The Simons Observatory:
Gain Calibration in the Small-Aperture Telescopes

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UC San Diego

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After SPIE proceedings [here](#)

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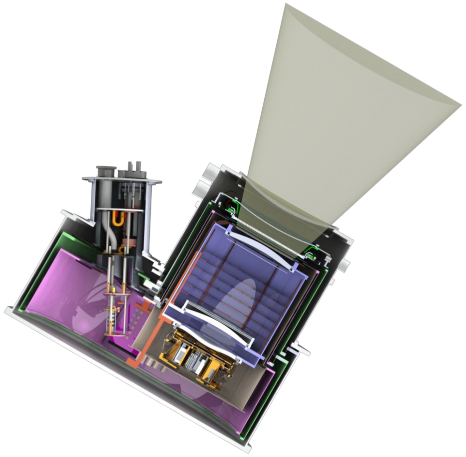
Motivation

- Imagine you are working on a new CMB instrument in the field and
  - The initial cooldown is complete
  - At least some detectors are working
  - Your telescope can be pointed by its platform
- What is the most likely question your supervisor will have?



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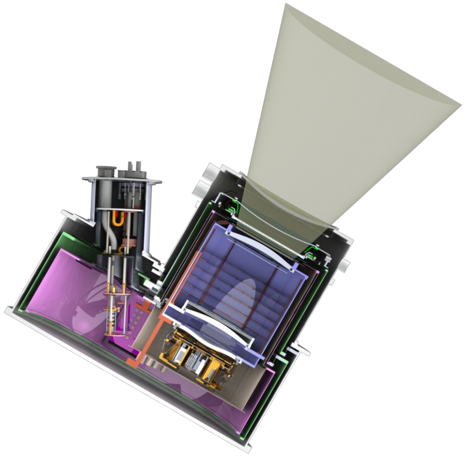

What are the NETs?

How do you answer the question?
+
What do I mean by “gain”?

$$\boxed{\mathrm{NET}} = \frac{1}{\sqrt{2}\eta}\frac{\delta T}{\delta P}\mathrm{NEP} = \frac{1}{\sqrt{2}\eta}\frac{\delta T}{\delta P}(S^{-1}\boxed{\mathrm{NEI}})$$

Noise in brightness
temperature units
(per rt[integration second])

Noise in TES current
calibrated by readout
resistances
(per 1/rt[Hz] bandwidth)

How do you answer the question?
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What do I mean by "gain"?

Absolute calibration
May be formed from coadded data

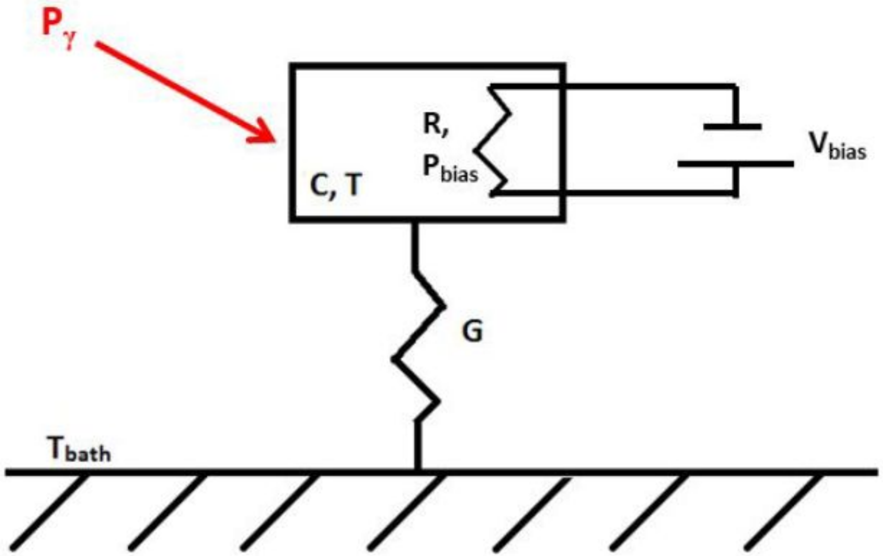
$$\mathrm{NET} = \frac{1}{\sqrt{2}\eta}\boxed{\frac{\delta T}{\delta P}}\mathrm{NEP} = \frac{1}{\sqrt{2}\boxed{\eta}}\frac{\delta T}{\delta P}\left(\boxed{S^{-1}}\mathrm{NEI}\right)$$

