Bond, Frolov, Huang dust/synch/CMB, with Boulanger, Ghosh, Miville-Deschenes, Martin
CITA mini-industry *e.g. Stacking also for LSS 2ndary CMB*
Alvarez, Stein, Codis + Connor Bevington, Bruno Régaldo-Saint Blancard for tSZ etc & to LIM w/ Ronan Kerr

Overview: dust maps in intensity and polarization are manifestly non-Gaussian, not statistically isotropic, not derived from a statistically homogeneous random field.
yikes. unlike early universe quest for perturbative nonG very hard to see

use "CMB/LSS" ideas to look at the complex ISM data, in particular Planck (& Herschel)
goals to have simplified compression of data *- e.g. novel stacking for dust, synch cf. CMB*

e.g. anisotropic random tensor fields of transformed fields: s(PX, s2s1) = - log{n(PX, s2s1)) +1, n(PX, s2s1)) = 2X2 distribution function matrix, (Wigner df)
=> ln I and p =P/I, e=E/I, b=B/I, q=Q/I, u=U/I, with some large-p modifications

does look more Gaussian, but still not.

Gaussian-ize the 1-point PDF, (using relative entropy minimization of PDF(I) and PDF_Gauss (newI) to justify doing what you think you should do anyway.

highly nonG Minkowski approach Gaussian, but still nonG deviations in tails.

anisotropic Gaussian random field with large scale (long wavelength) constraints to define anisotropy directions. so far no really good tensors built from knowledge of e.g., Bhat_Perp because I hoped to get it just from the measures TBD

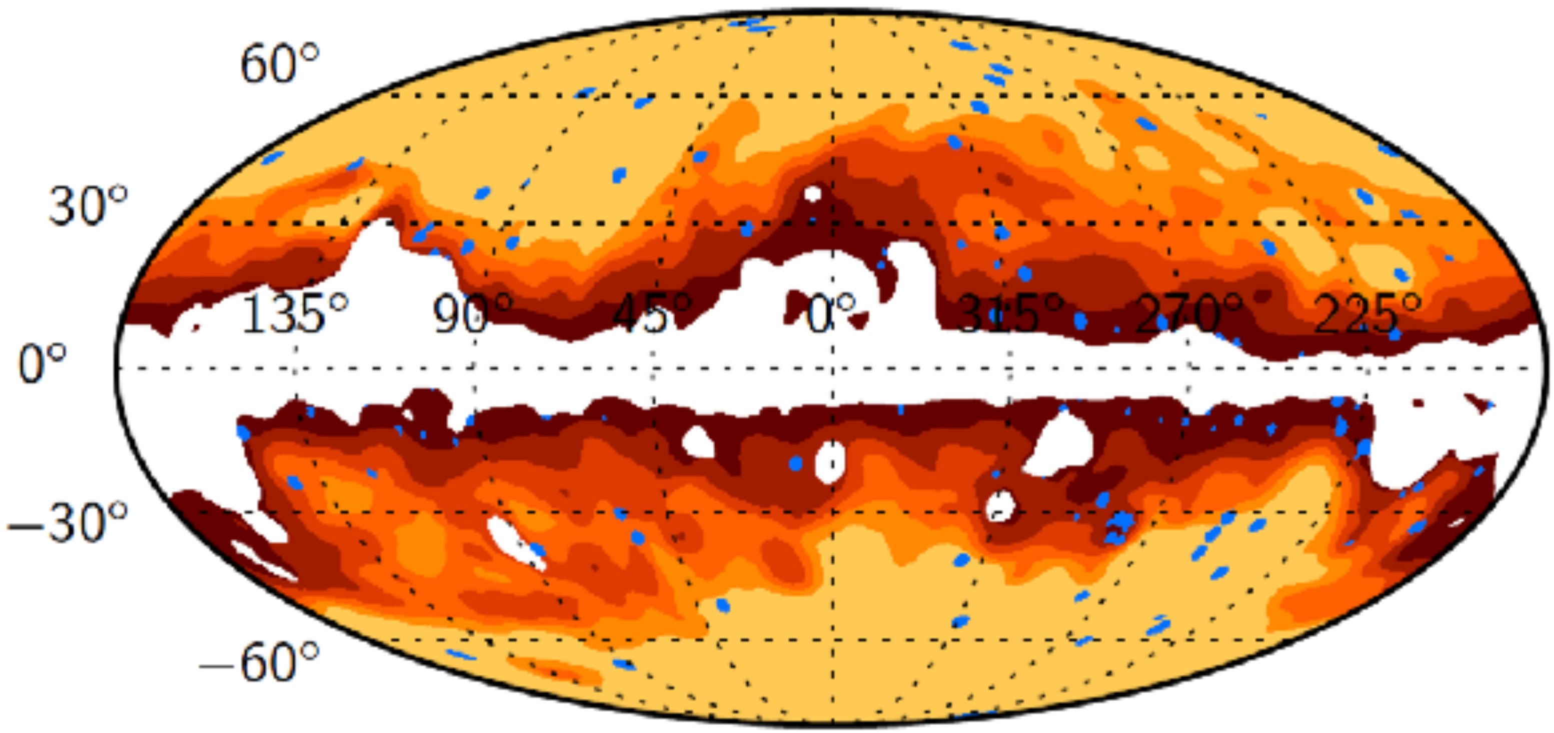
1. the transform and how the maps look
2. how EE, BB power spectra look in e, b
3. how IE, IB, EB look ieb cf IEB

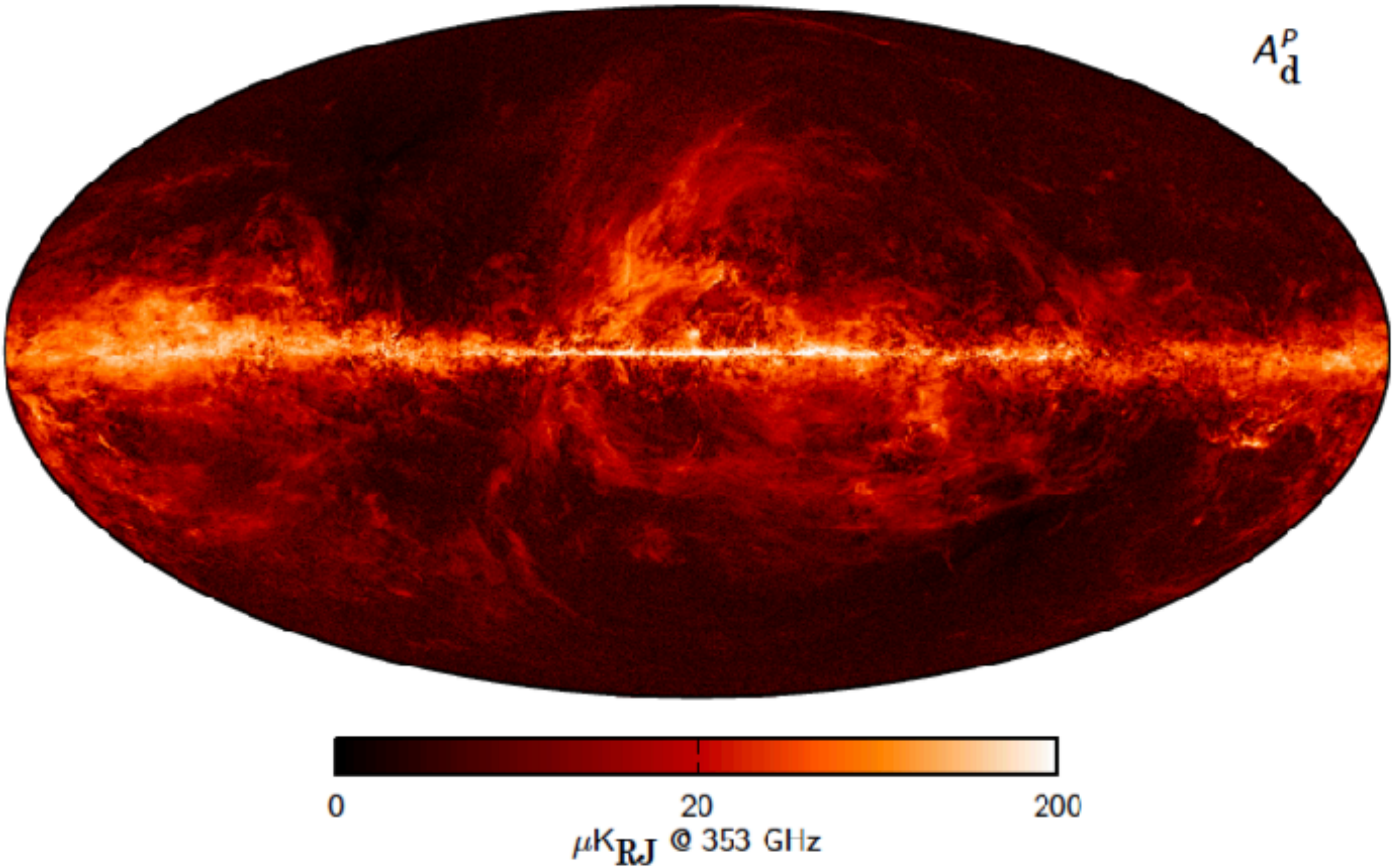
for these not yet done in ieb, but chose a strong bcut> 30deg Galactic mask for these results

