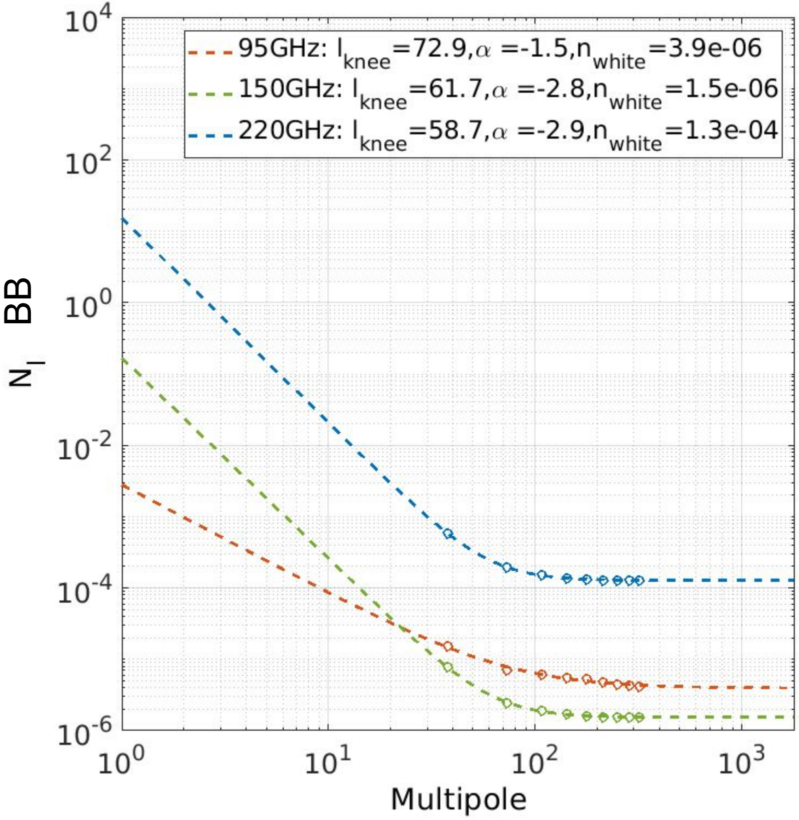
Performance-based forecasting

Clem Pryke for *r* Forecast Group
CMB-S4 Collaboration Meeting March 2021

Rational/Background

- Rather than attempt to calculate from scratch take published results and scale them to bigger experiment and/or different sky coverage.
- Intrinsically includes all of the imperfections and inefficiencies of real world experiments (on the assumption that one will do no better/worse than previously)
- At the very least a useful cross check on *ab initio* calculations
- Calculations developed for the CDT and DSR now submitted for journal publication (ApJ) as https://arxiv.org/abs/2008.12619 (First S4 journal paper?)
- Two threads to this work
    - Scale bandpower-covariance matrix and use Fisher matrix techniques to predict uncertainty on parameters - in particular $\sigma(r)$
    - Scale noise power spectra (N_l) and make map based sims - will talk about this type today - try to show how simple/transparent it is

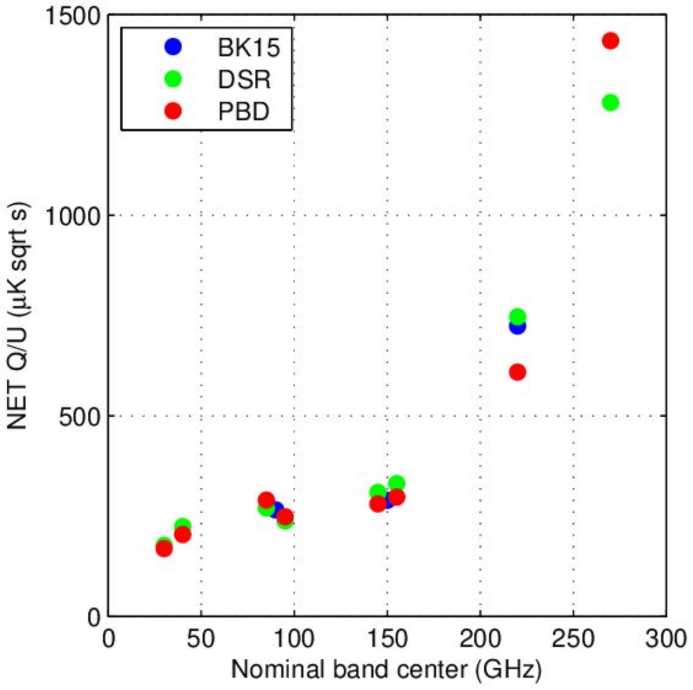
Take BK15 published N_l spectra...



Above plot taken from Ben Racine posting

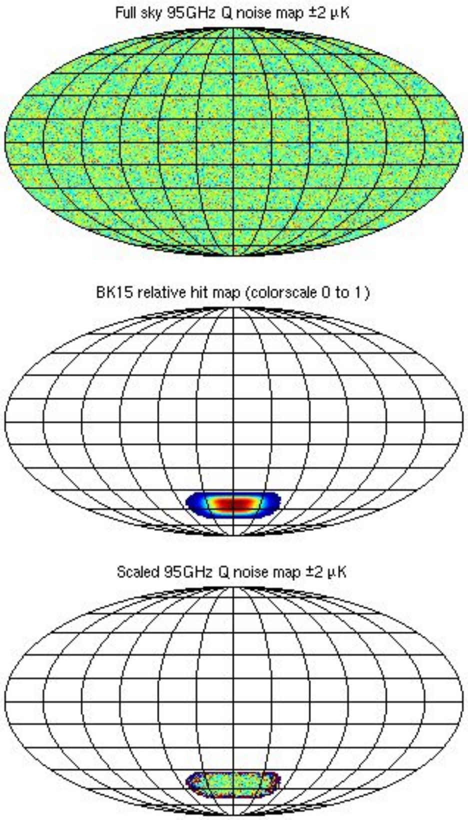
- Spectra available for download here, paper here
- Fit to white + 1/f model as this 02/2019 posting
- Convert from N_l to μK-arcmin (sqrt)
  - (for BB 6.8, 4.3, 39 μK-arcmin at 90/150/220GHz)
- This step inherited from Ben Racine
- (note these spectra have been corrected for tod filtering)