Part 2:
Relative efficiency

Part 1:
Responsivity

SO responsivity input: the model

- Power balance equation holds in small signal limit for times > time constant



$\Delta P_\gamma + \Delta P_{bias} = \Delta P_{th}$ (power to bath)

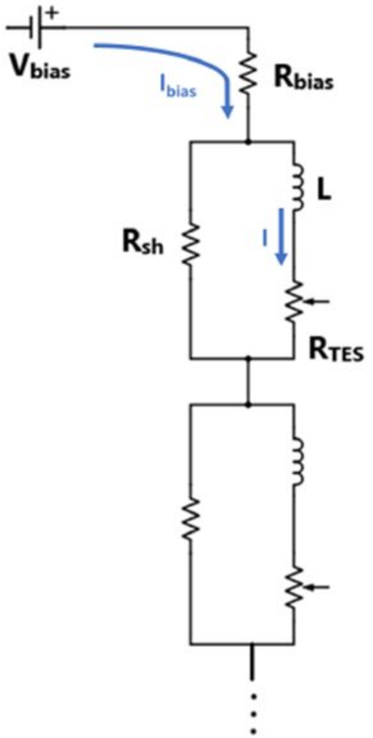
$\Delta P_{bias} = \Delta P_J = I(R_{\mathrm{TES}} - R_{\mathrm{sh}})\Delta I + I R_{\mathrm{sh}} \Delta I_{\mathrm{bias}}$

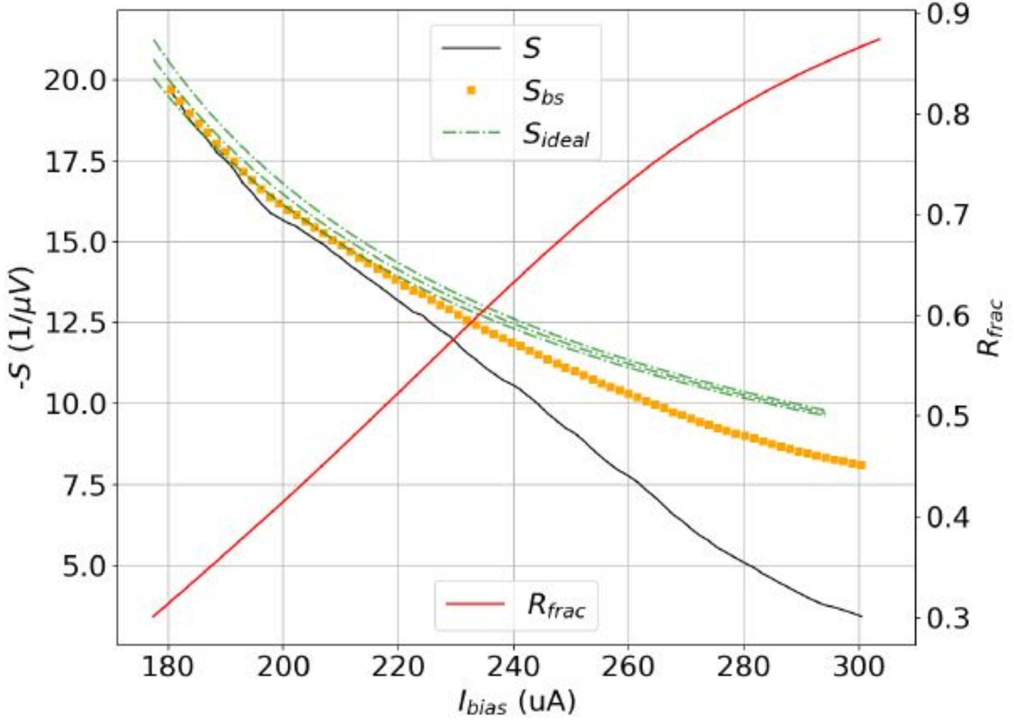
$\Delta P_\gamma = G\mathcal{F}\Delta R_{\mathrm{TES}}(I, I_{bias}) - \Delta P_J$

