r Forecast "Data Challenge" Maps for PICO

Minneapolis Workshop

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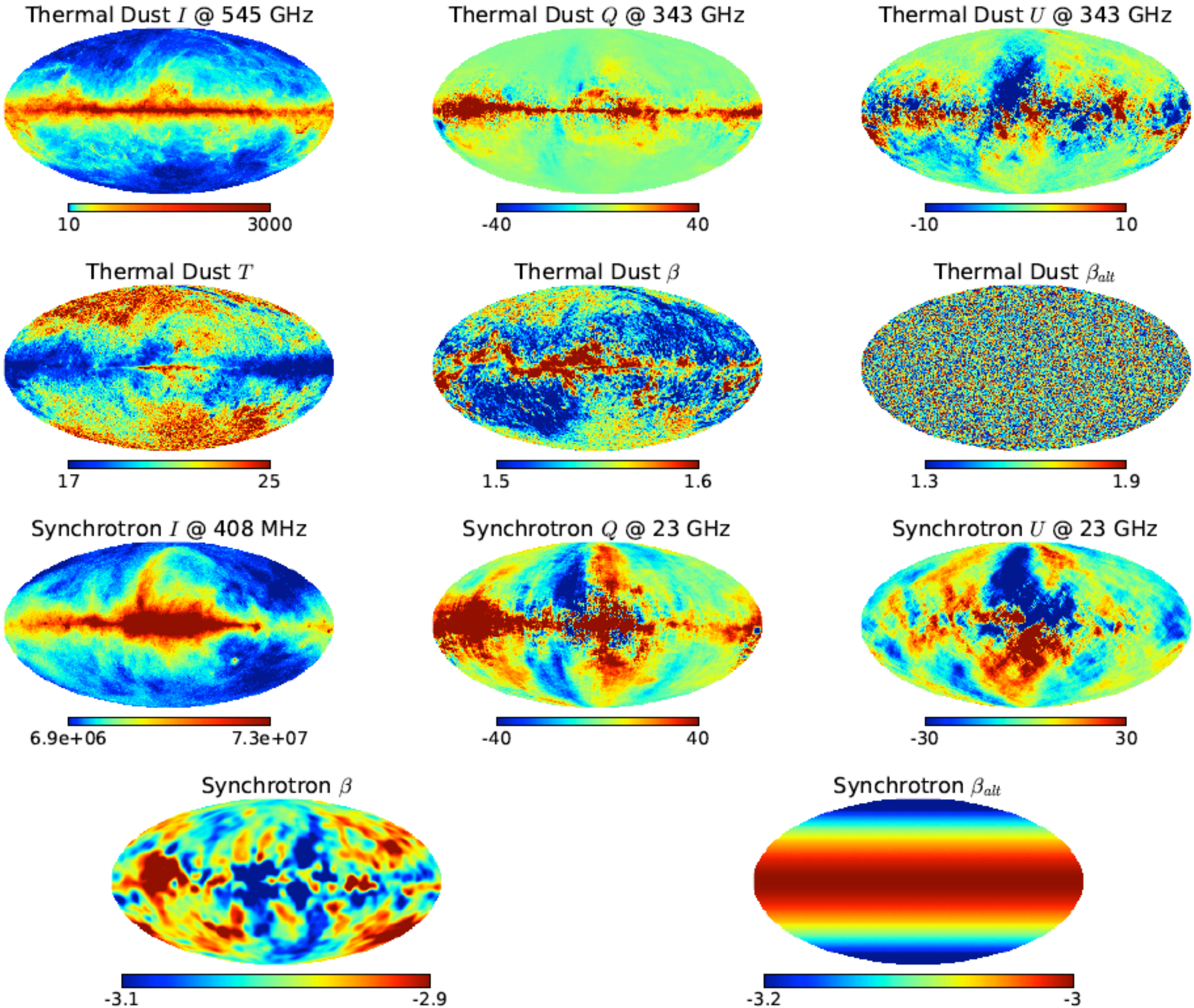
PICO Sims for *r* forecast

- Leveraging existing generator code etc. from CMB-S4
- “Data Challenge” approach – sets of shared simulated data maps available on NERSC
  - Include LCDM, foreground, noise and tensors
- Idea is to have multiple groups and individuals run re-analysis on these with using multiple techniques
  - Try to separate out tensor signal
- Investigate $\sigma(r)$ and bias on *r* across a range of foreground models

PySM Foreground Model Package

- PySM = "Python Sky Model" – relatively simple python code for generating realizations of the sky at given set of frequencies – see arXiv: 1608.02841 and http://github.com/bthorne93/PySM_public
- Contains several models for each of AME (a), dust (d), free-free (f), and synchrotron (s)
  - Designated as a1d1f1s1, a2d4f1s3, a2d7f1s3 etc
  - The above are the three we have used for CMB-S4 so far and this choice has been inherited for PICO
- Uses templates from Haslam, WMAP, Planck and various analyses thereof (inc. Commander)
  - Spatial/spectral variation (decorrelation) included

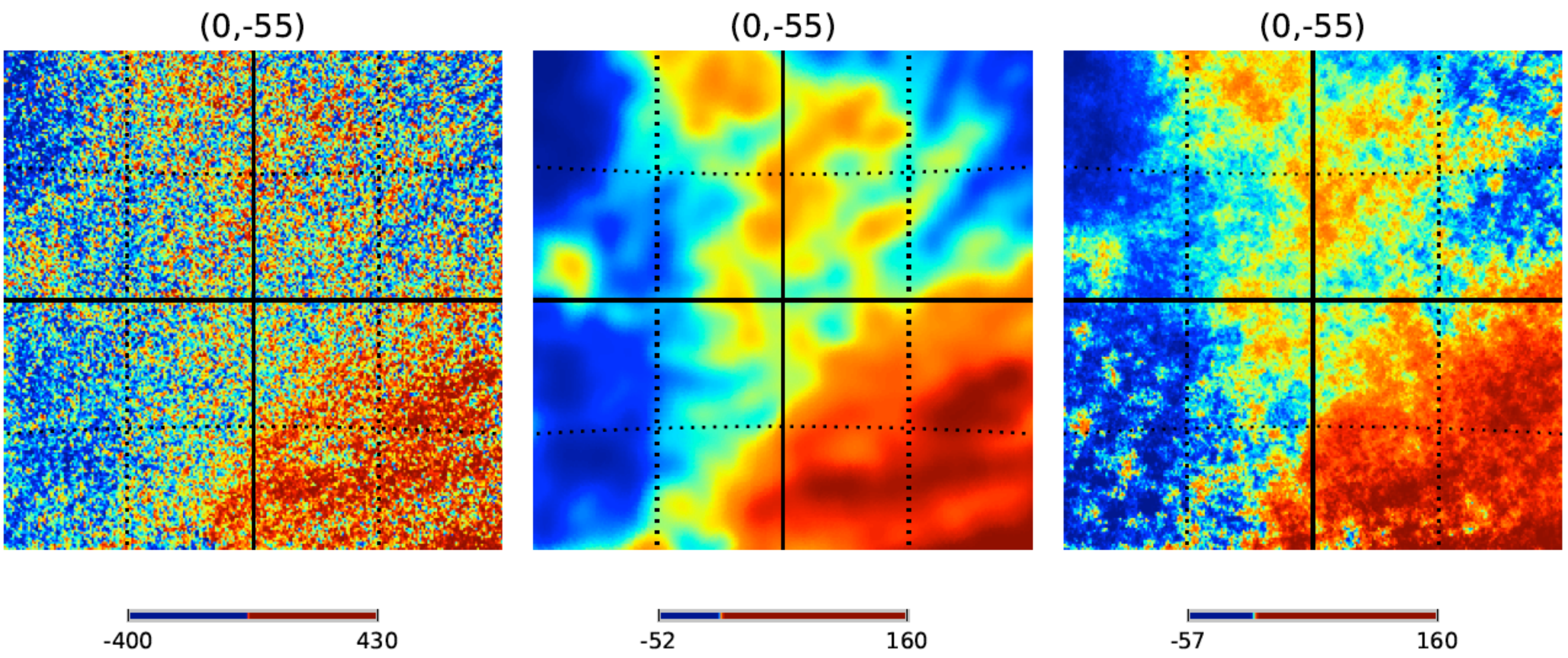


Thermal Dust I @ 545 GHz
10
3000
Thermal Dust Q @ 343 GHz
-40
40
Thermal Dust U @ 343 GHz
-10
10
Thermal Dust T
17
25
Thermal Dust β
1.5
1.6
Thermal Dust β_{alt}
1.3
1.9
Synchrotron I @ 408 MHz
6.9e+06
7.3e+07
Synchrotron Q @ 23 GHz
-40
40
Synchrotron U @ 23 GHz
-30
30
Synchrotron β
-3.1
-2.9
Synchrotron β_{alt}
-3.2
-3

