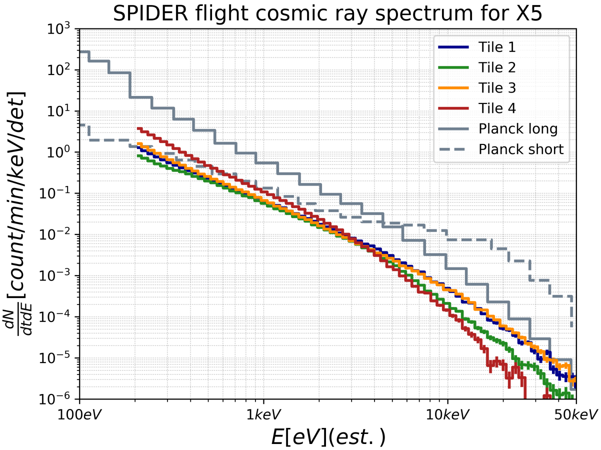
Flight Spectrum 3/6



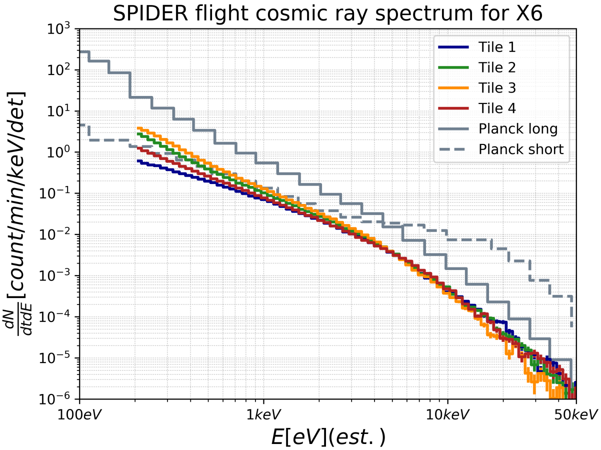
Flight Spectrum 4/6



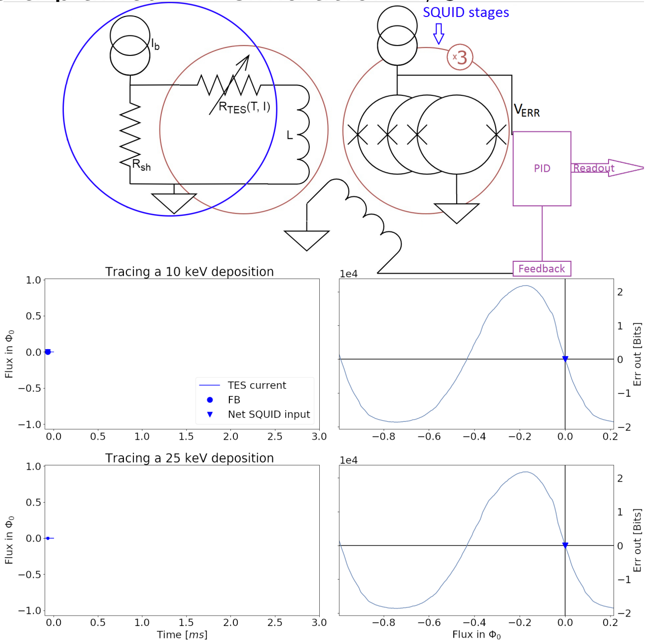
Flight Spectrum 5/6



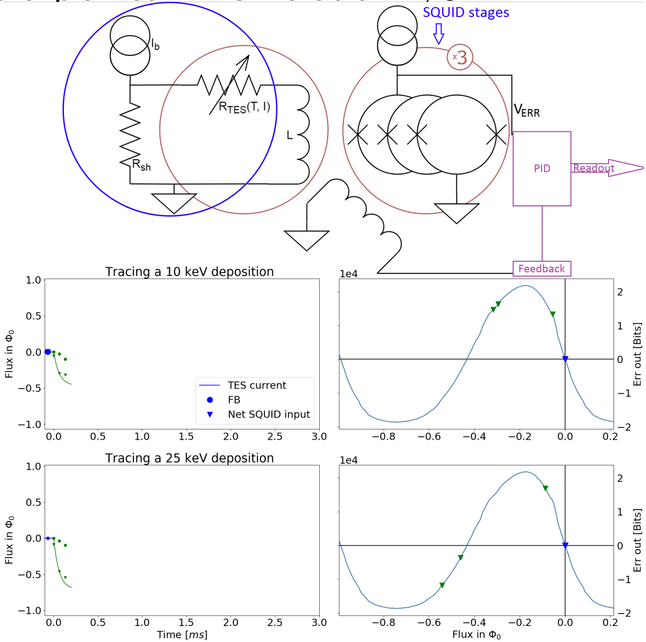
Flight Spectrum 6/6



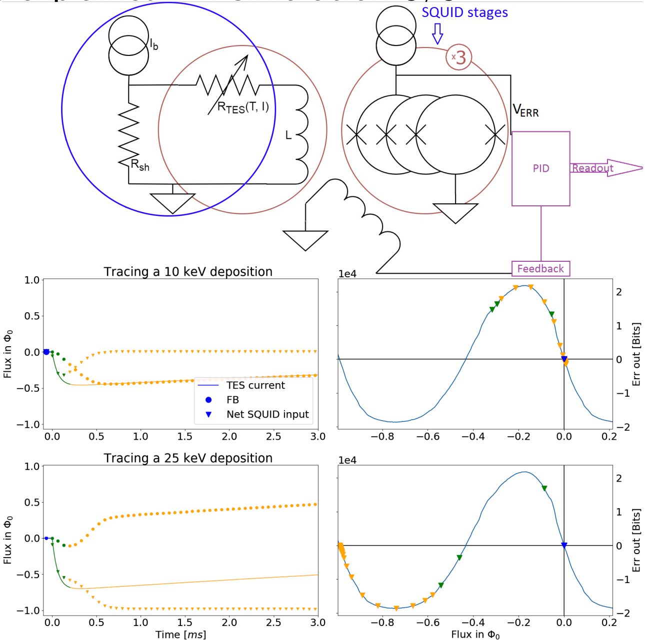
Flux slips explained: In simulation 1/3



Flux slips explained: In simulation 2/3

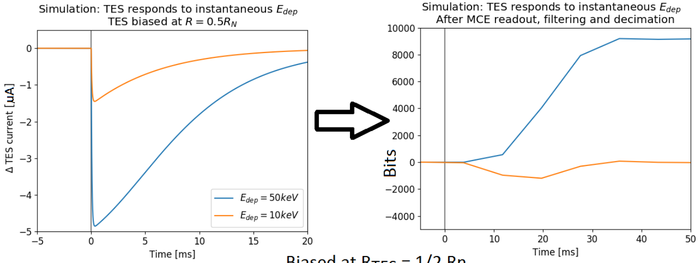


Flux slips explained: In simulation 3/3



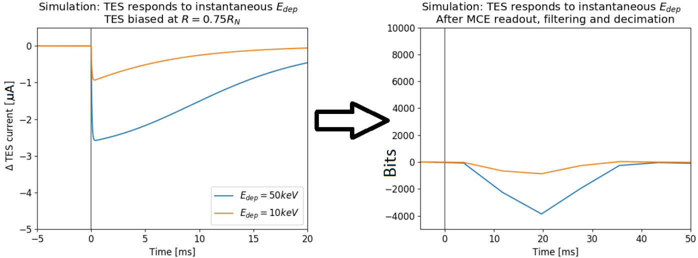
Effects of bias on flux slips

Flux slips can be prevented in tuning or TES design