filament-ariness is characterized by anisotropic coherence of stacks, but not straight (squeezed 3-point turned out not to be that useful for filaments - Planck with Tuhin Ghosh - projected filaments are curved, and Interstellar web is more complex. power pre decade rises above scale invariance at low L => huge fluctuations for GRF. Many ideas in Planck 2015, pip XXX, and some in Planck 2018 landS

4. PDF, Minkowski functionals
5. filaments - perimeter cf. area of contours (with care because of noise).
6. field point stacks as anisotropy changes
7. peak (hot spot) catalogue properties with scale. n_pk of dust cf. CMB (nu, nu_e similar to p pol fraction)
CUTS for filament strengths
8. stacks for high ellipticity peaks cf. low
9. stacks on P, P_T etal
10. stacks on everything else, saddle points are fun, etc

Planck 18 LIV more aggressive: cut on smoothed 857 intensity, intersect with cut on smoothed CO line map, plus some point sources and anodize with 5 degree Gaussian..fsky = 24, .33, .42, .52, .62, .71





$P = \sqrt{Q^2 + U^2}$, at 353 GHz, smoothed to $10'$

Polarization is caused by magnetic field alignment:

$$I = \int S_\nu e^{-\tau_\nu} d\tau_\nu \left[1 - p_0\left(\cos^2\gamma - \frac{2}{3}\right)\right]$$

$$\left\{ \begin{array}{c} Q \\ U \end{array} \right\} = \int S_\nu e^{-\tau_\nu} d\tau_\nu \left\{ \begin{array}{c} \cos 2\phi \\ \sin 2\phi \end{array} \right\} p_0 \cos^2\gamma$$

(p_0 is intrinsic polarization fraction ~ 0.21)

For a single layer, P/I determines magnetic field orientation:

$$\frac{I - P}{I + P} = 1 - \frac{6p_0}{2p_0 + 3}\cos^2\gamma$$

s(PX, s2s1) = - log{n(PX, s2s1)) +1, n(PX, s2s1)) = 2X2 df matrix aka Wigner df tensor

Transform polarization tensor into polarization fraction tensor:

$$\begin{bmatrix} i+q & u \\ u & i-q \end{bmatrix} = \ln \begin{bmatrix} I+Q & U \\ U & I-Q \end{bmatrix}$$

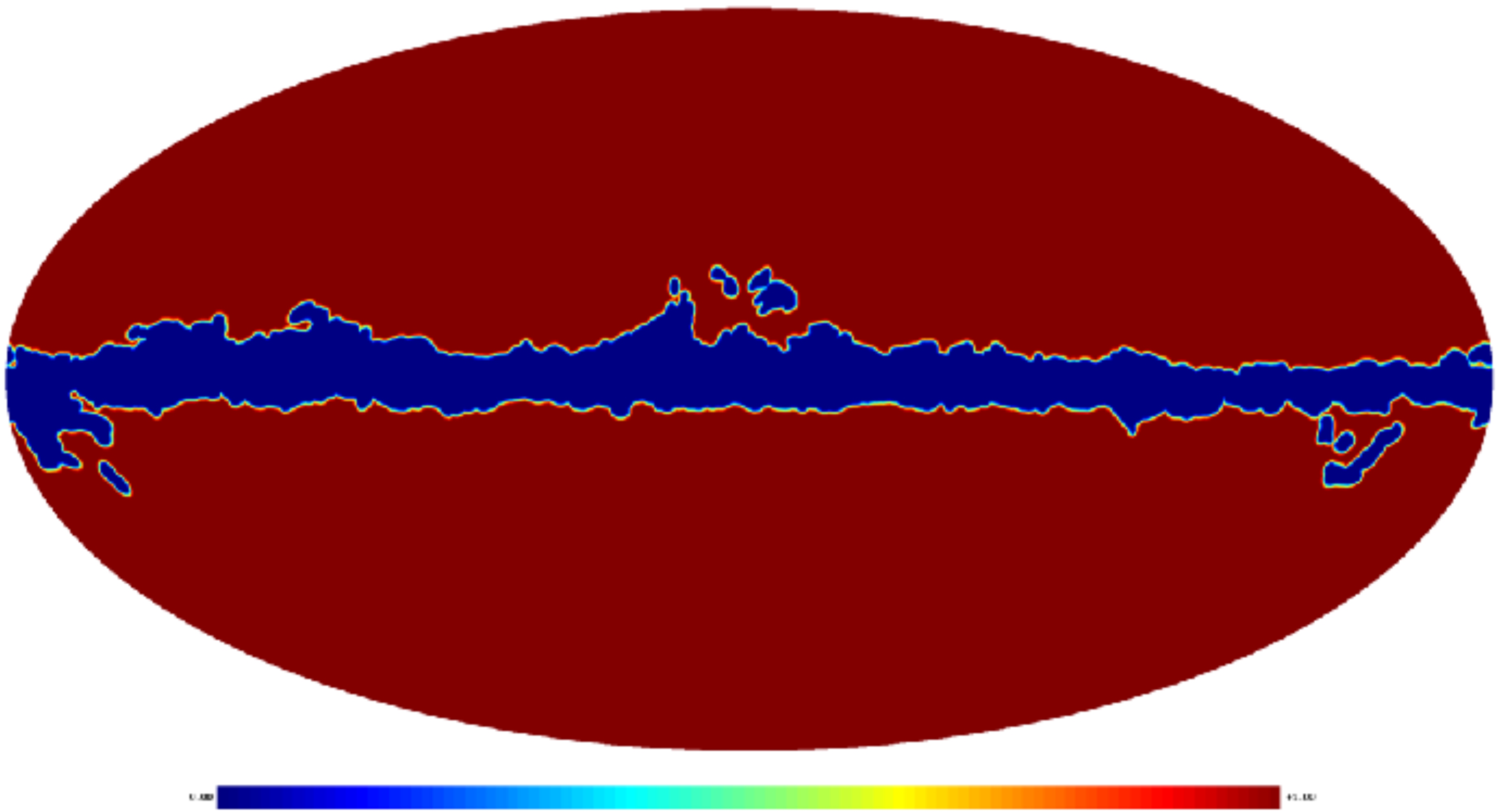
This is an invertible transformation on IQU maps:

$$i = \frac{1}{2}\ln\left(I^2 - P^2\right), \quad q = \frac{1}{2}\frac{Q}{P}\ln\frac{I+P}{I-P}, \quad u = \frac{1}{2}\frac{U}{P}\ln\frac{I+P}{I-P}$$