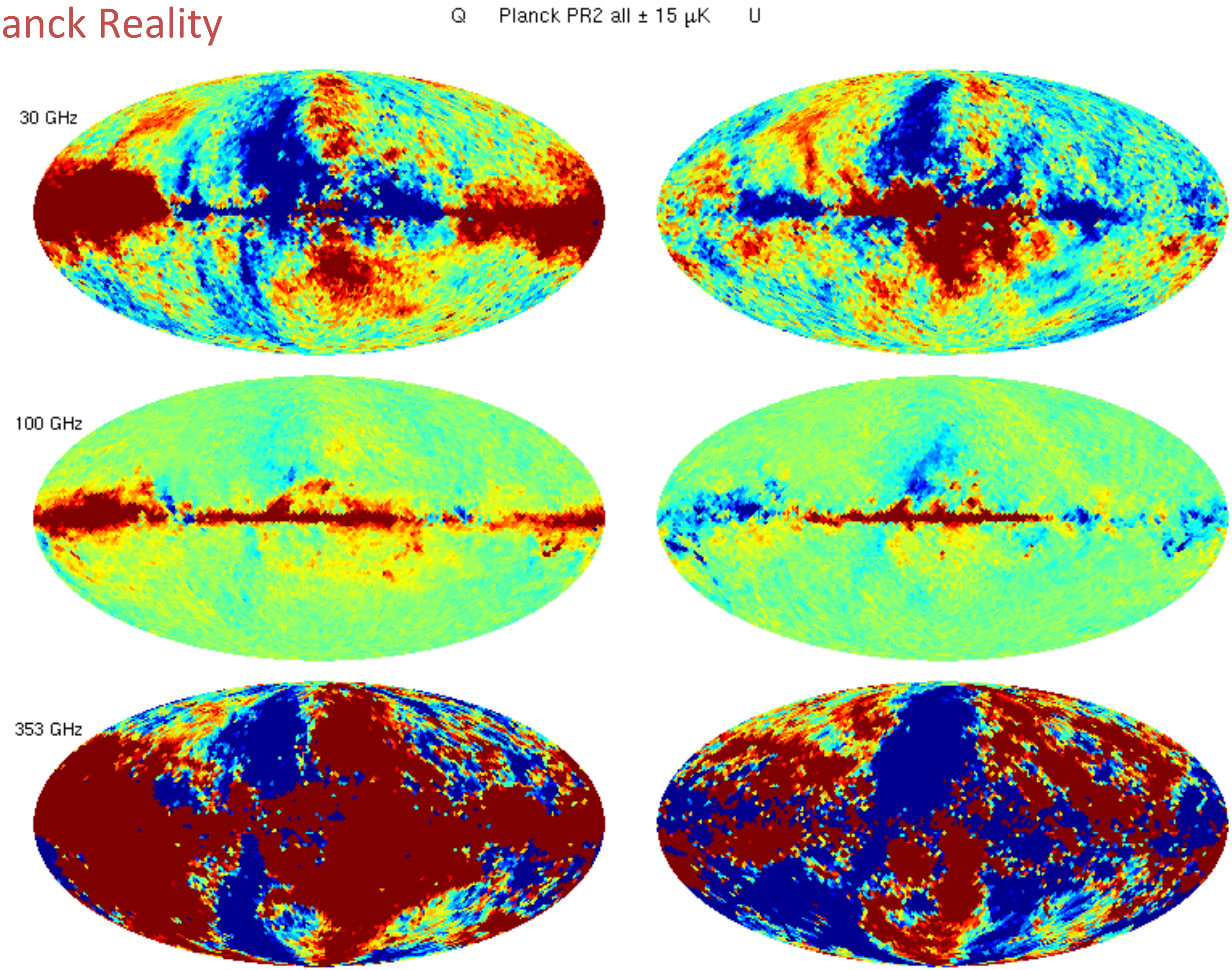
PySM small scale power fill in

- Small angular scales are noise dominated – filters them out and fills back in (Gaussian) small scale structure to produce continuous power-law foreground spectra
- Modulates small scale amplitude across sky to keep match

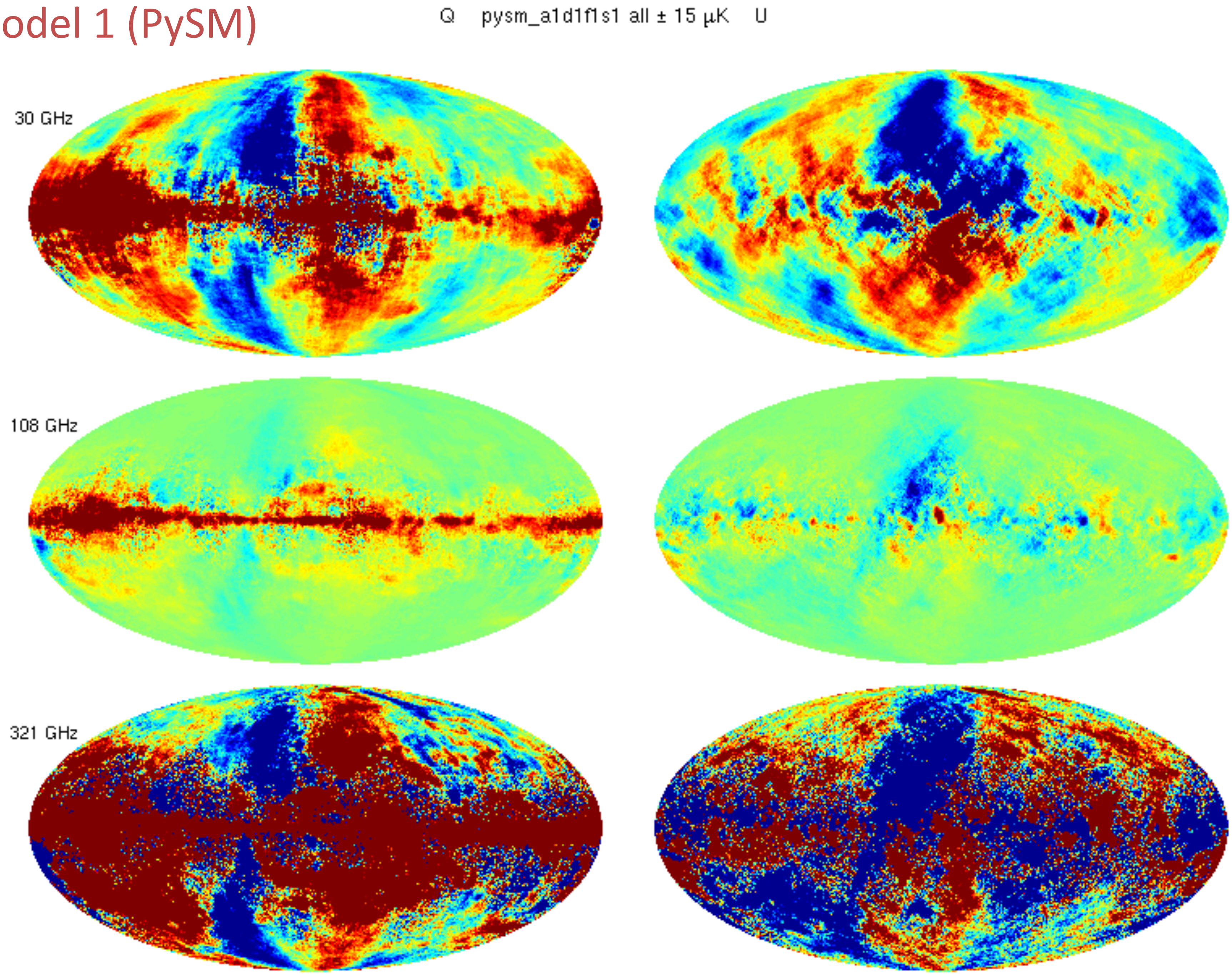
Left: noisy template, middle: smoothed template, right: plus Gaussian small scale power