For large loop gain ($F \rightarrow 0$):

$$S_{\mathrm{ideal}} = -\frac{1}{R_{\mathrm{sh}}\left(I_{\mathrm{bias}} - 2I\right)}$$

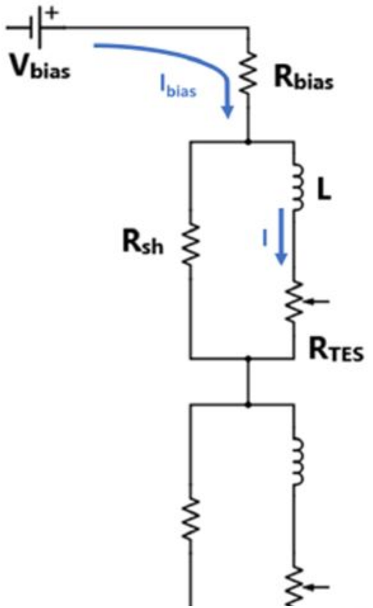
SO responsivity model: I-V input

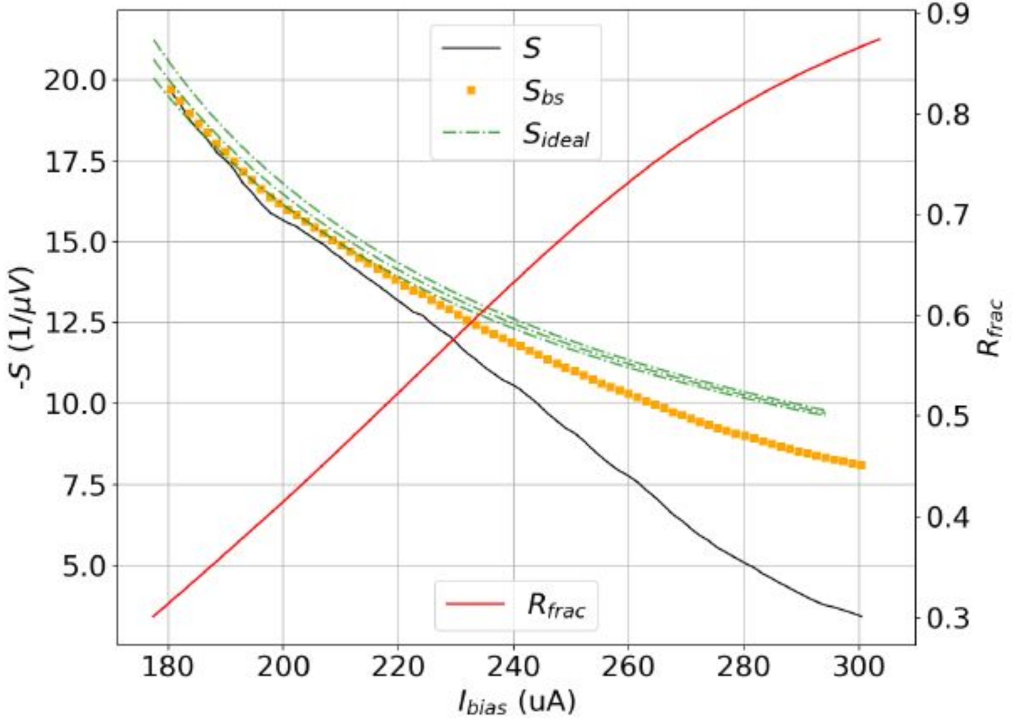




- Control V_{TES} using $V_{bias} \rightarrow I_{bias}$
- Record $I_{TES}(V_{TES})$ or $I_{TES}(I_{bias})$
  - Calibration to absolute units w/in I-V
- Estimate responsivity at each point