Biased at R_{TES} = 1/2 Rn

Biased at R_{TES} = 3/4 Rn



More details on SPIDER flight coincidences

FPU	$N_{events}^{dets>1}/N_{events}$	$N_{events}^{dets\leq 2}/N_{events}^{dets>1}$
X1	7.7%	87.4%
X2	3.7%	91.3%
X3	4.0%	89.0%
X4	2.5%	93.7%
X5	9.0%	83.0%
X6	4.9%	90.5%

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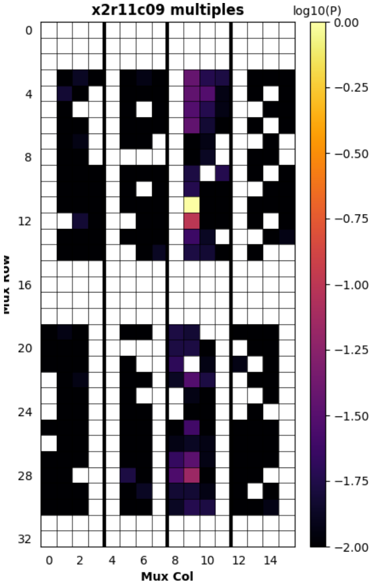

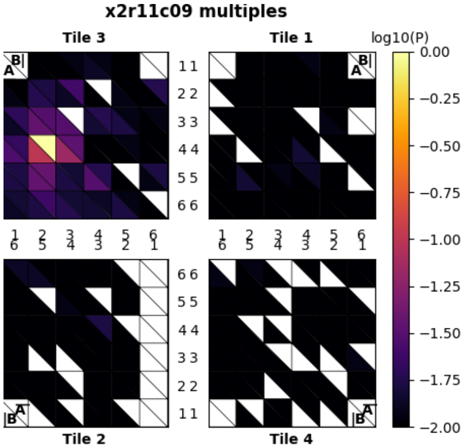

SPIDER 150GHz simulation parameters

I_c	$2A$
T_c	$500mK$
α_0	125
R_n	$32m\Omega$
C	$1pJ/K$ at $450mK$
G	$20pW/K$ at $450mK$
β_c	2.8
β_G	2.1
L	$2.4mH$
R_{sh}	$3m\Omega$
R_b	1096Ω
P_{opt}	$0.3pW$