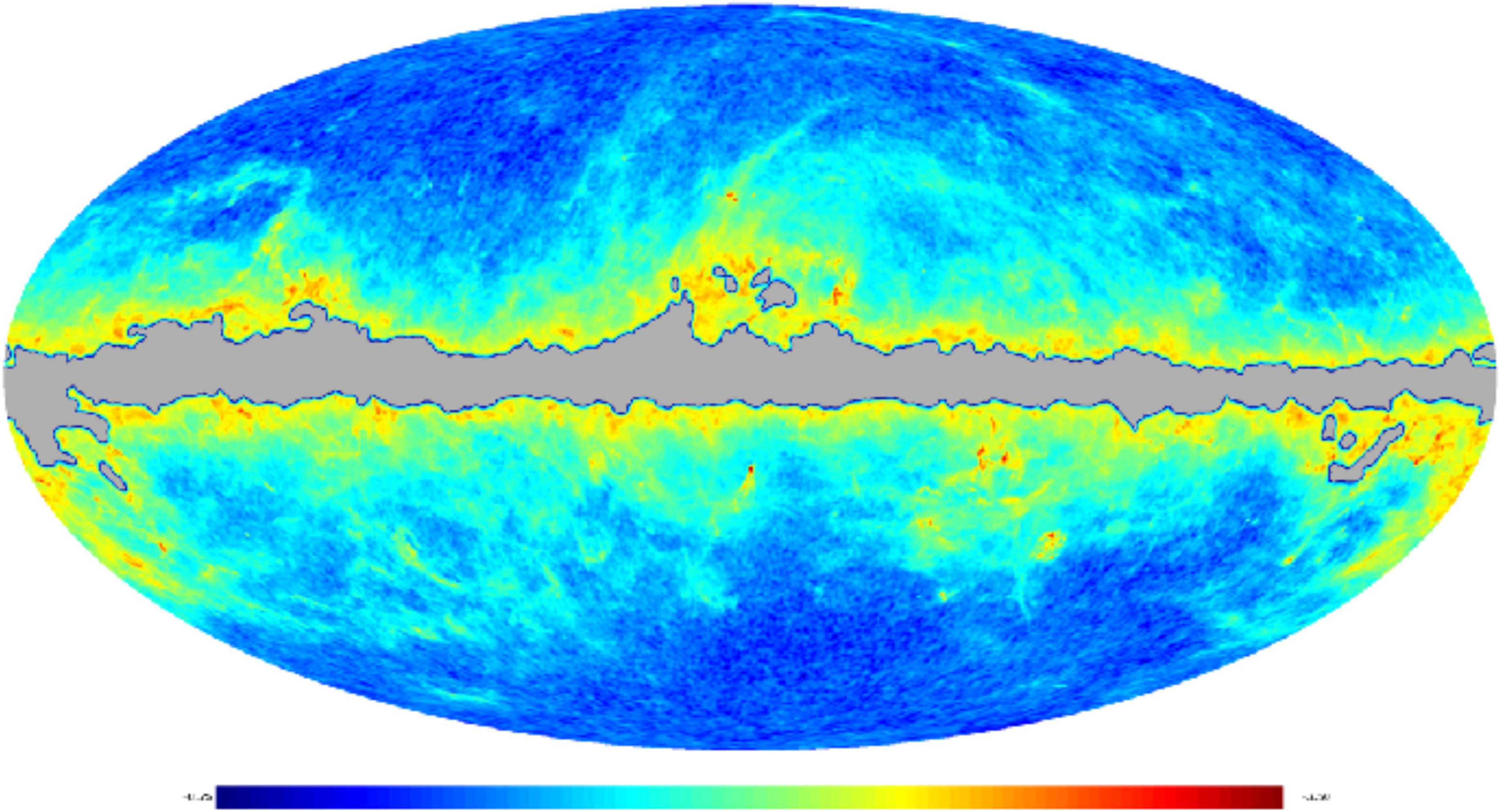
$$I = e^i \cosh p, \qquad Q = \frac{q}{p}e^i \sinh p, \qquad U = \frac{u}{p}e^i \sinh p$$

for small p, i=ln I and p =P/I, e=E/I, b=B/I, q=Q/I, u=U/I
=> Planckian increased emphasis on polarization fractions

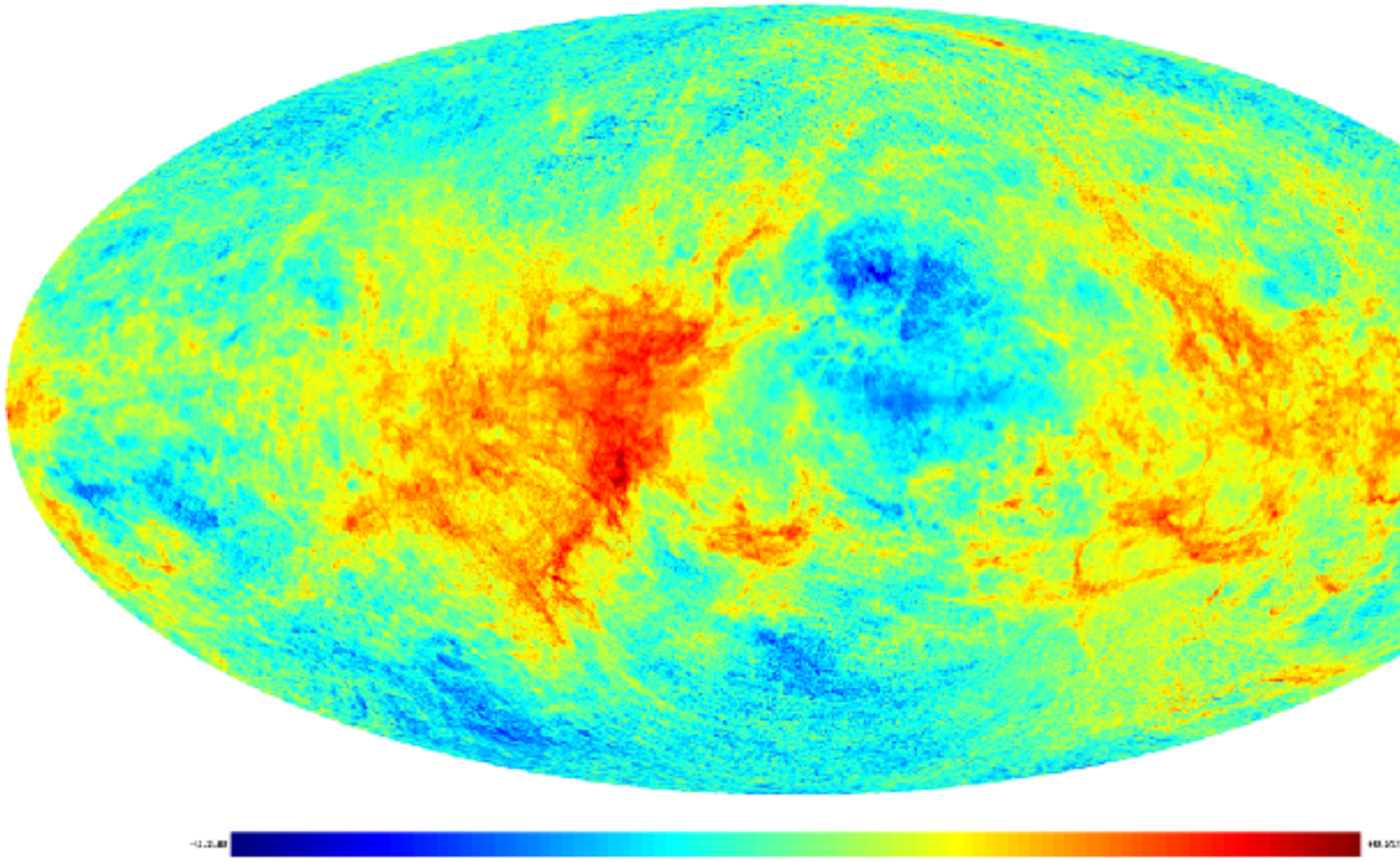
mask based on intensity cuts, apodized. cf. Planck 18 LIV more aggressive: cut on smoothed 857 intensity, intersect with cut on smoothed CO line map, plus some point sources and anodize with 5 degree Gaussian..fsky = 24, .33, .42, .52, .62, .71