SO responsivity model: I-V input





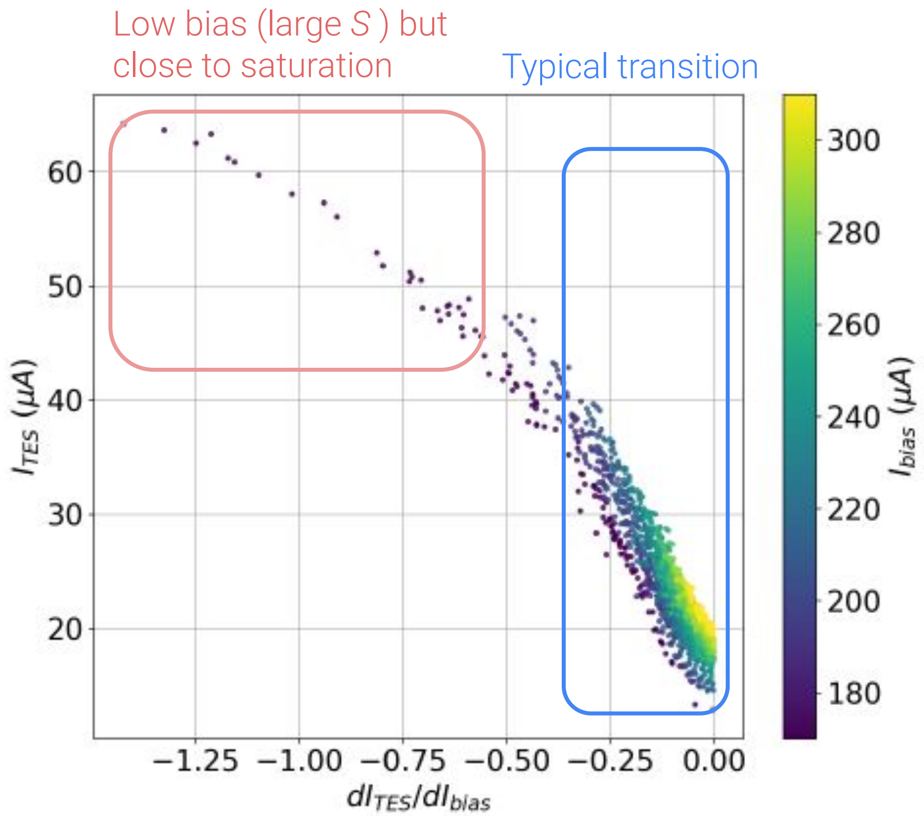
$$S_{\mathrm{bs}} = \frac{2A-1}{R_{\mathrm{sh}} I_{\mathrm{bias}}}$$

$$S = -\frac{1}{R_{\mathrm{sh}}\left(I_{\mathrm{bias}} - 2I\right)}\left[\frac{(I_{\mathrm{bias}} - 2I)(I_{\mathrm{bias}} - IA^{-1})}{2IA^{-1}(I - I_{\mathrm{bias}})}\right]$$