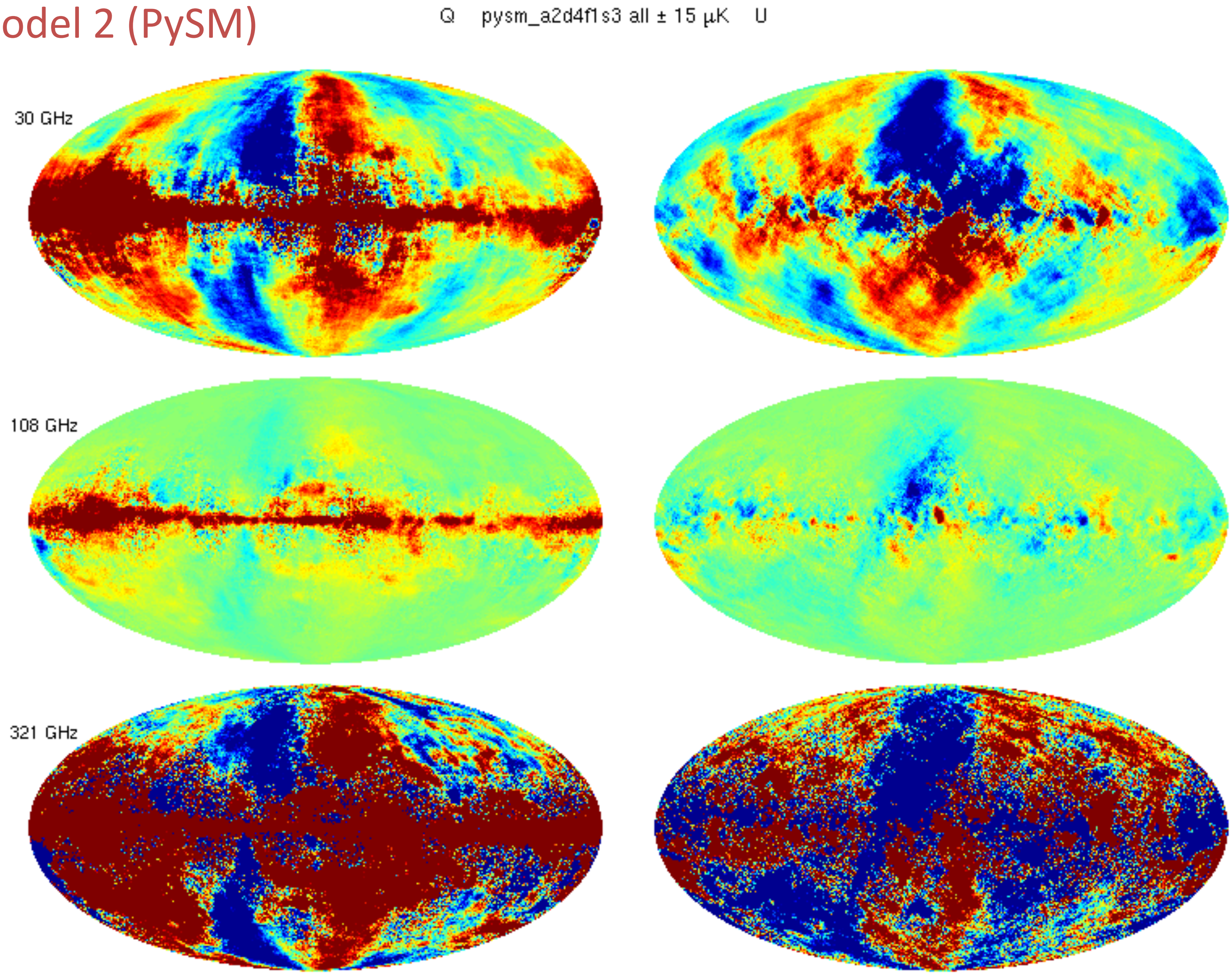
Planck Reality



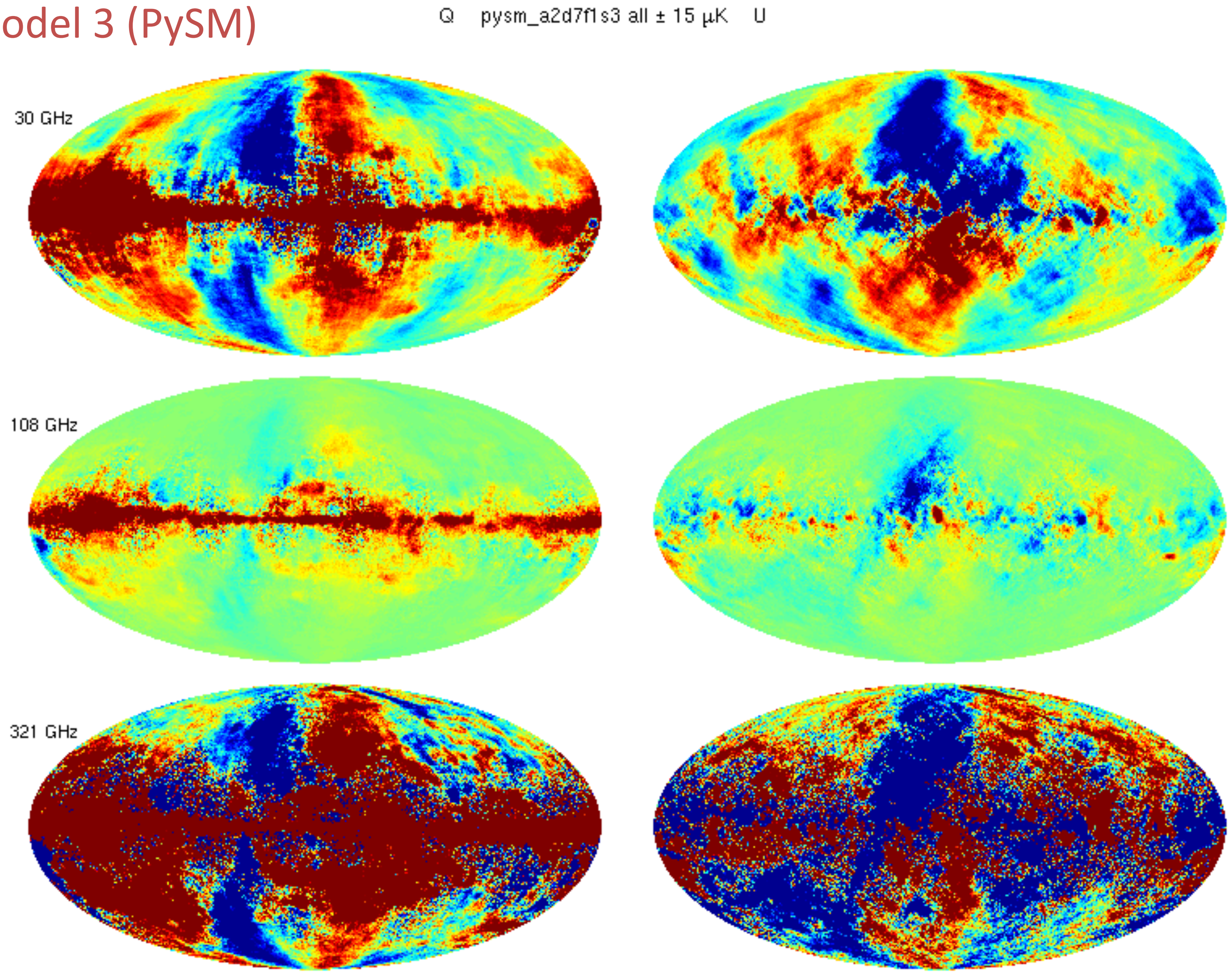
Model 1 (PySM)