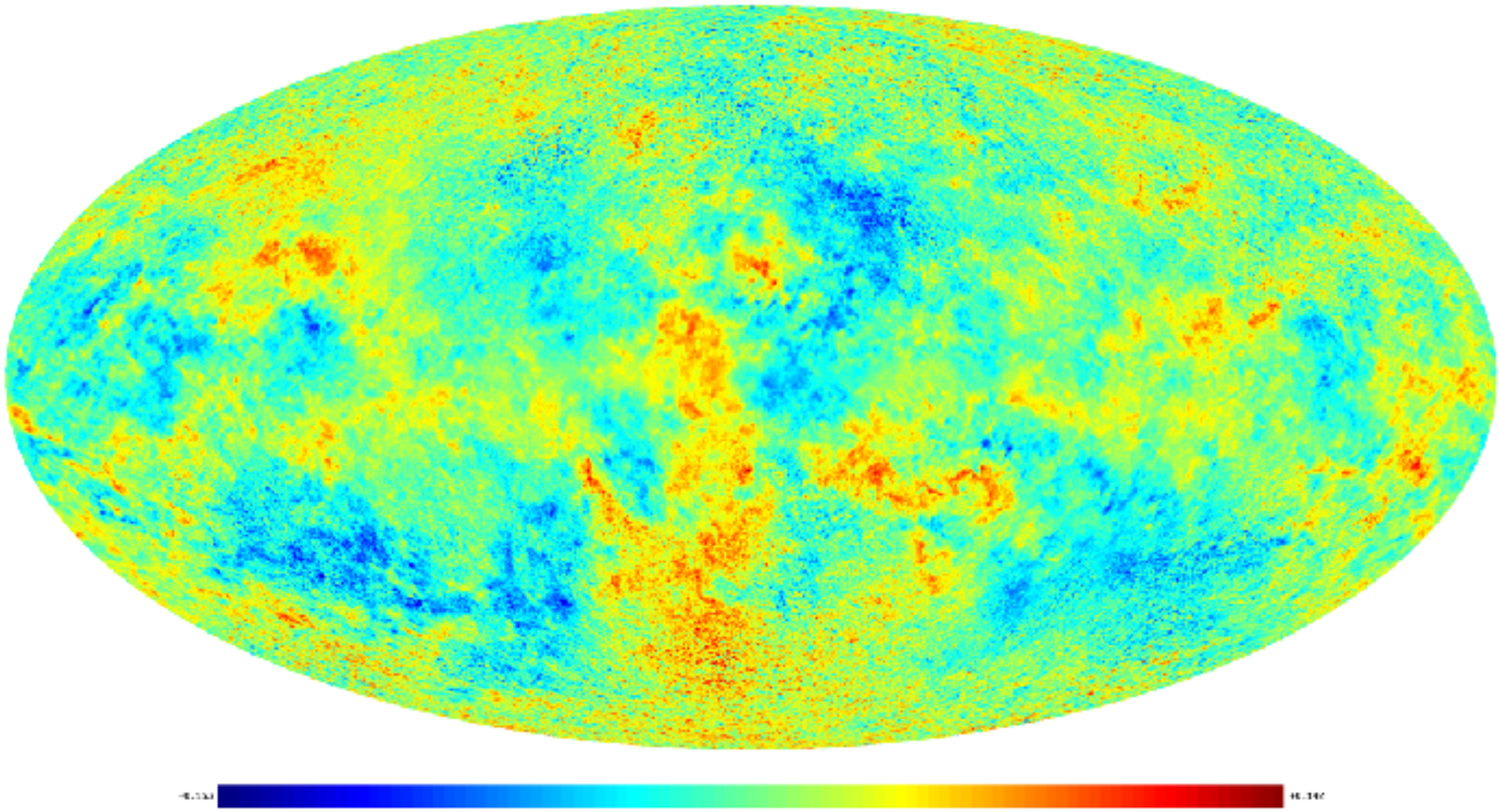
In I in unmasked region. spurs etc.