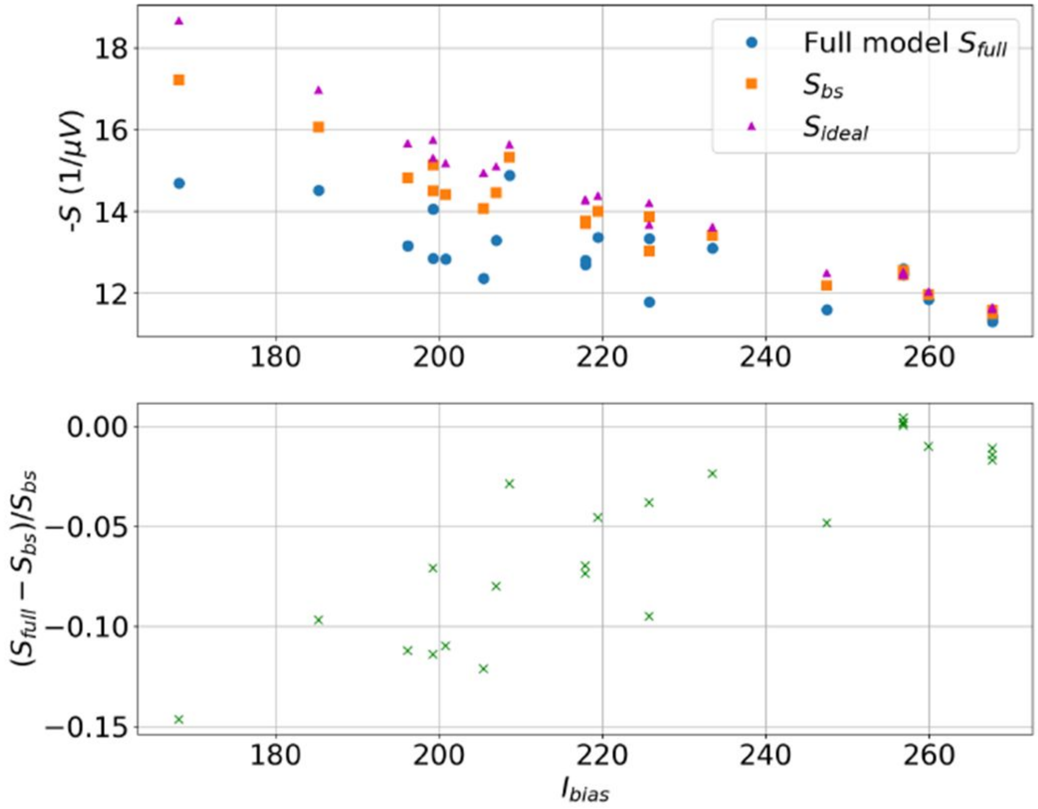
- S_{bs} = using bias step output
  $A = dI/dI_{bias}$ only
- S = using I, I_{bias} $A = dI/dI_{bias}$

Recovering I without direct I-V data

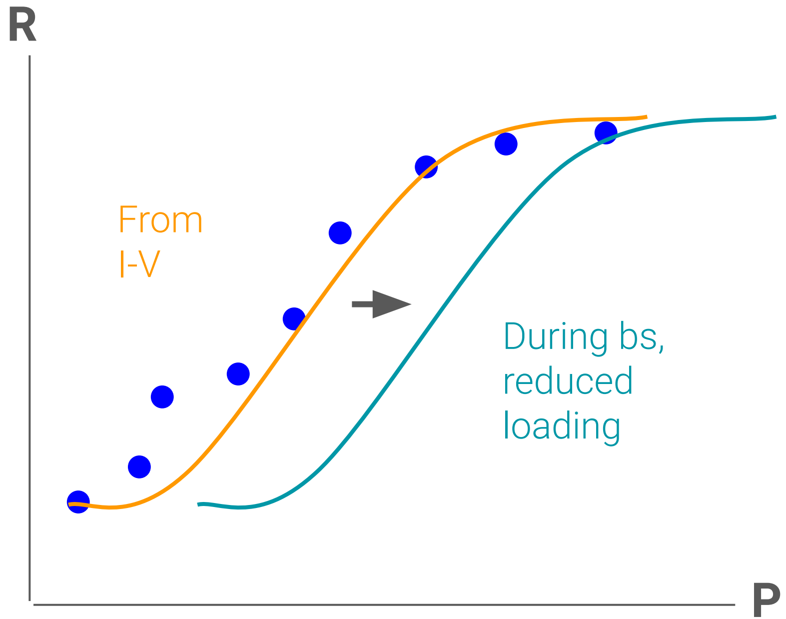
- O(100) I-Vs in test case (single channel)
- Form bins in I_{bias}
- Fit I (y-axis) vs. A (x-axis) in each bin
- For range of bias step datasets:
  - Estimate I from measurement of A in appropriate I_{bias} bin