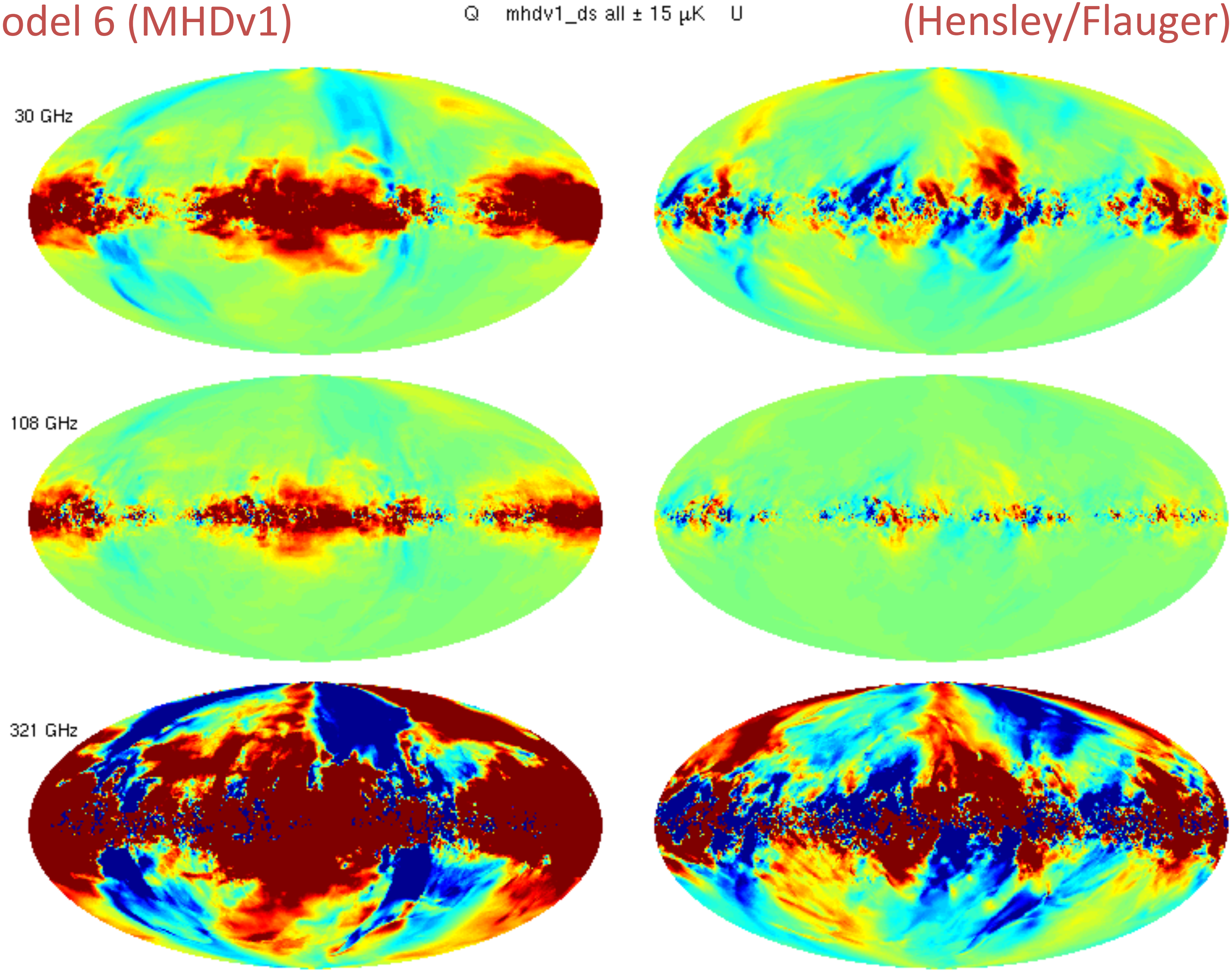
Model 2 (PySM)



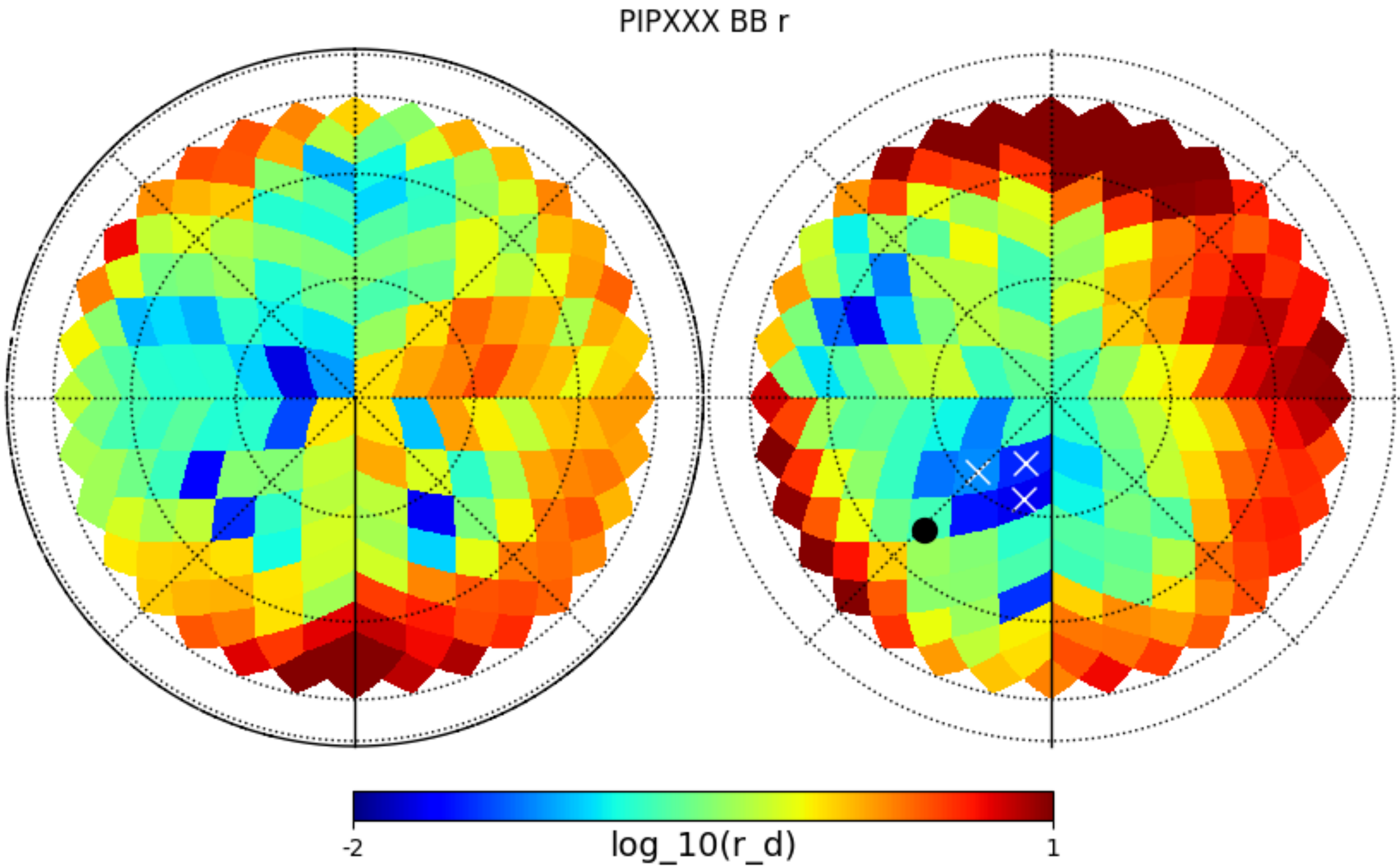
Model 3 (PySM)



Model 6 (MHDv1) (Hensley/Flauger)