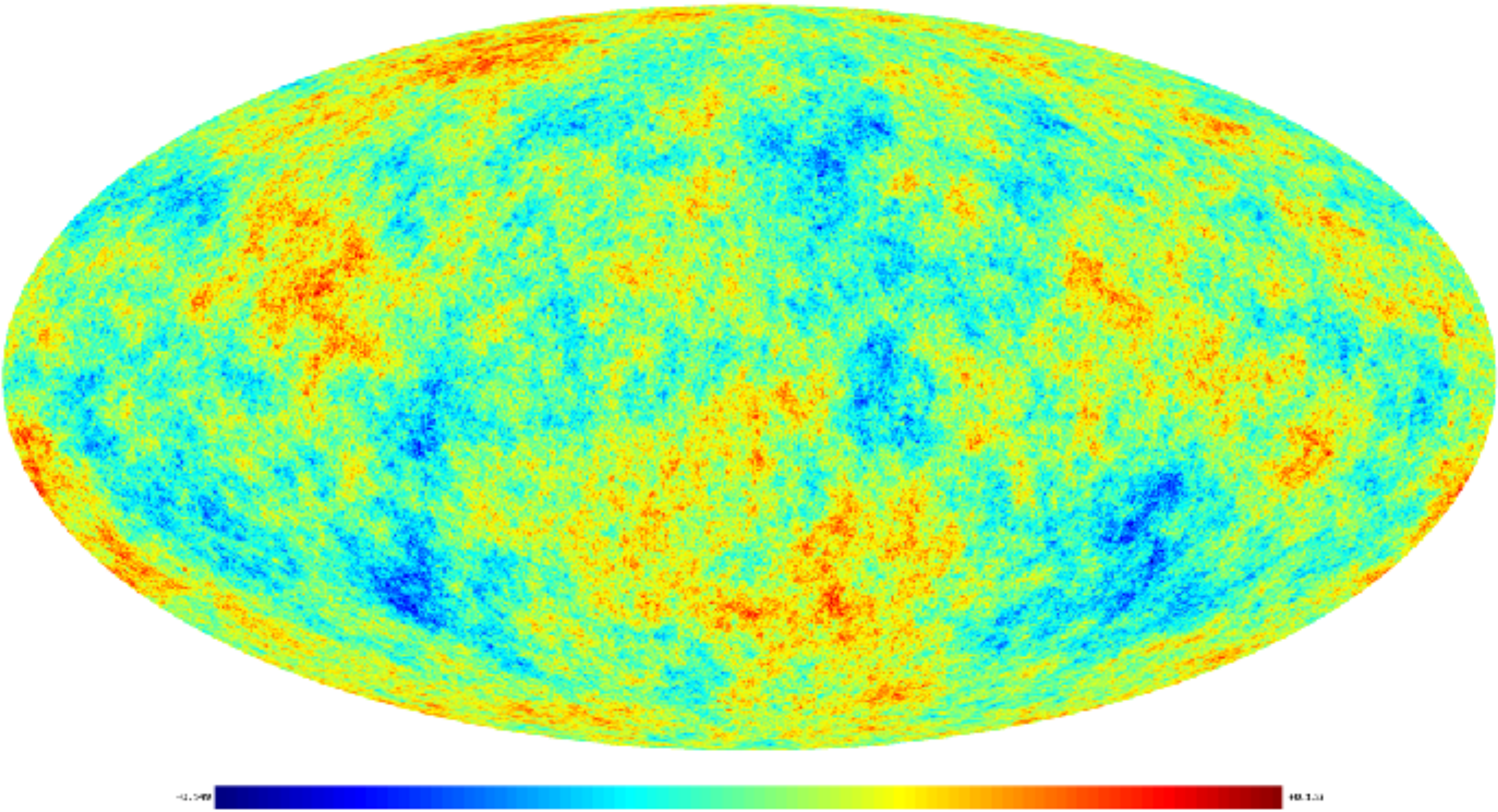
original e map



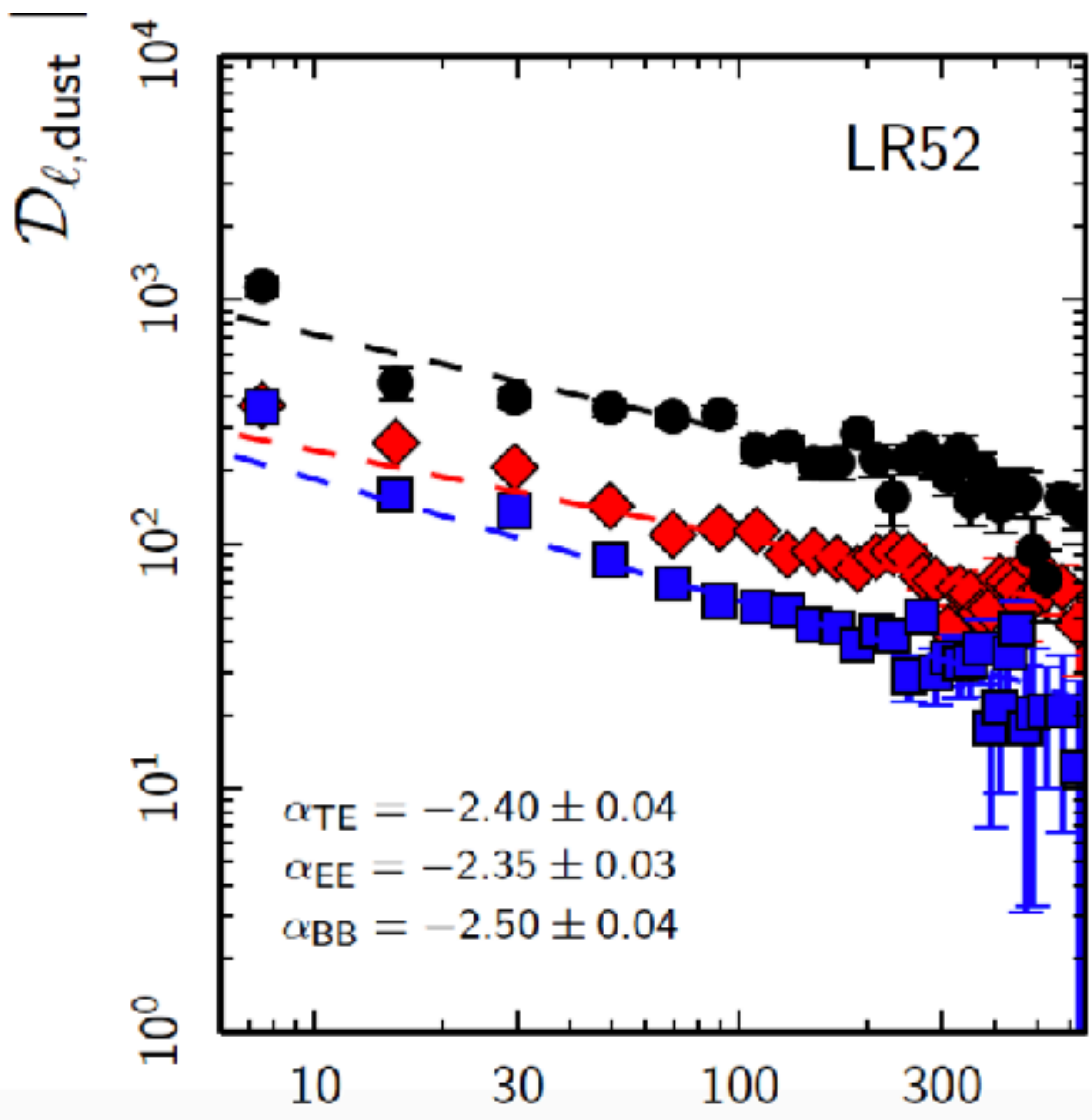
original b map



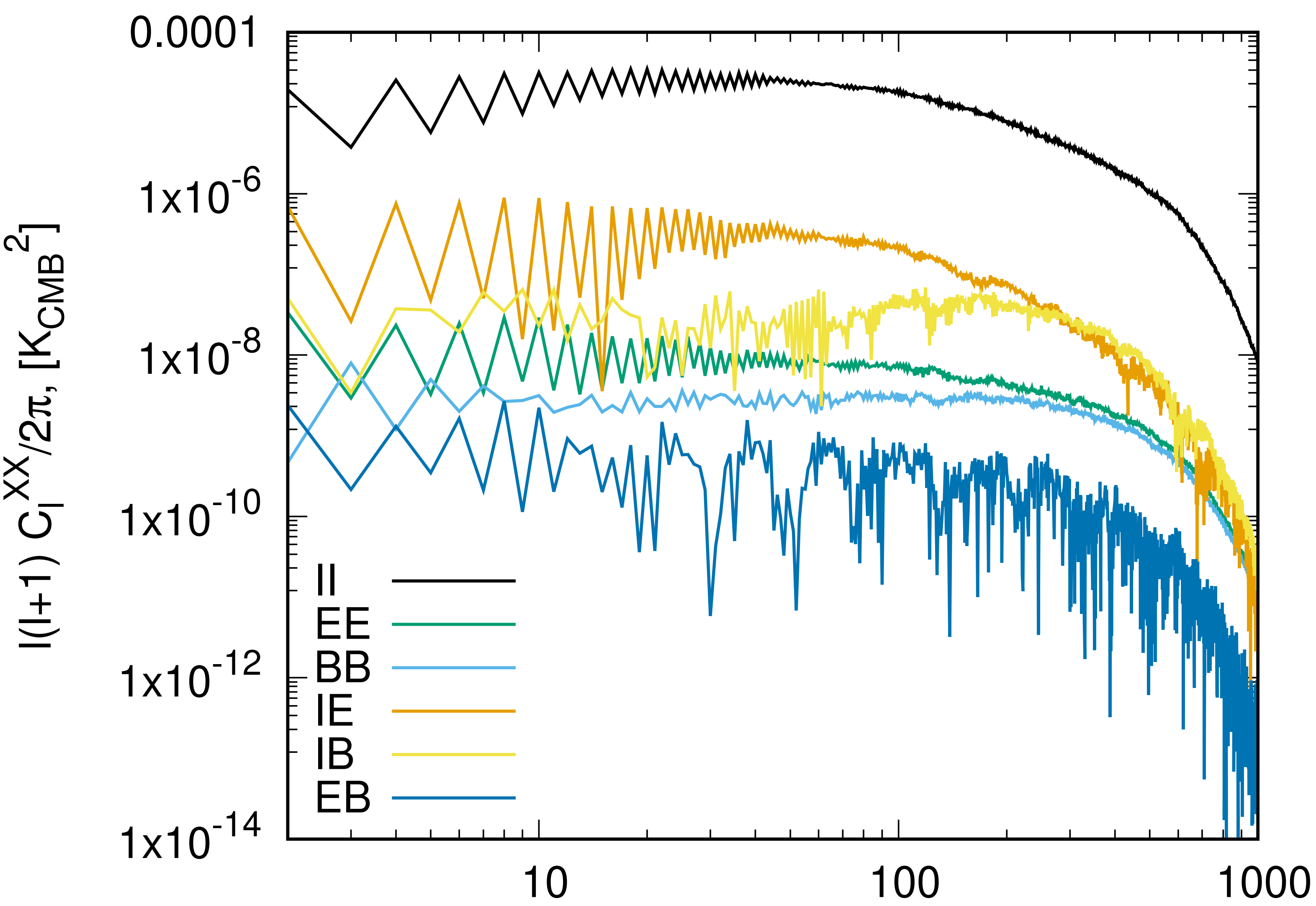
an approach to adding fluctuations in B via a randomized b map, with modes L=1 to 4 constrained and other constraints