Comparing responsivity estimates



Alternative path: model transition
Thanks to S Takakura, R Gerras, J Lashner

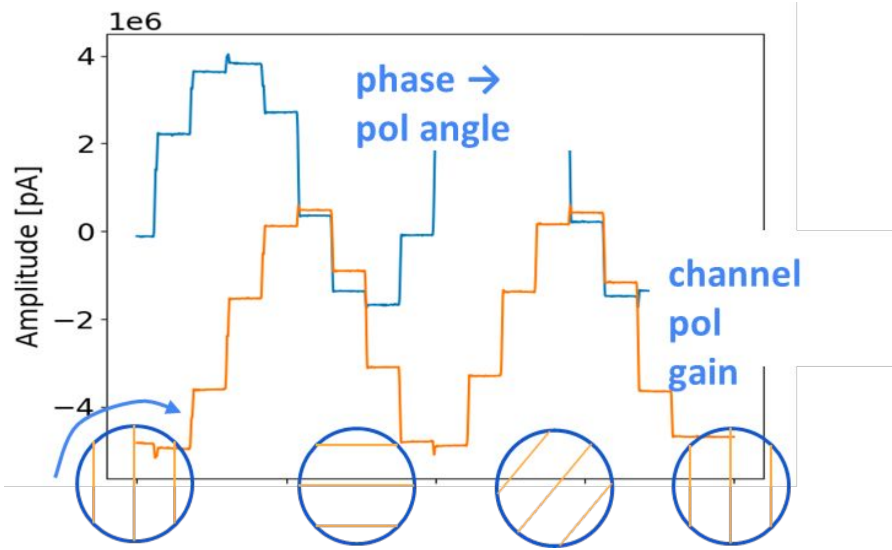


- Use fitting function to model R (P_J) curve from I-V data
  - Actually model parameter describing TES resistance sensitivity to power
- Capture change in P_J
  - A from bias step vs. A from I-V bias point
- Recover loop gain, R
- Generating results from this model currently
  - Improves R, S_i estimates!

Part 2: relative calibration (flat-fielding)

- Different detectors see different ΔP_γ for same input signal
- Methods to solve:
  - Apply source w/ flat brightness or modeled brightness distribution
  - Compare ΔP_γ for each working channel
  - Normalize each channel by “flat-field factor” (w/ g_i ~ response, to be defined)

$$F_i = \mathrm{med}(g_i)/g_i$$



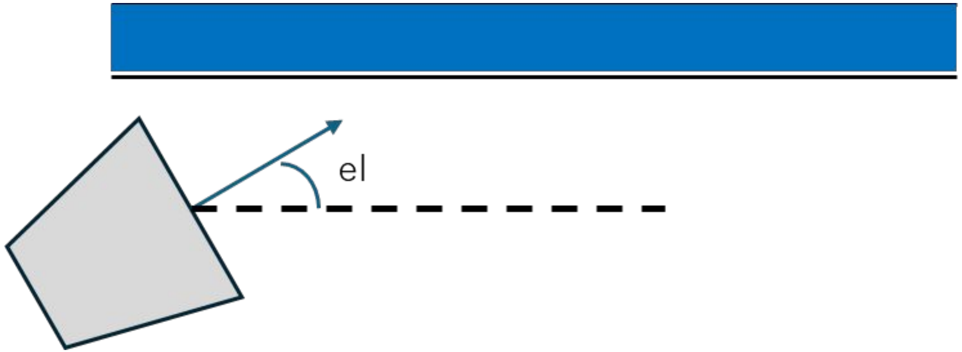
- Options for SO:
  pt sources, **wiregrid**, atmosphere, **elnods**