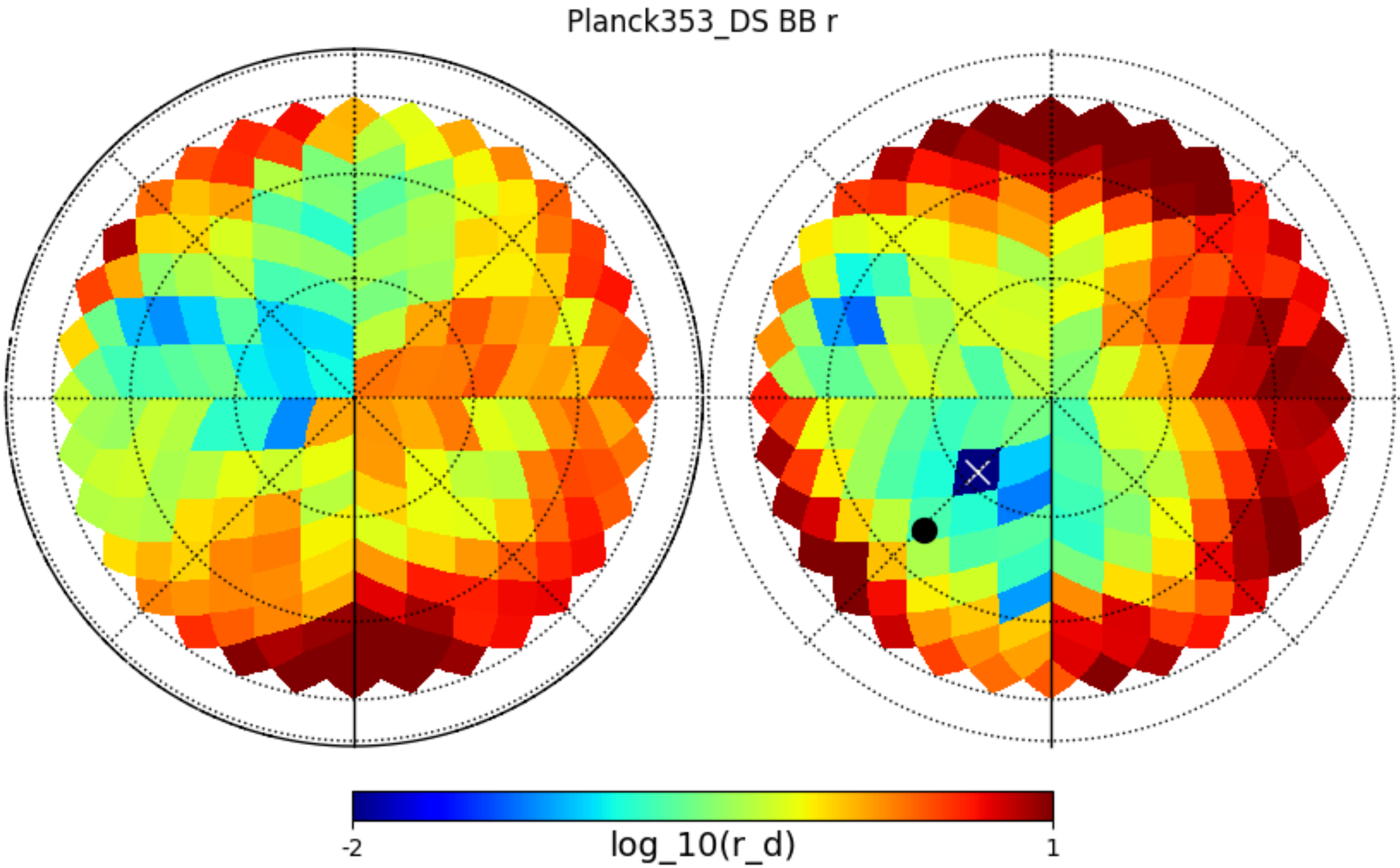
BB Dust Power Variation Across the Sky



Original plot from PIPXXX paper –

log(abs(r equiv. dust at 150GHz)) for overlapping 400 deg^2 patches

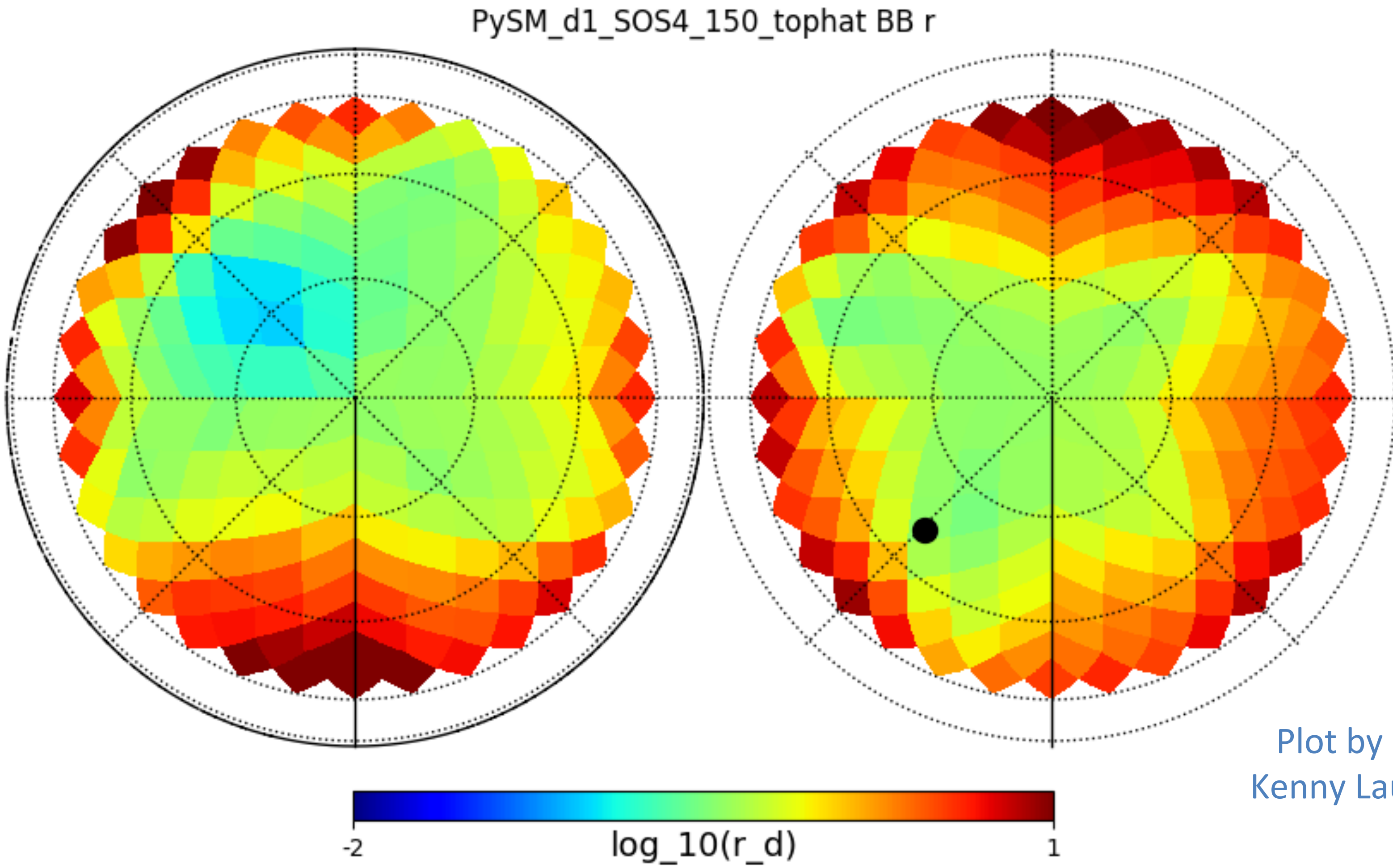
BB Dust Power Variation Across the Sky



Our (BK group) attempt to reproduce –

similar, but smoother looking variation (not sure why)