Planck pip 2018 LIV



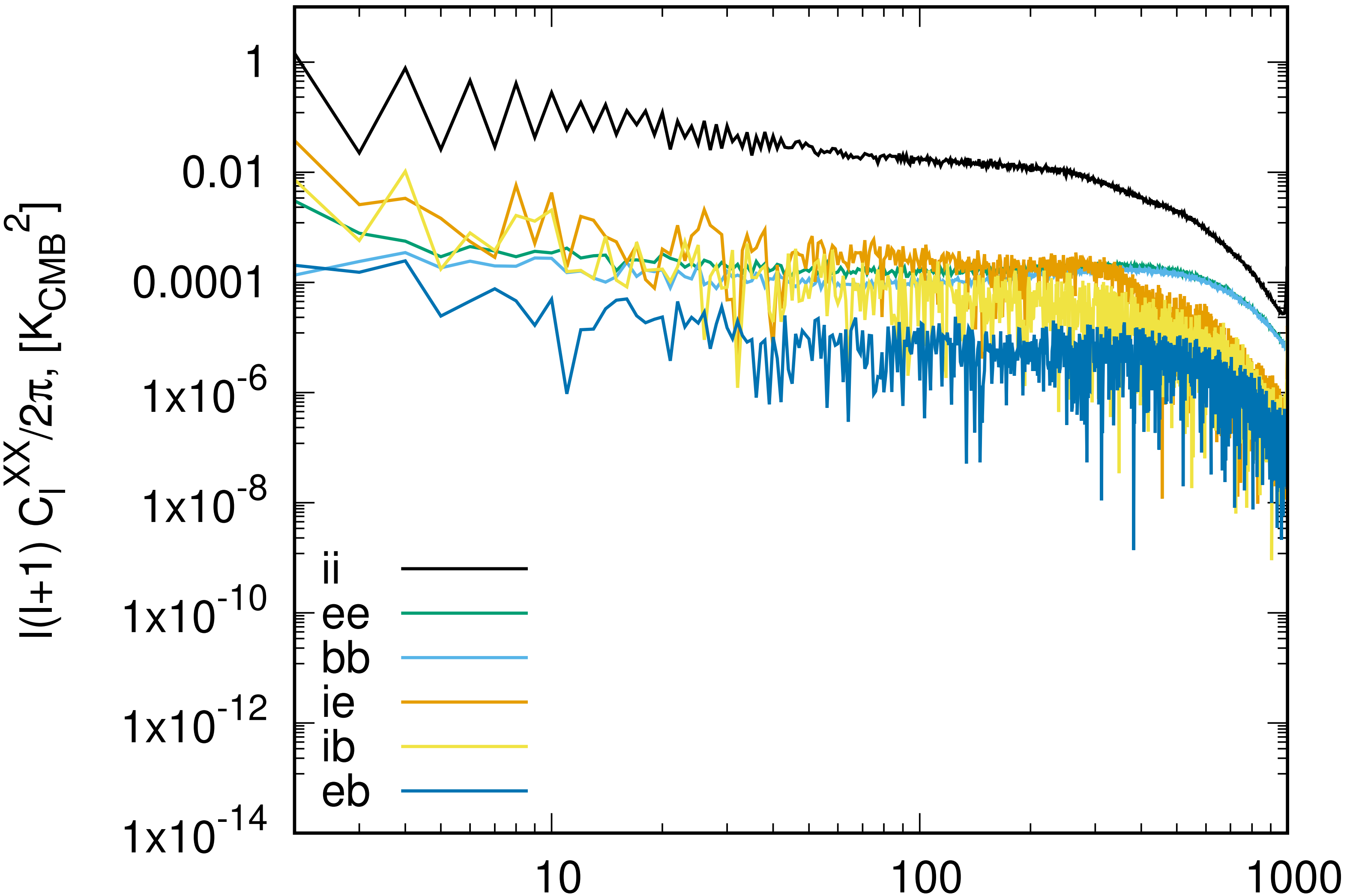
with 90% mask



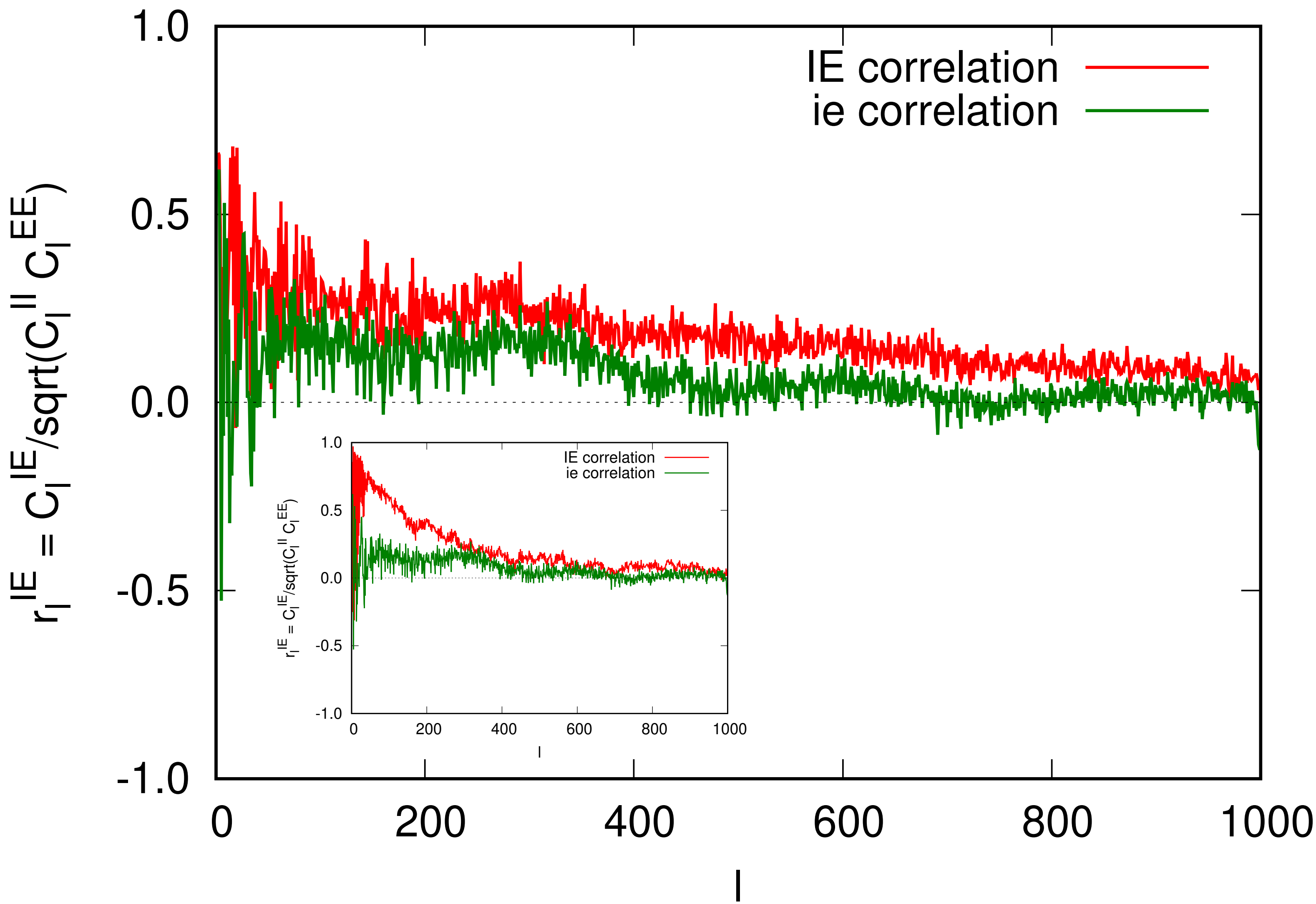
0.0001
1x10^-6
1x10^-8
1x10^-10
1x10^-12
1x10^-14
10
100
1000
l(l+1) C_l^XX/2π, [K_CMB^2]
II
EE
BB
IE
IB
EB