...and scale by ratios of calculated NET's

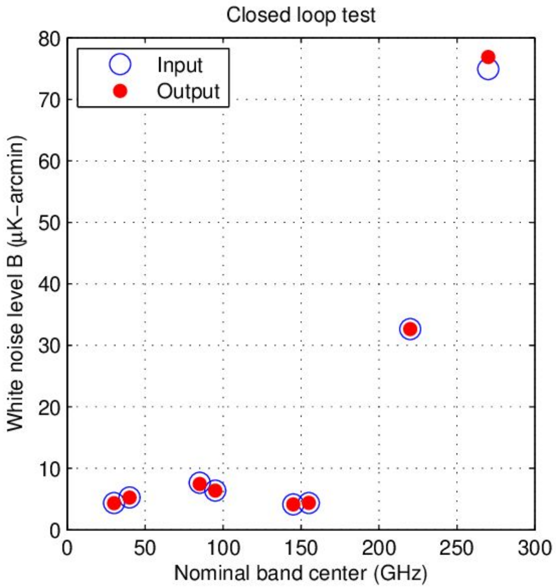


- Latest generation for PBD: John Ruhl operating bolocalc in [this google spreadsheet]
  - Run calcs for BICEP/Keck 90/150/220GHz designs
  - Run calcs for S4 design (changes include DR, bandwidths etc)
- Multiply BK15 µK-arcmin numbers by the ratio - now we have “what BK15 would have gotten if it had DR and S4 bands, but same number of detectors and overall efficiency.”
- Take ratios versus the closest BK15 band.
- (These ratios are quite close to one.)

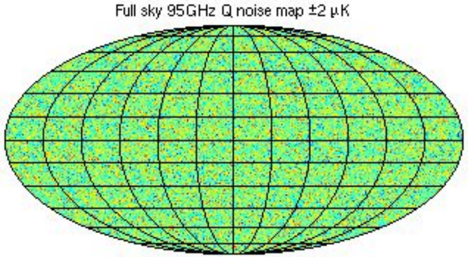
Now make full sky noise maps...

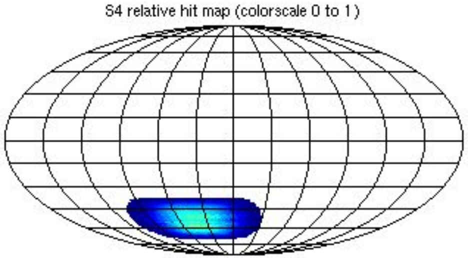


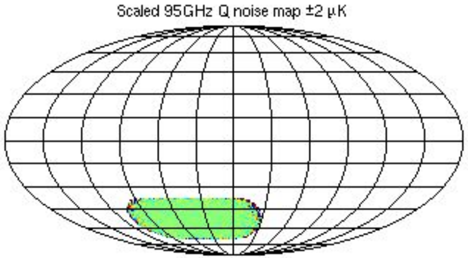
Make full sky noise maps with level set such that when divided by the sqrt of the BK15 relative hit map, and power spectrum taken with hit map as apodization mask, recover the input μK-arcmin numbers