BB Dust Power Variation Across the Sky

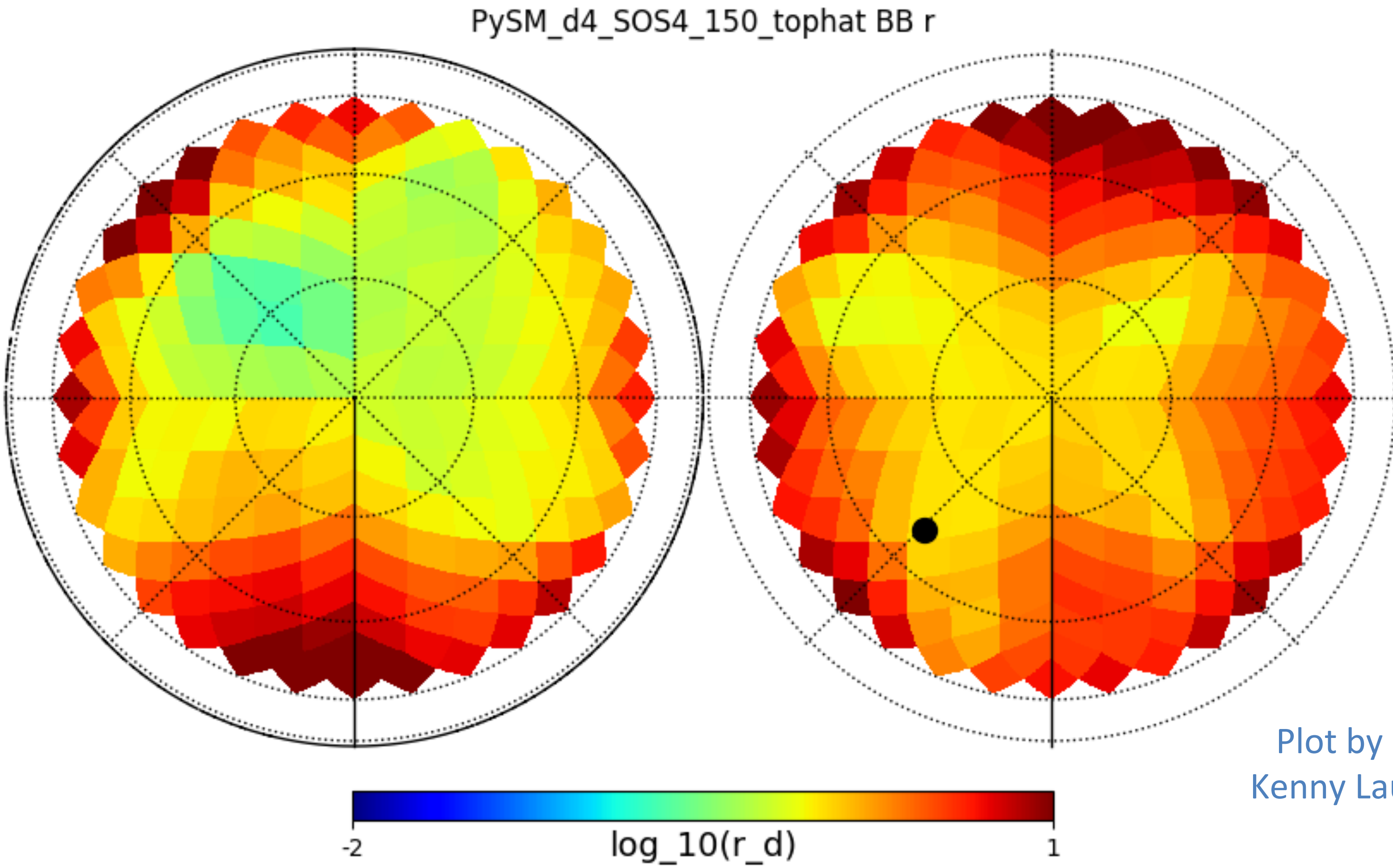


Plot by Kenny Lau

Same thing for PySM d1 model –

not fully “realistic” but maybe “representational”

BB Dust Power Variation Across the Sky



Plot by
Kenny Lau

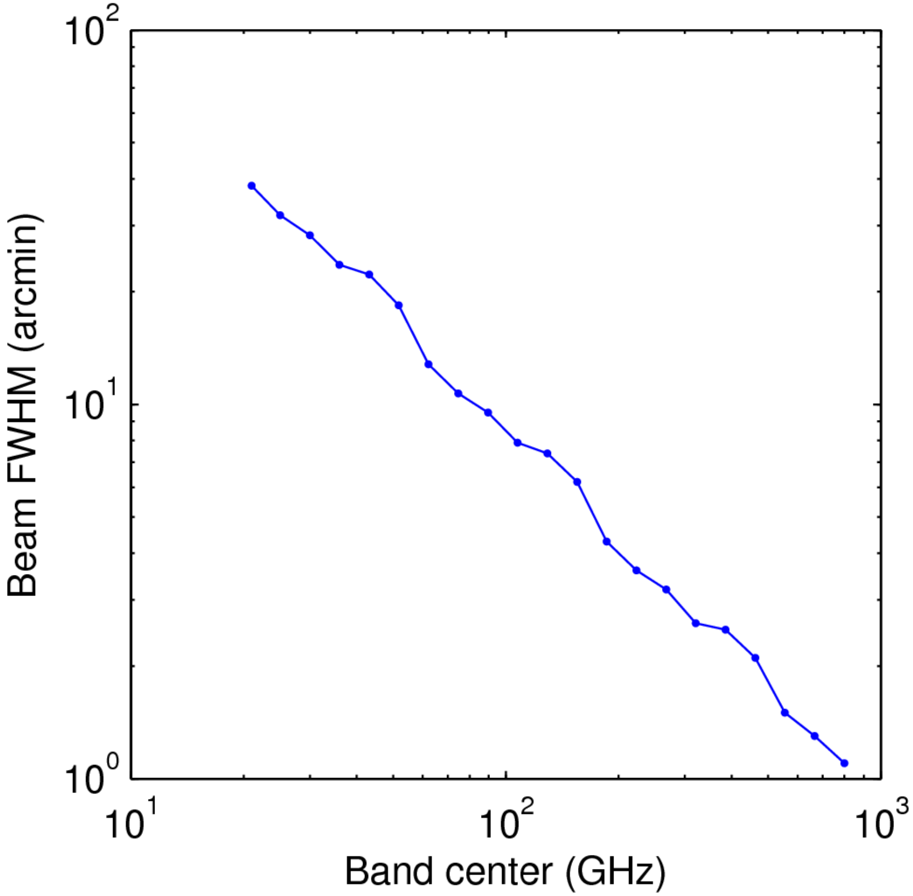
Same thing for PySM d4 model –

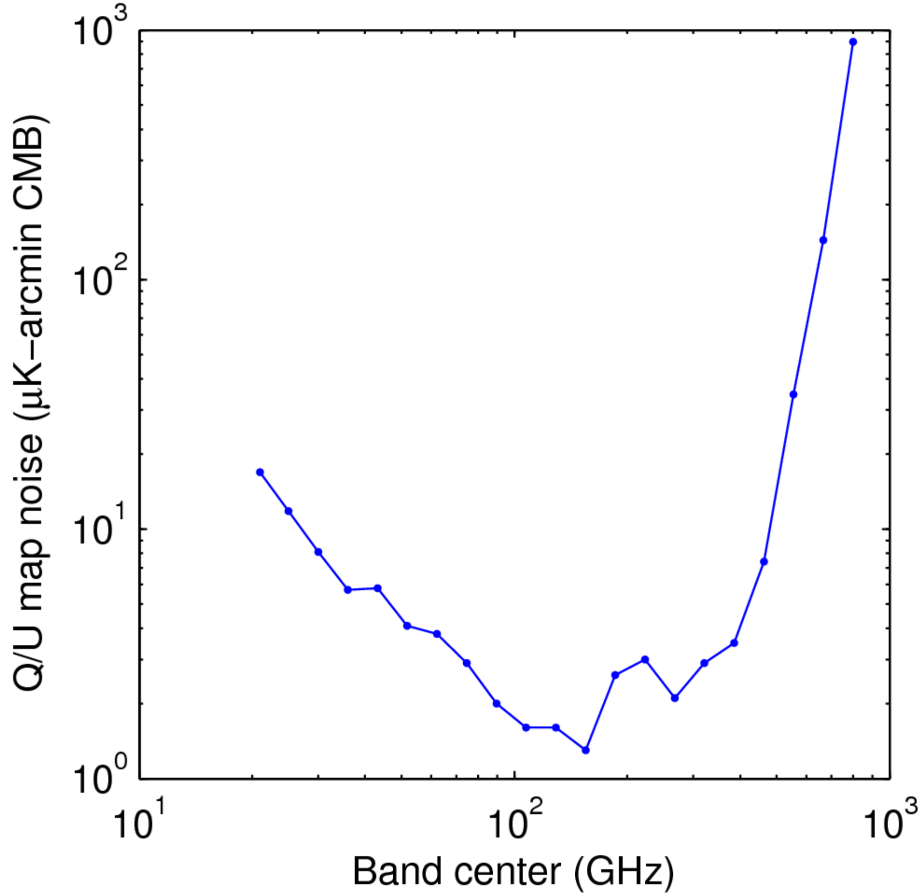
way more BB power – not representational