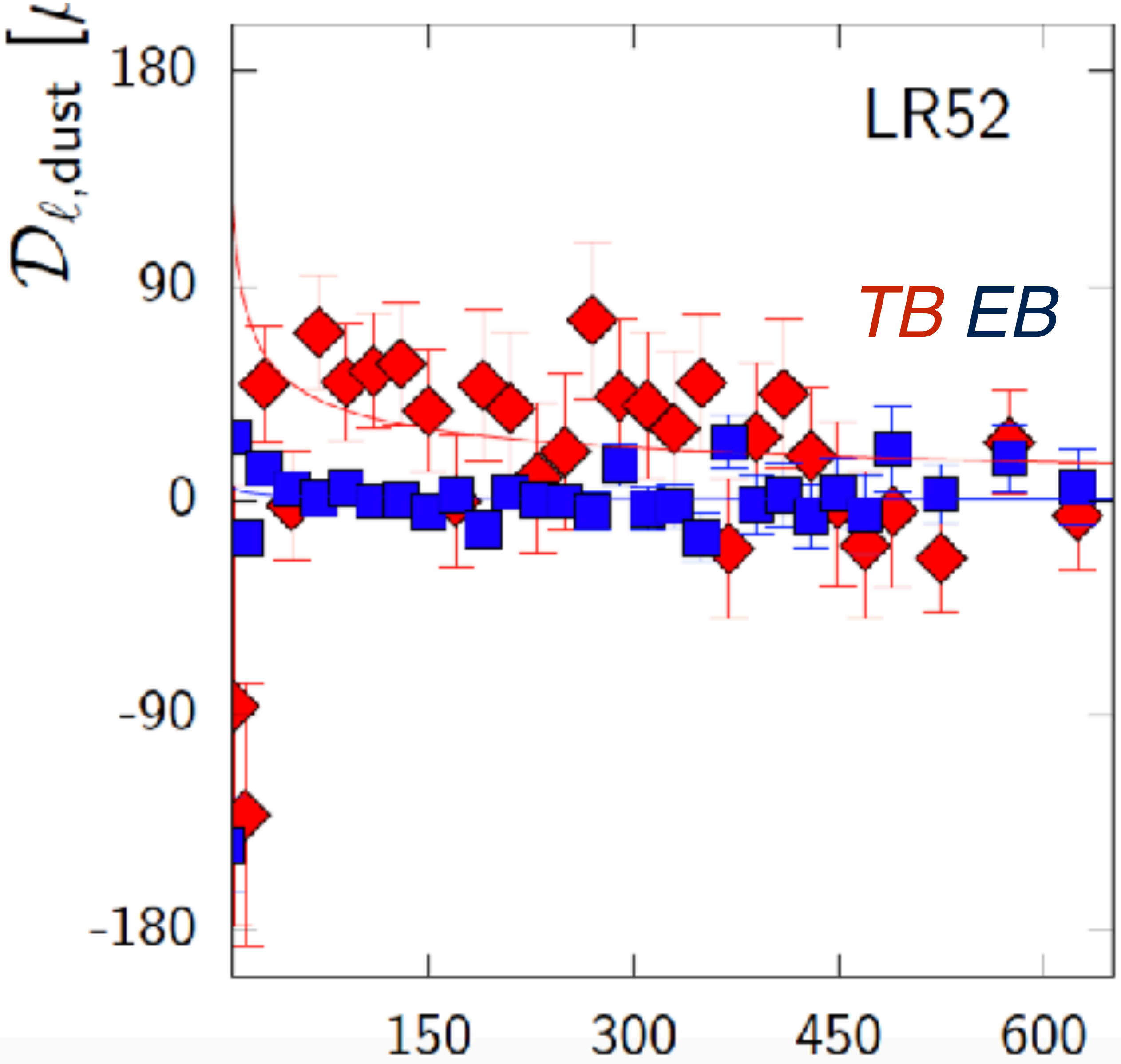
90% mask

with no further cuts, in ee, bb power spec are almost scale invariant, ie diminished, ib still there though less, no eb