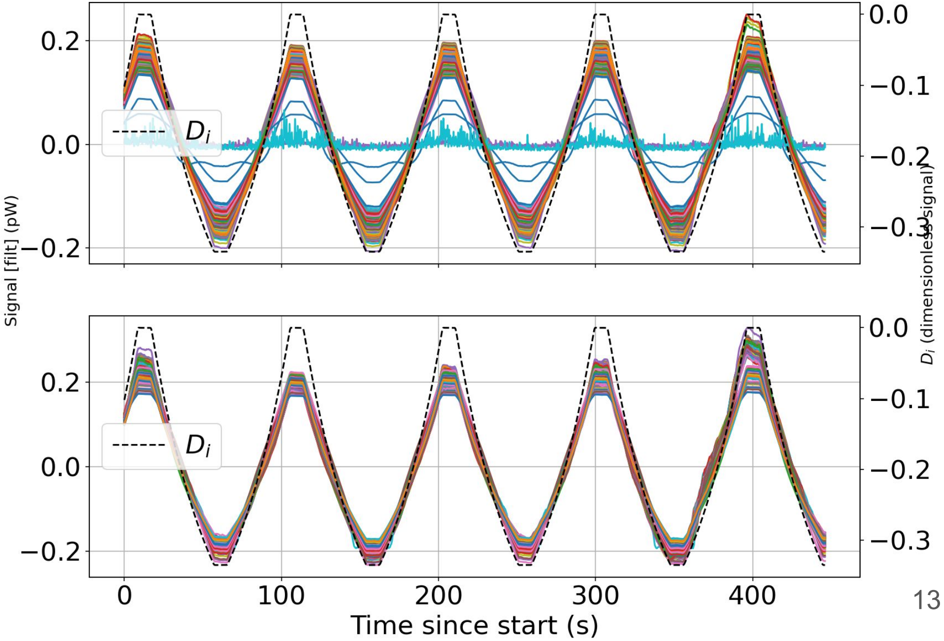
S Day Weiss talk!

H Nakata talk!

El nods

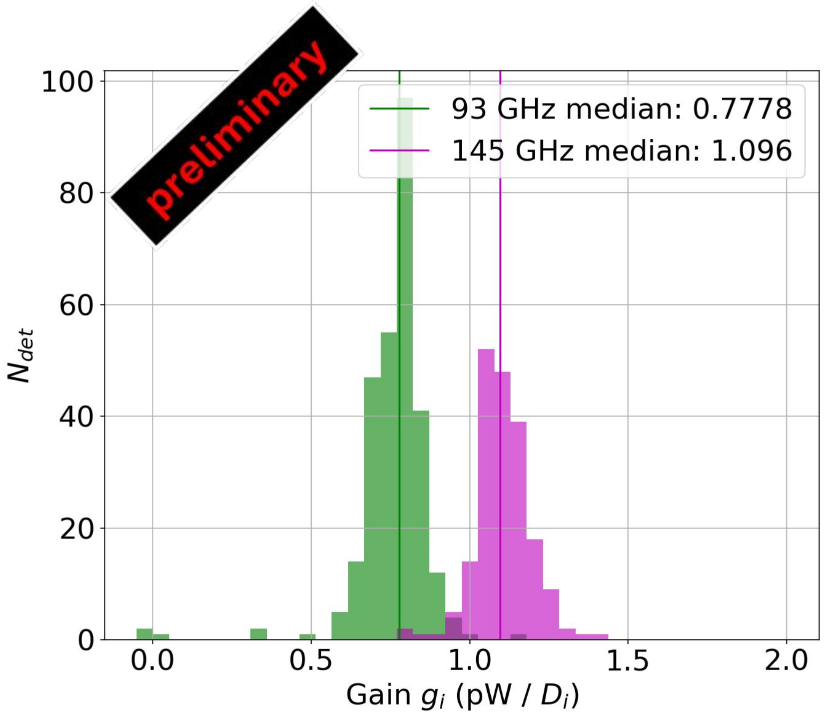
- Assuming slab model of atmospheric emission:
  Photon power ∝ 1/sin(el)
- Move telescope through range of elevations
  Signal ∝
  D_i = csc(el) – csc(min(el))