Make PICO Sims

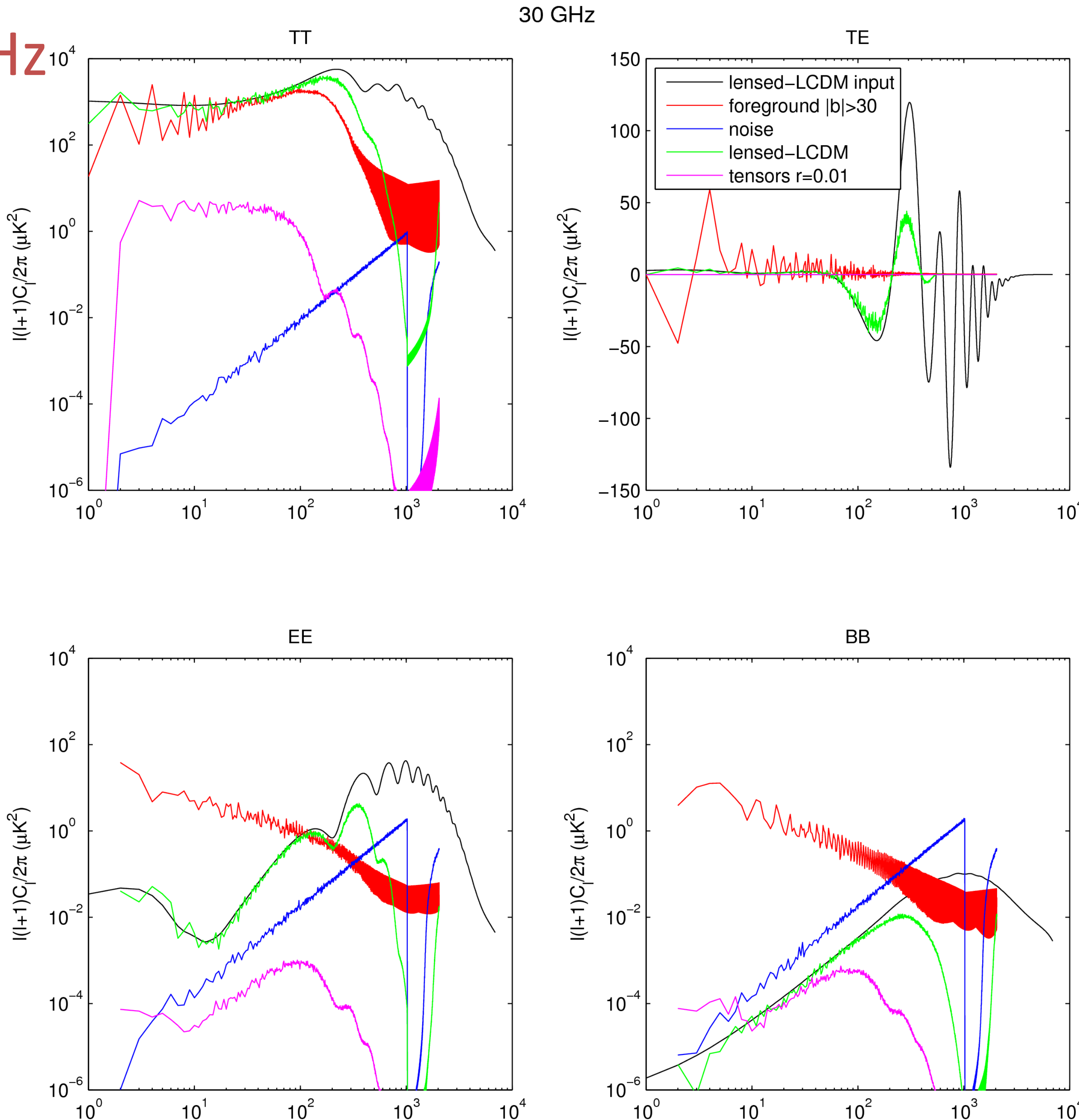
- LCDM realizations inherited from *Planck* – available as both unlensed and lensed a_{lm}'s
  - For the moment "fake" delensing by combining unlensed and lensed maps to obtain effective A_L=0.15
- Beam smoothing applied to LCDM and foreground as per PICO v3.2 specs.
- Noise taken as white with level as per PICO v3.2 specs.
- A little bit of tensors injected into every even numbered realization (at the moment r=0.003)
- (Only one "realization" for PySM model – so add it on top of varying LCDM/noise realizations.)
- (Also have toy "model 0" uniform Guassian with uniform spectral index.)