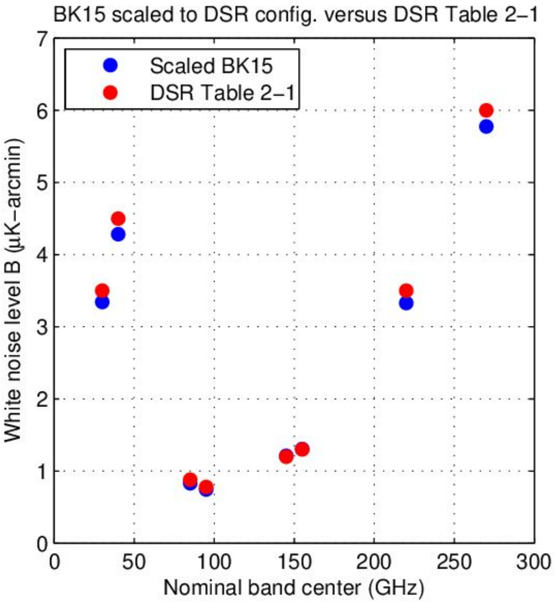
… and scale from full sky to S4







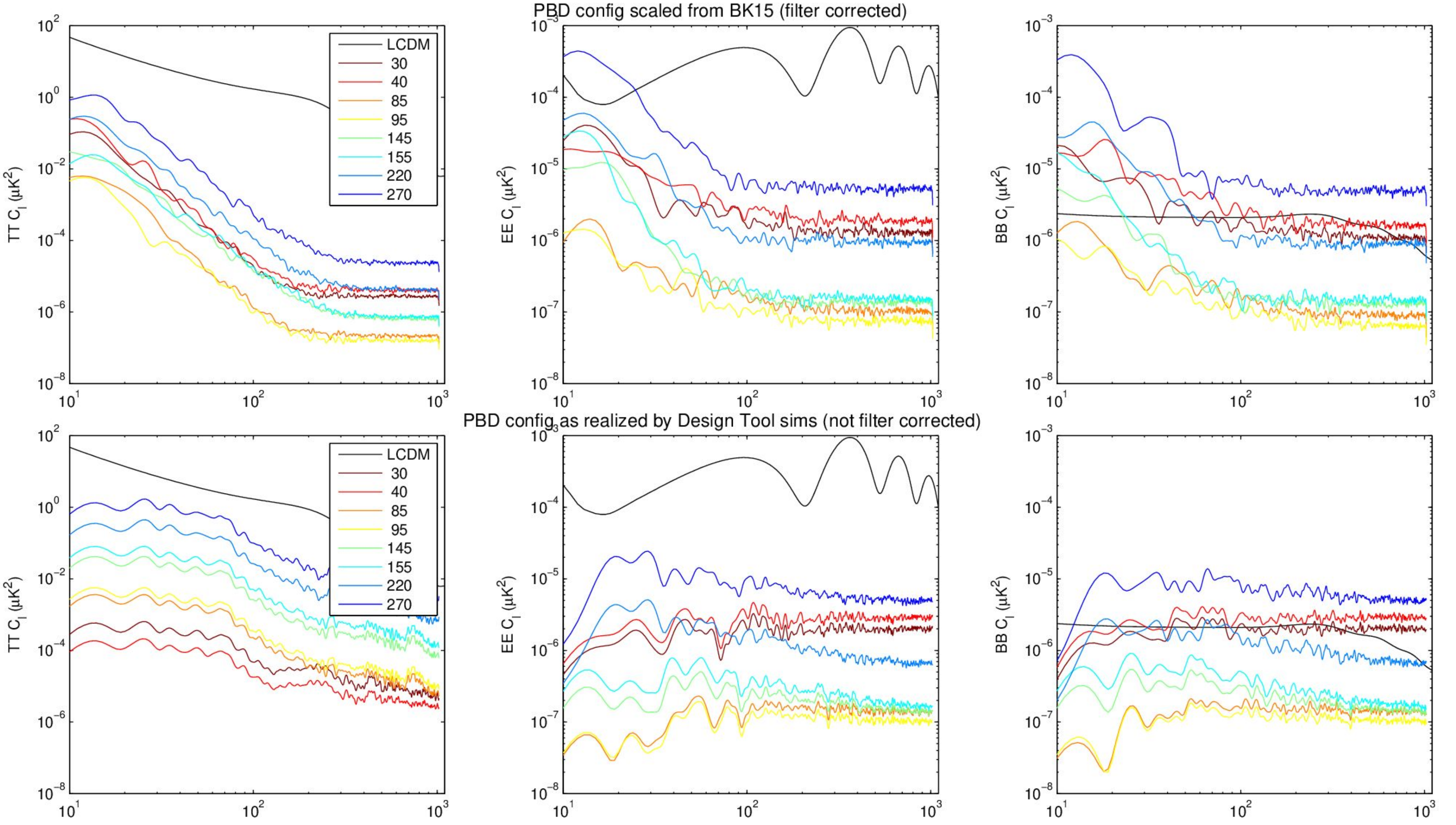
- Now take S4 sim hit map and normalize to have same sum as BK15 one - “redeploy the hits on the sky”
- ...and then multiply by the ratio of detector-years S4/BK15 - “scale up the observations”
- Divide the full sky noise map by the sqrt of this hit map - we get S4 noise map
- Going back to power spectrum recover the DSR μK-arcmin numbers



DSR μK-arcmin numbers also came from BK15 scaling but through a different method (not hit map redeployment) as described in this post

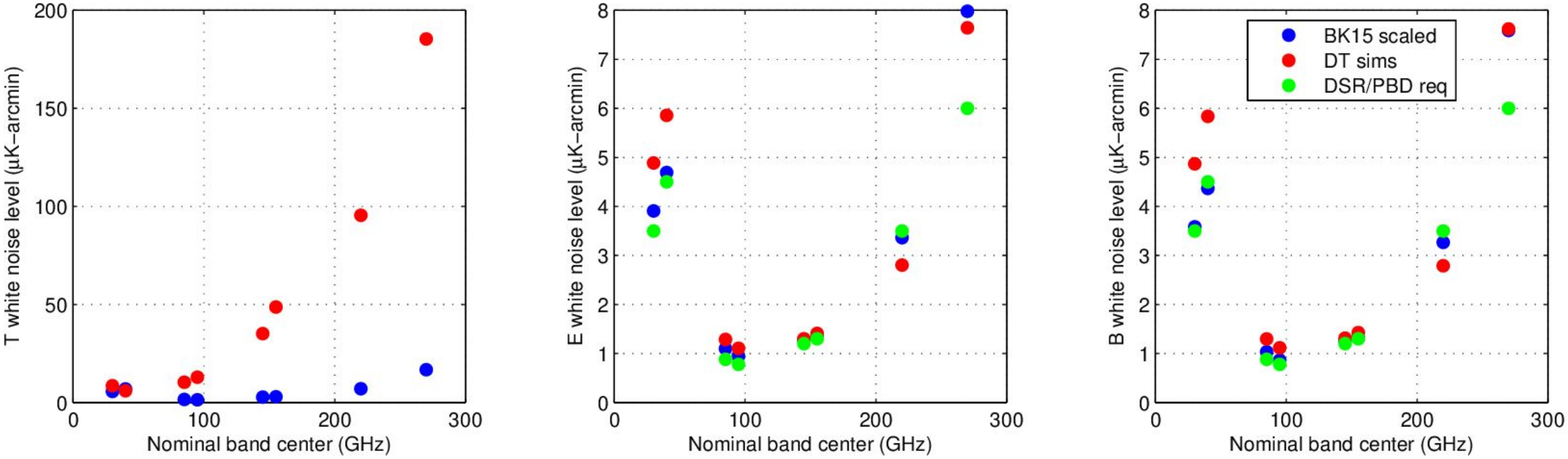
Checking the (brand new) Design Tool sims