Single module in SAT-MF1
All detectors passing cuts
el = 50° to el = 70°

El nod results: fitted gain

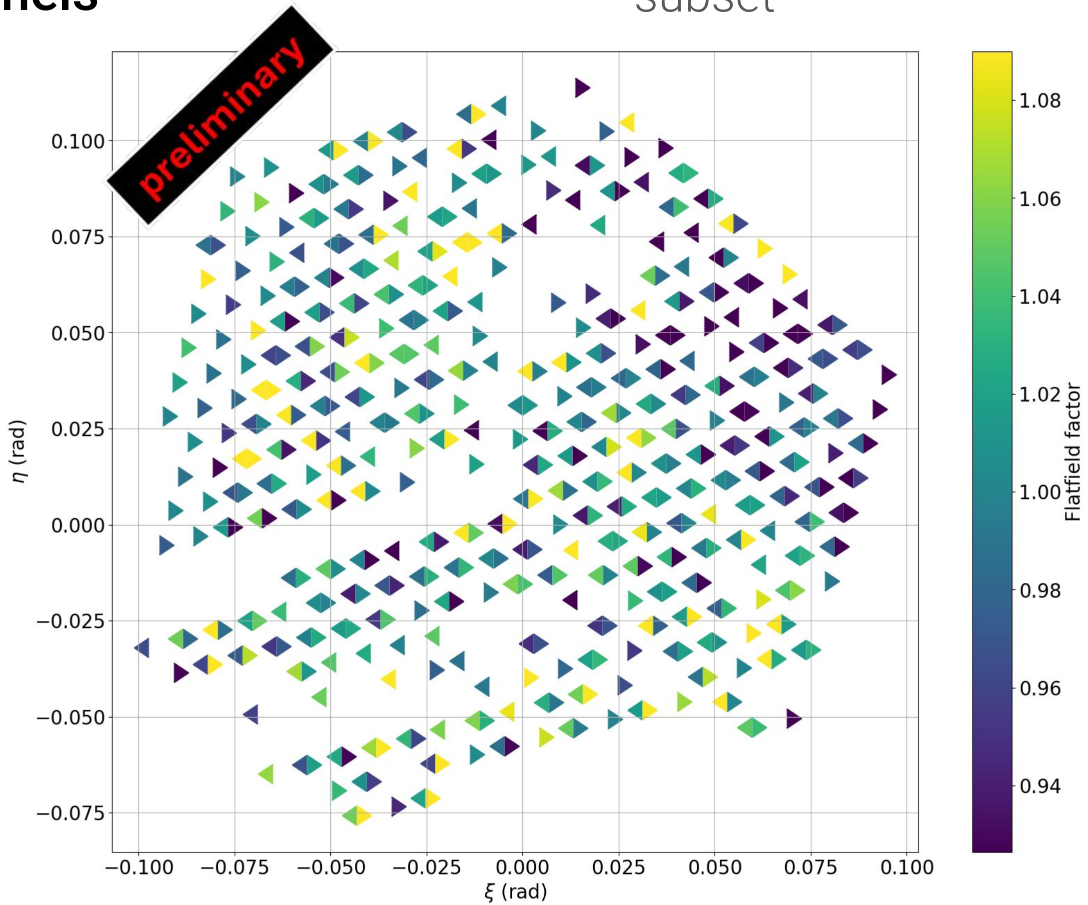


Single module in SAT-MF1
All detectors previous w/ good fits

- Fit slopes for each detector
  g_i = pW / D_i
- Less sensitive to nonlinearity than amplitude estimates
  (fitted over whole range of elnod)

El nod results: flat field factors
150 GHz channels

F_i from slide 10 across single UFM subset



Summary

- Detector calibration for SO exploring range of responsivities
    - Need models, fits to capture per-detector electrical response
    - Can help separate detector tuning dependence (time variation) from optical performance dependence (bandpass, efficiency variation)
- Relative calibration to optical signals has multiple paths
    - Comparison of multiple probes → cross-checks on systematic uncertainties
    - El nod + wiregrid signal amplitude comparison underway
- Detailed sensitivities from absolute calibration on planets, CMB [Planck] to come!

Thank you!

BACKUP

Ex dataset: fitting line to data