v3.2 Beam widths and Noise levels



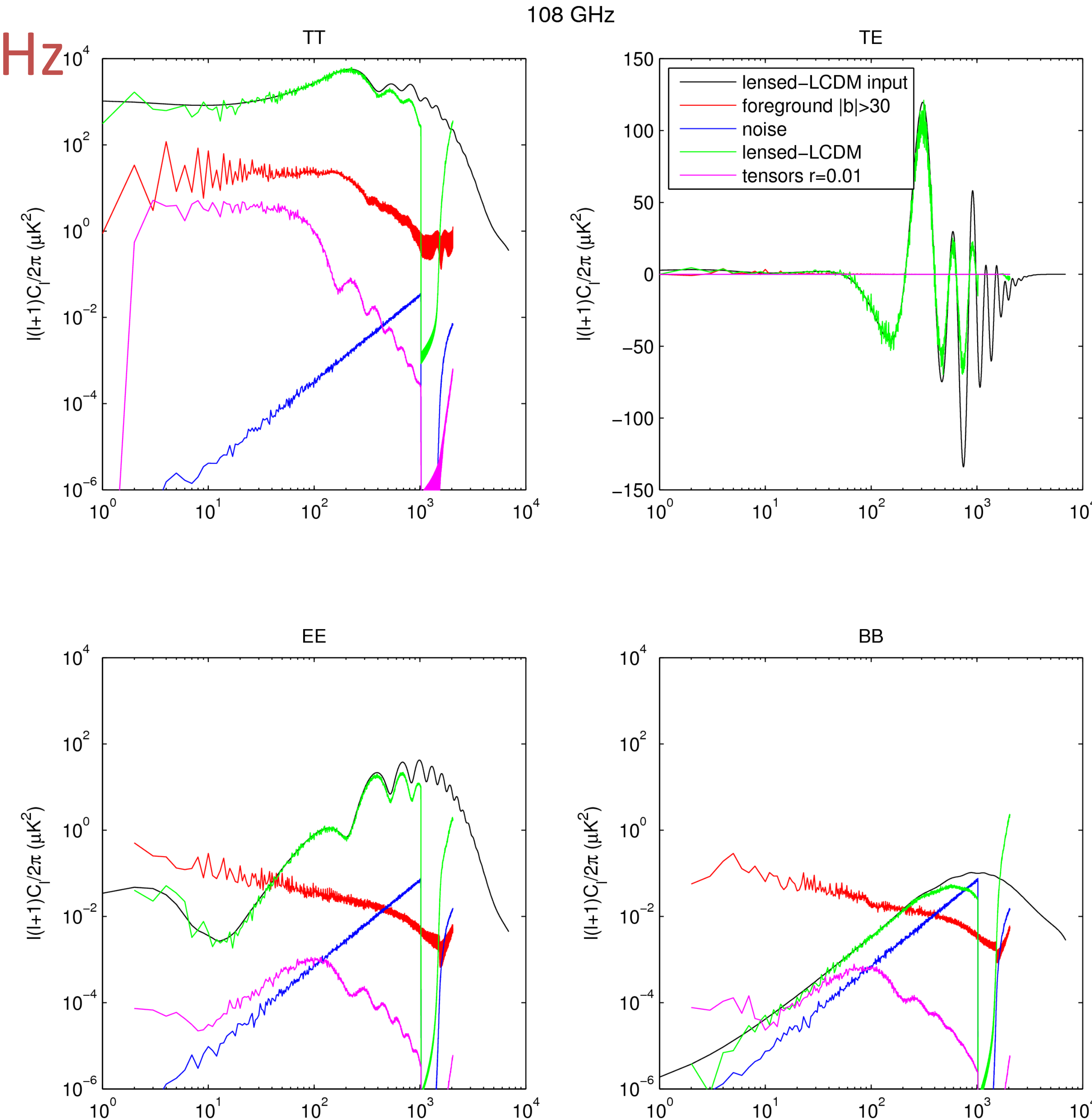


30 GHz



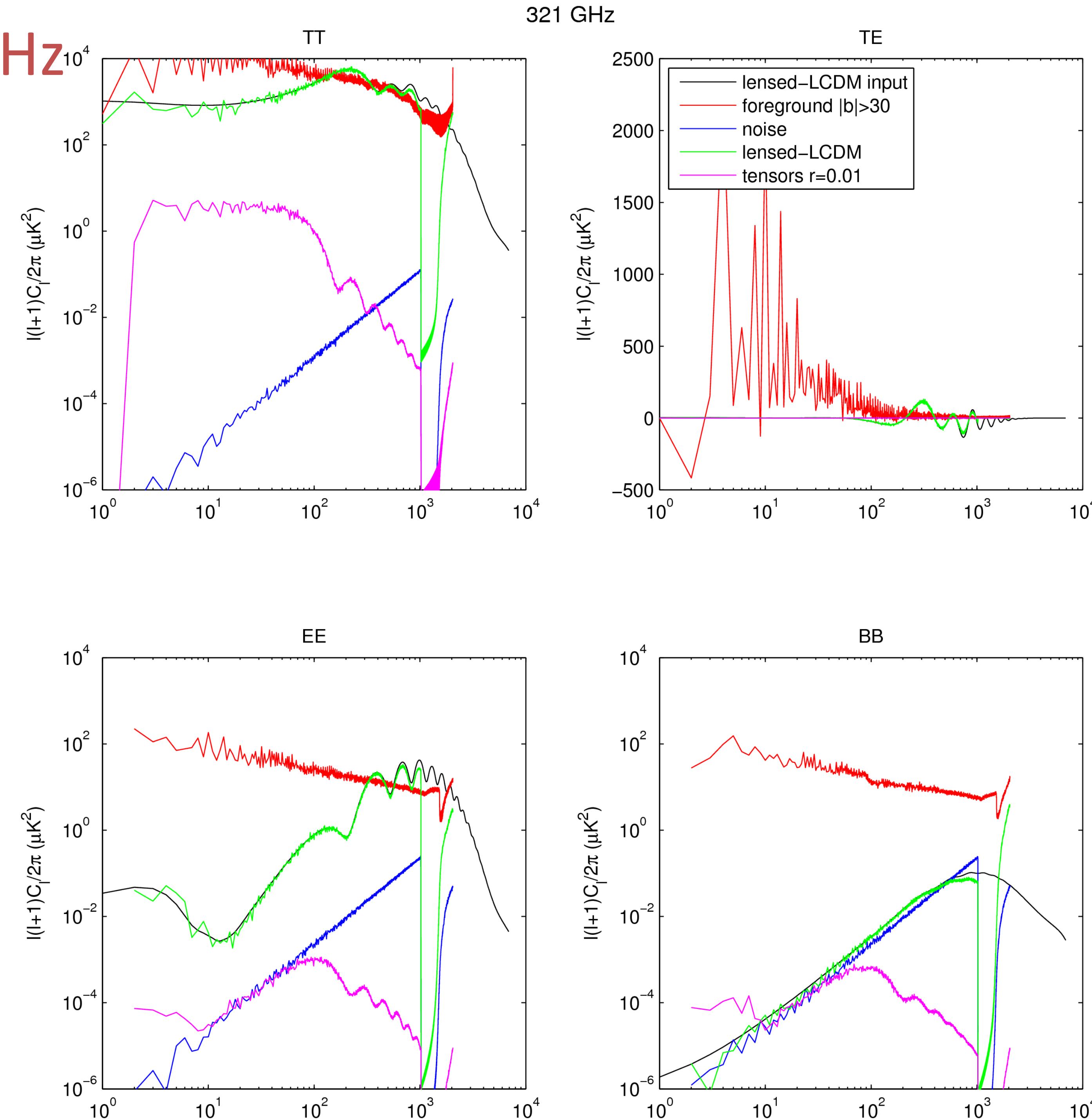
30 GHz
TT
TE
EE
BB
lensed−LCDM input
foreground |b|>30
noise
lensed−LCDM
tensors r=0.01
l(l+1)C_l/2π (μK^2)

108 GHz



For this model need to clean by 1-2 orders of mag at fg min.

321 GHz


321 GHz
TT
TE
EE
BB
lensed−LCDM input
foreground |b|>30
noise
lensed−LCDM
tensors r=0.01
l(l+1)C_l/2π (μK^2)

The Task

- Take the stacks of multi-frequency maps and run component separation.
- Mask out the unrecoverable galactic plane region.
- Take the power spectra of the resulting map using a method with sufficiently low *E* to *B* mixing for the given mask.
- Derive the maximum likelihood value of r
- *Or any equivalent series of operations…*
- Repeat for many realizations and look at histogram of values
  - Look at mean (bias), sigma (uncertainty), etc.

Results

- Errr…
- Unfortunately we got a late start and don’t have much more from this effort yet
- Mathieu has some results from PSM based sims...

So instead a worked example:

- Did a very similar study for CMB-S4 Concept Definition Task Force (CDT) study, and reported in appendix A of Final Report
  https://www.nsf.gov/mps/ast/aaac/cmbs4cdt.jsp
- 3% patch of clean high latitude sky
- Two independent re-analyses
  - (a) ILC based (Raphael Flauger)
  - (b) parametric multi-component fit (BK group, Victor Buza)

CDT Report Results

Table 7: Results of two analysis methods applied to map-based simulations assuming the Science Book Configuration and our suite of sky models. All simulations assume an instrument configuration including a (low-resolution) 20 GHz channel, a survey of 3% of the sky with 1.0×10^6 150-GHz-equivalent detector-years, and $A_L = 0.1$. Note that this configuration is not the final strawperson concept, and in particular has fewer detector-years.

		ILC		Parametric	
r value	Sky model	$\sigma(r) \times 10^4$	r bias $\times 10^4$	$\sigma(r) \times 10^4$	r bias $\times 10^4$
0	0	5.7	0.0	6.7	0.2
	1	7.0	0.3	7.8	5.8
	2	7.7	0.8	7.1	3.1
	3	5.6	0.8	8.1	1.8
	4	7.5	5.0	9.3	−3.4
	5[a]	16	18	14	−2.5
	6	5.8	−1.1	7.3	1.1
0.003	0	7.2	−4.0	10	0.3
	1	9.1	0.0	9.0	6.2
	2	9.6	−1.9	9.4	3.5
	3	7.2	−0.3	10	1.6
	4	10	5.8	11	−1.8
	5[a]	20	20	15	3.0
	6	8.3	−1.1	9.9	1.1

[a] An extreme decorrelation model—see § A.1.2. The parametric analysis includes a decorrelation parameter. No attempt is made in the ILC analysis to model decorrelation.

Thoughts/Conclusions

- The point of such a study is not that any one of the considered foreground models can be known to be "correct"
- The idea is that taken together they represent some kind of "spanning set" of the range of possible real foreground behavior
  - If the re-analysis can be shown to be robust under all "reasonable" considered models then maybe OK to proceed
- That may sound kind of weak but I personally don't think it is possible to offer any greater guarantee of success.
- All potential component separators and re-analyzers invited! The maps are available on NERSC.
- It would be great if we could do "real delensing" – I think there are people in the room right now who know how…