- Reijo and co have recently been doing ab initio simulation of PBDR config.
- Wish to check these against “scaling from achieved performance”
- Take John R NET ratio numbers as above
- Take hit pattern from Reijo’s as above
- Call these “07b” sims - scaling reiterated in this posting
- Compare to single noise realization provided by Reijo/Andrea in files like cmbs4_KCMB_SAT-MFHS1_pole_nside512_1_of_1.fits etc



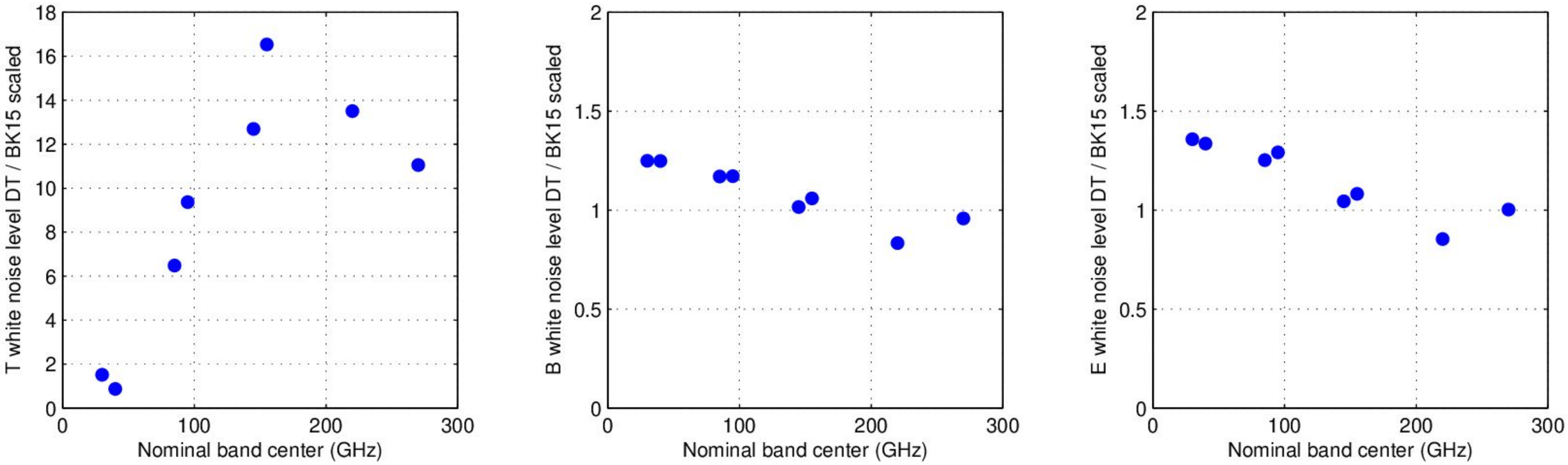
PBD config scaled from BK15 (filter corrected)
PBD config as realized by Design Tool sims (not filter corrected)
TT C$_l$ (μK^2)
EE C$_l$ (μK^2)
BB C$_l$ (μK^2)
LCDM
30
40
85
95
145
155
220
270
10^{2}
10^{0}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
10^{-8}
10^{1}
10^{3}

Comparing white noise levels



- BK15 scaled comes close to measurement requirements
  - No surprise since MR basically came from this scaling - but ideal NET's have shifted
- The two sets of map based sims are pretty close (for pol)
  - See next slide for details...

Ratio BK15 scaled to DT Sims



- Polarization noise is close to agreement at 145/155/270GHz. At 220GHz it's a bit lower and at 30/40/85/95GHz significantly higher.
  - Since we used the same NET's and DT sims used overall efficiencies basically taken from BK experience it is not clear why it doesn't agree even better
- TT noise is a little insane...

Next Steps

- Reijo and co have effectively already put in an overall efficiency factor taken from BK - this could just be tuned to force agreement in all bands
  - But we should try and figure out why.
- As a practical matter we will need to keep doing our own sims since apparently there will be only one noise realization in the DT sims but we need hundreds to produce $\sigma(r)$
  - The filenames currently don't even have provision for multiple realisations...
- We are already using the hit pattern which Reijo provides. We can also start to use the observing matrix which they are now providing to produce noise and signal maps which have been filtered appropriately.
  - This will mean we need to reanalyze using some equivalent of the BK "purification matrix" to get sufficient E/B separation purity.

The End

Minimum Complexity Sky Hit Pattern Rescaling

- Previous (inc. 04) sims scaled map area by defining an f_{sky} for the parent and daughter experiments.
  - Gets a little complicated - there is actually an $f_{sky,signal}$ and an $f_{sky,noise}$
- Can simplify:
  - Take hit map of parent experiment
  - Make full sky noise realizations with level set such that when observed with actual hit map of the parent experiment one gets back the published N_l
  - Observe these maps with the hit pattern of the daughter experiment where the total of that hit map is scaled up by the ratio of the detector-years daughter/parent - just "redeploy the hits on the sky" from existing experiment to planned experiment
  - See this posting for details
  - This hit pattern can come from a detailed simulation of the observations
  - Closed loop testing is possible (see this posting) - $\sigma(r)$ came back within 20% of published BK15 result

NET Rescaling

- We may wish to make changes to the detector design etc versus the existing experiments we are scaling from…
  - For instance current SAT design calls for detectors at 100mK rather than 250mK (going to dilution fridge)
- Strategy is to calculate the NET for both old and new configurations and scale N_l by the *ratio* of these.
  - See this spreadsheet giving pBD versus BK numbers

Rational/Background

- Long history of *ab intio* ("from the beginning") calculations of experimental performance turning out to have been overly optimistic once the experiment has been built and the data analyzed.
- An intrinsically conservative alternative is to scale from the achieved performance of previous experiments - preferably actual published results.
- All CMB-S4 forecasts for sensitivity to the tensor-to-scalar ratio *r* so far have used this method.

CMB-S4 *r* Forecast Paper

- Calculations developed from the CDT, Science Book to DSR and now submitted for journal publication (ApJ) as https://arxiv.org/abs/2008.12619 (First S4 journal paper?)
- Two threads:
  - Rescaling of bandpower covariance matrix followed by **Fisher matrix style** calculation of $\sigma(r)$ - Advantage: very fast - can optimize expt. config. Disadvantage: uncertainty estimate only, all in the context of a specific parametric foreground model.
  - Rescaling of noise power spectra N_l followed by **generation of simulated maps**. Then re-analyze these maps as if real experimental data. Advantage: can deal with arbitrary foreground models and mismatch thereof between generation/reanalysis. Disadvantage: many orders of magnitude slower - can only compute for a small number of expt. configs.

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CMB-S4: FORECASTING CONSTRAINTS ON PRIMORDIAL GRAVITATIONAL WAVES

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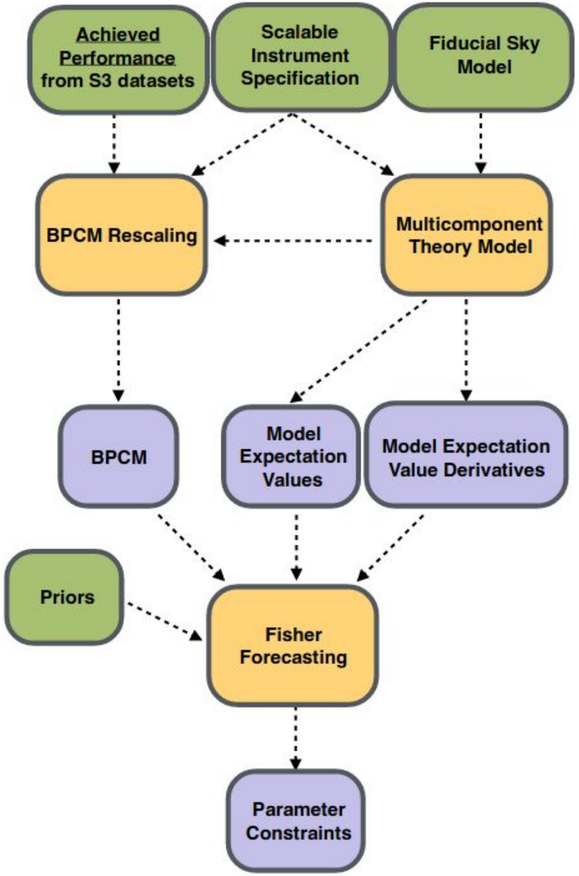
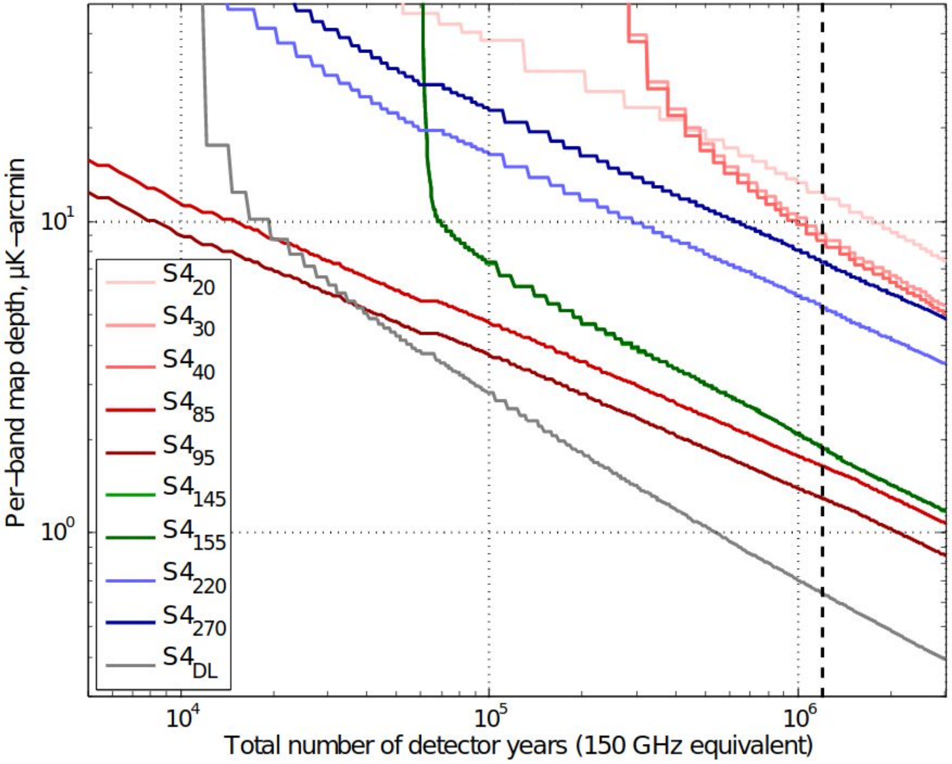
Fisher Matrix Style

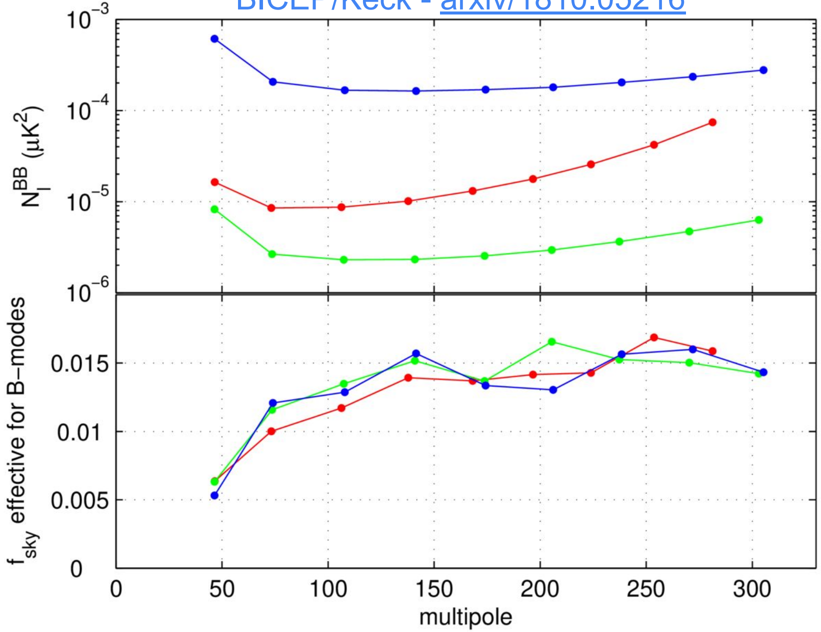




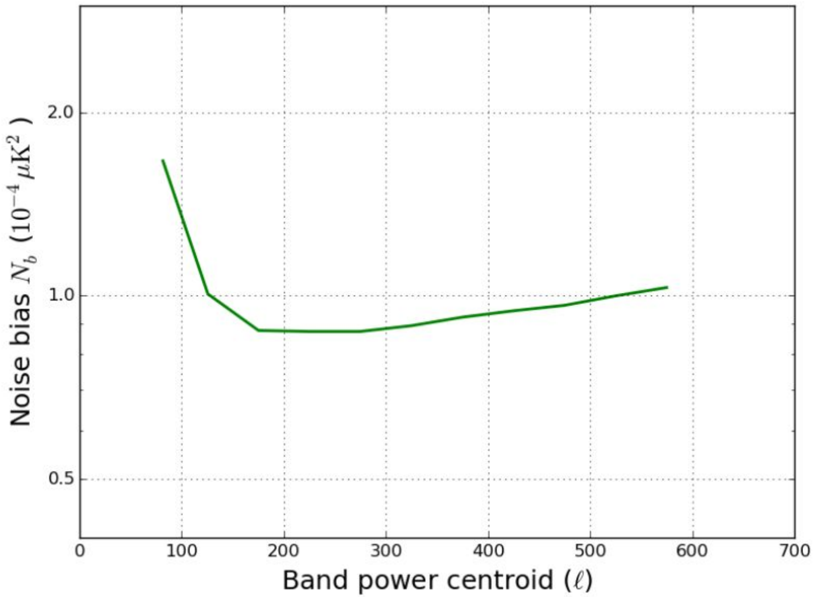
For a given amount of experimental effort can tell you the deployment of detectors across bands which gives the lowest $\sigma(r)$

Map Based Style

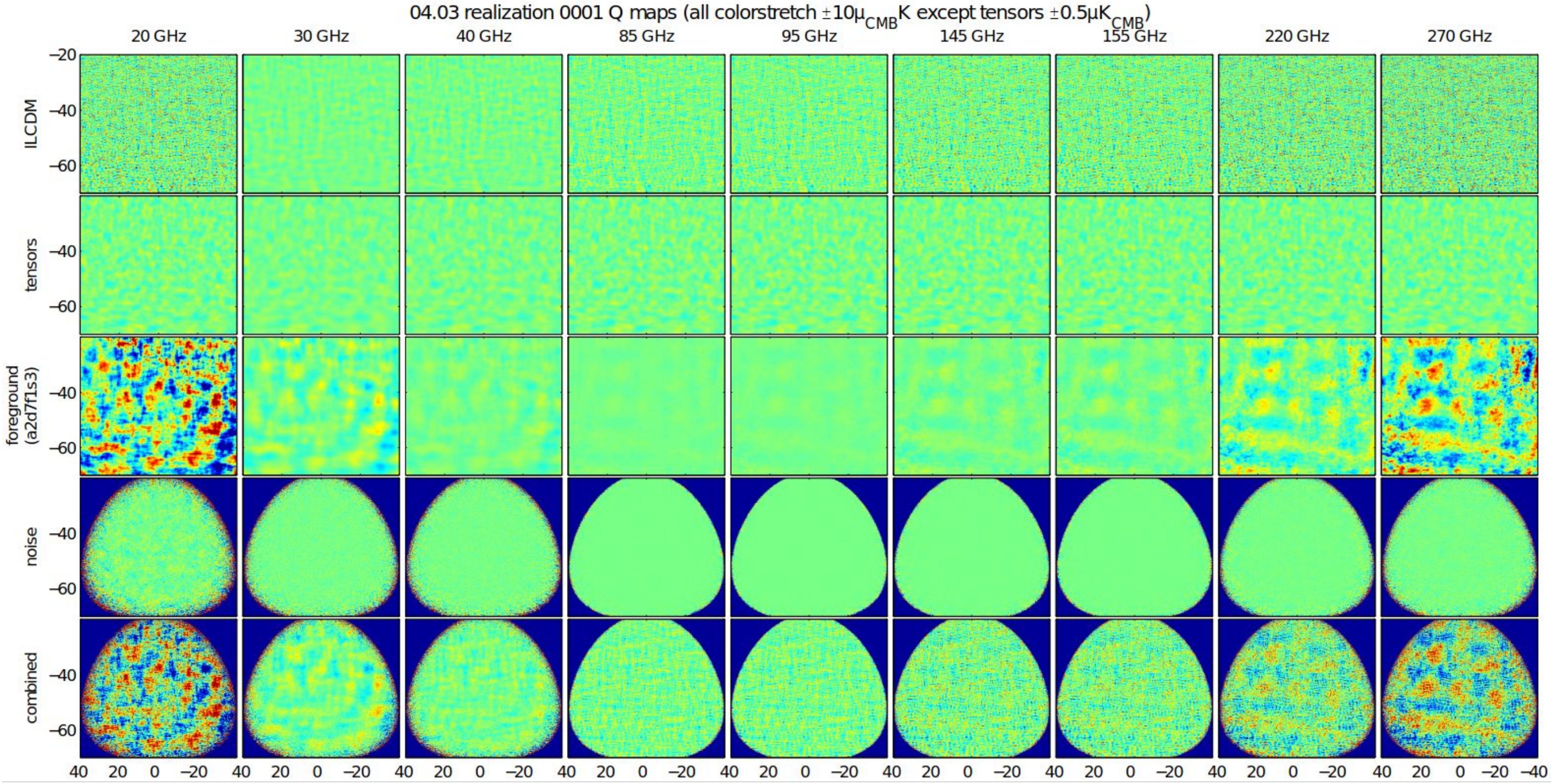
BICEP/Keck - arxiv/1810.05216



POLARBEAR - arxiv/1910.02608



Take published results specifying i) achieved noise power spectrum, ii) corresponding sky coverage, iii) detector-calendar-years used, scale and generate noise maps



Generate noise, include LCDM, explicit foreground model, add all together

Map Based Results from Forecast Paper

Table 2

Results of two analysis methods applied to map-based simulations assuming the CMB-S4 CDT Report (Lawrence et al. 2017) configuration and our suite of sky models (DC4). All simulations assume an instrument configuration including a (high-resolution) 20-GHz channel, a survey of 3% of the sky with 1.2×10^6 150-GHz-equivalent detector-years, and $A_L = 0.1$.

		ILC		Parametric (no decorrelation)		Parametric (incl. decorrelation)	
r value	Sky model	$\sigma(r) \times 10^{-4}$	r bias $\times 10^{-4}$	$\sigma(r) \times 10^{-4}$	r bias $\times 10^{-4}$	$\sigma(r) \times 10^{-4}$	r bias $\times 10^{-4}$
0	0	4.4	−0.2	4.4	0.2	5.7	0.3
	1	4.6	0.8	4.7	6.8	6.4	5.2
	2	4.7	0.7	4.8	3.8	6.5	1.9
	3	4.6	1.2	4.7	6.0	6.7	0.7
	4	6.5	4.8	7.9	43	8.3	−7.7
	5[a]	18	17	31	340	15	0.2
	6	4.8	−1.8	4.8	0.6	6.5	1.8
0.003	0	6.6	−0.7	6.2	0.3	8.1	0.4
	1	6.9	0.9	6.5	6.9	8.5	5.4
	2	6.5	−0.1	6.4	3.9	7.9	1.9
	3	7.0	1.4	6.6	6.7	8.7	0.9
	4	11	7.1	10	51	11	−6.2
	5[a]	23	17	34	350	17	0.4
	6	7.5	−0.2	7.1	1.4	8.6	2.5

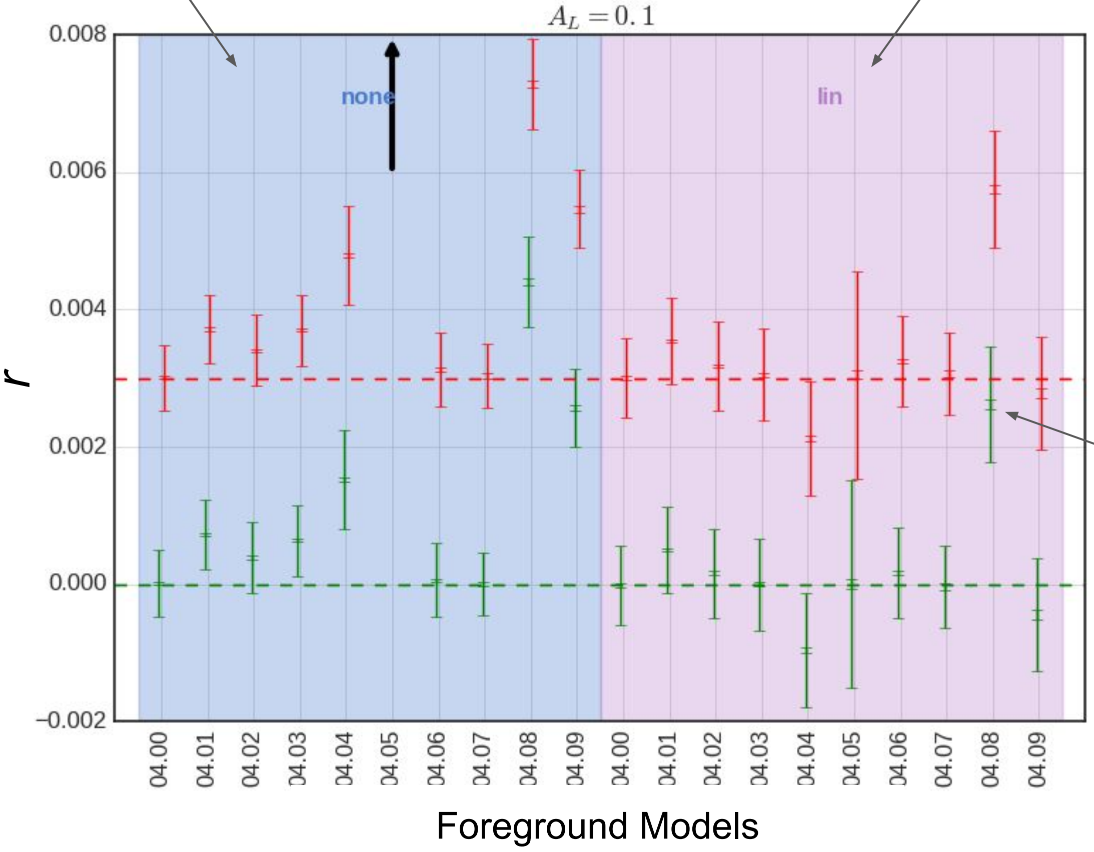
[a] An extreme decorrelation model—see Section 4.2. In the right column the parametric analysis includes a decorrelation parameter. No attempt is made in the ILC analysis to model the decorrelation. The middle columns shows the parametric analysis when we do not include deccorelation parameters.

Two independent re-analyses of the same simulated maps. Can probe for bias due to mismatch between foreground model and re-analysis assumptions.

Results from Map Based Sims (04)

Without decorrelation in the model

With decorrelation in the model



Red is r=0.003

This model produces strong bias

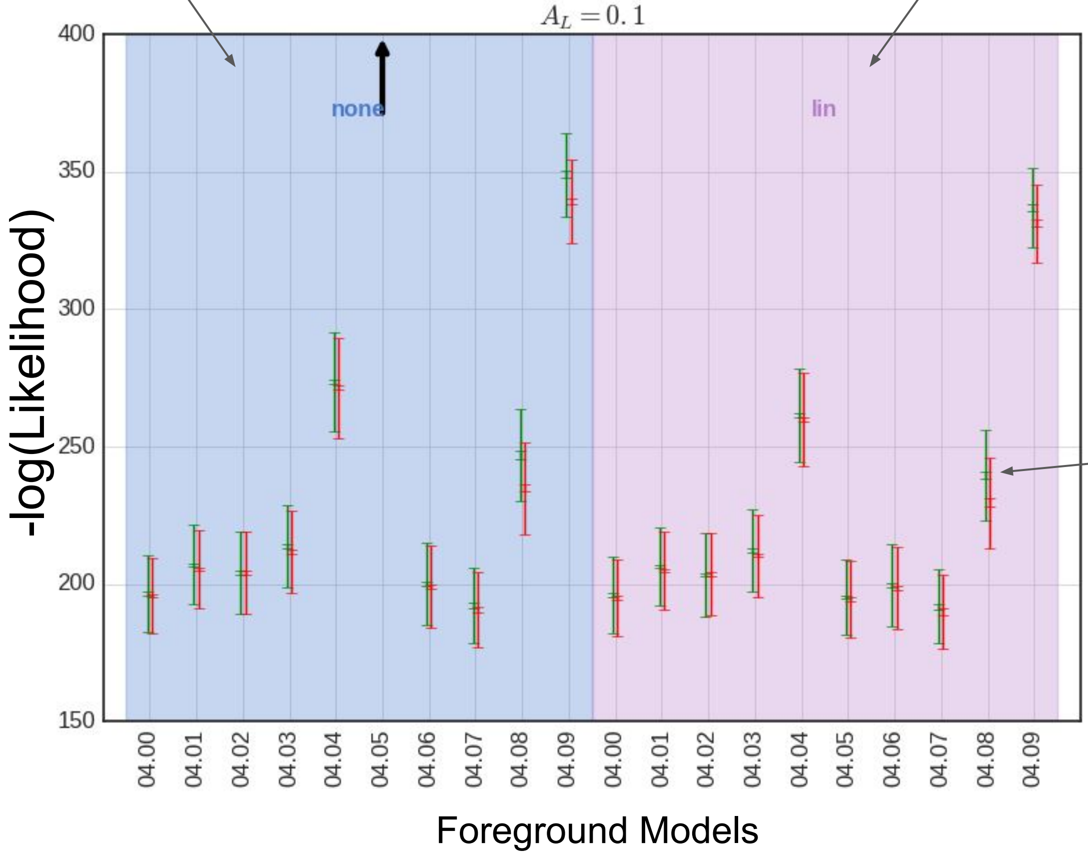
Green is r=0

Plot from this posting for free β & A_L

Results from Map Based Sims (04)

Without decorrelation in the model

With decorrelation in the model



But we can tell this model is not a good fit

Plot from [this posting](#) for free β & A_L