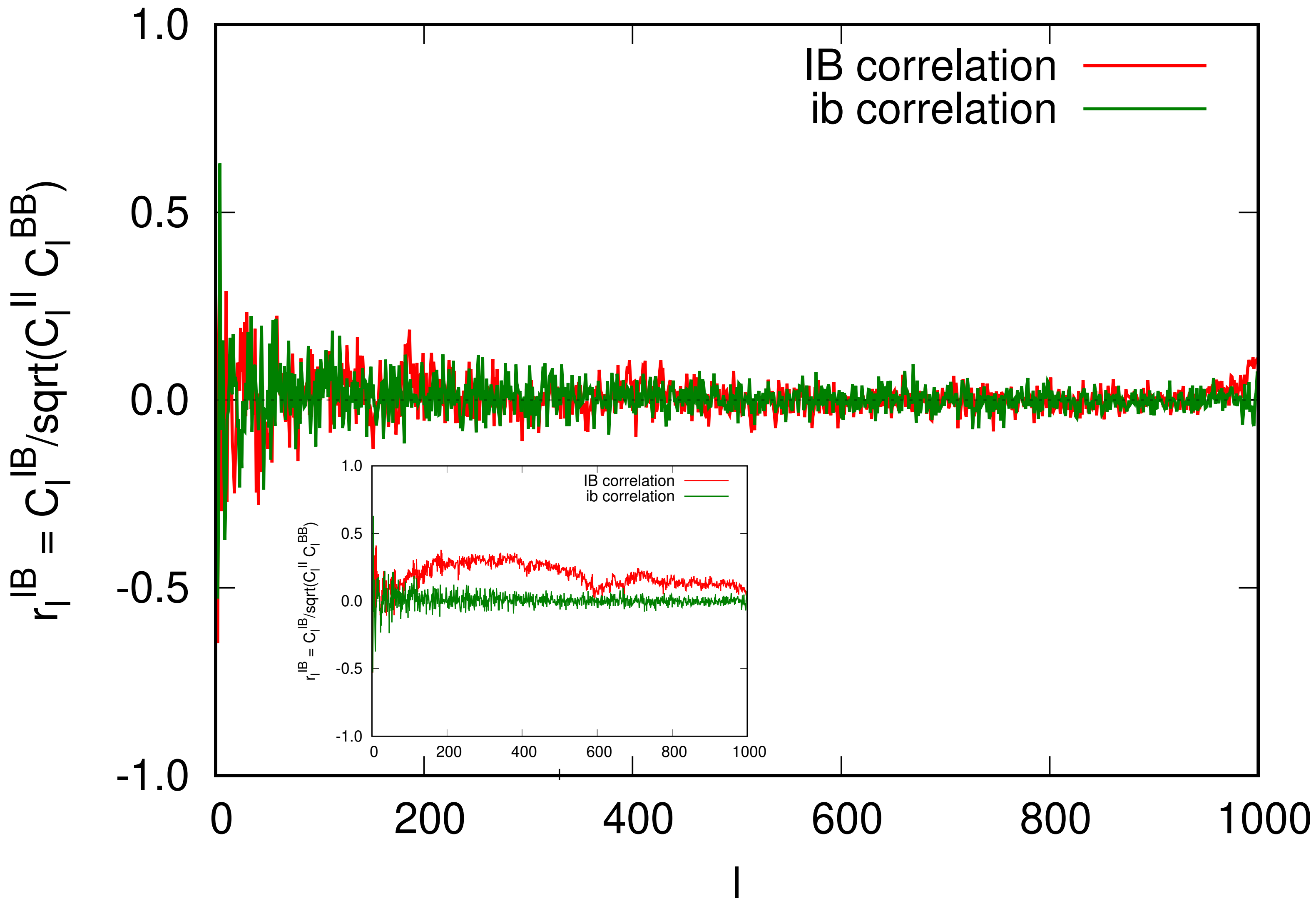


90% mask


IE correlation
ie correlation
$r_l^{IE} = C_l^{IE}/sqrt(C_l^{II} C_l^{EE})$
l
1.0
0.5
0.0
-0.5
-1.0
0
200
400
600
800
1000

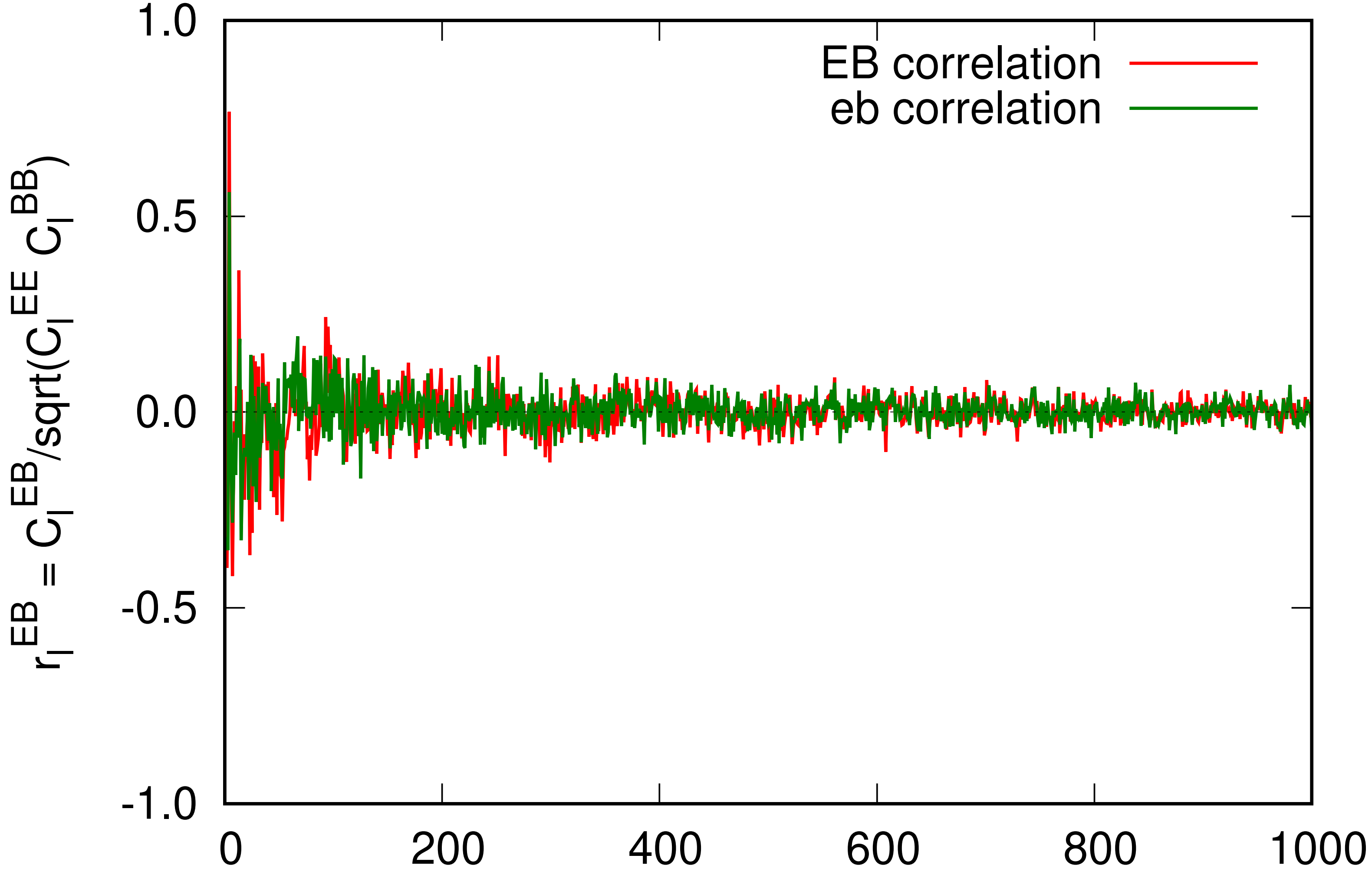

$\mathcal{D}_{\ell,\mathrm{dust}}$ [μ
180
90
0
-90
-180
150
300
450
600
LR52
TB EB

90% mask



IB correlation
ib correlation
$r_l^{IB} = C_l^{IB}/sqrt(C_l^{II} C_l^{BB})$
l
1.0
0.5
0.0
-0.5
-1.0
0
200
400
600
800
1000

90% mask



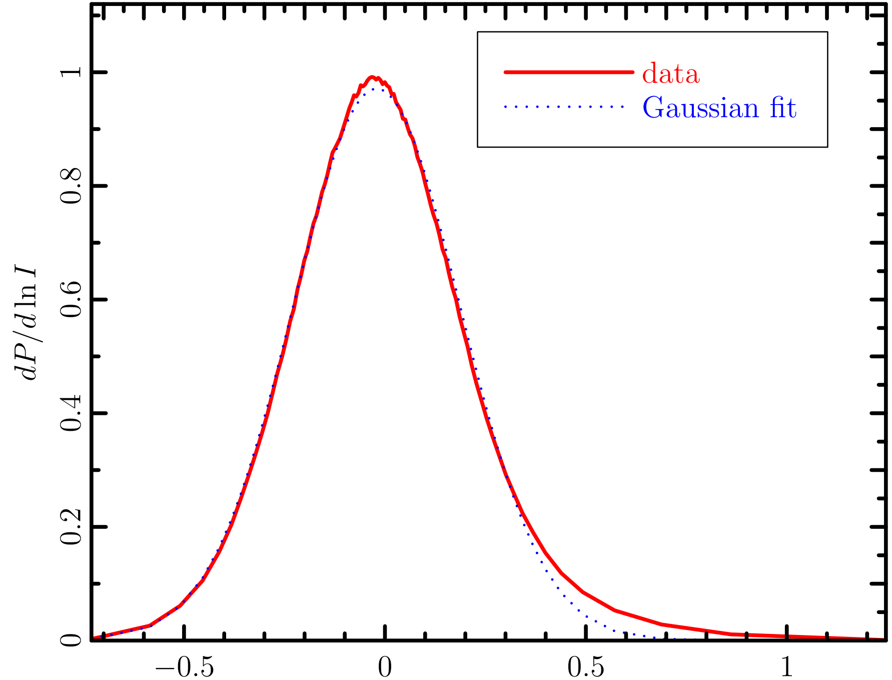
EB correlation
eb correlation
1.0
0.5
0.0
-0.5
-1.0
0
200
400
600
800
1000
l
$r_l^{EB} = C_l^{EB}/sqrt(C_l^{EE} C_l^{BB})$

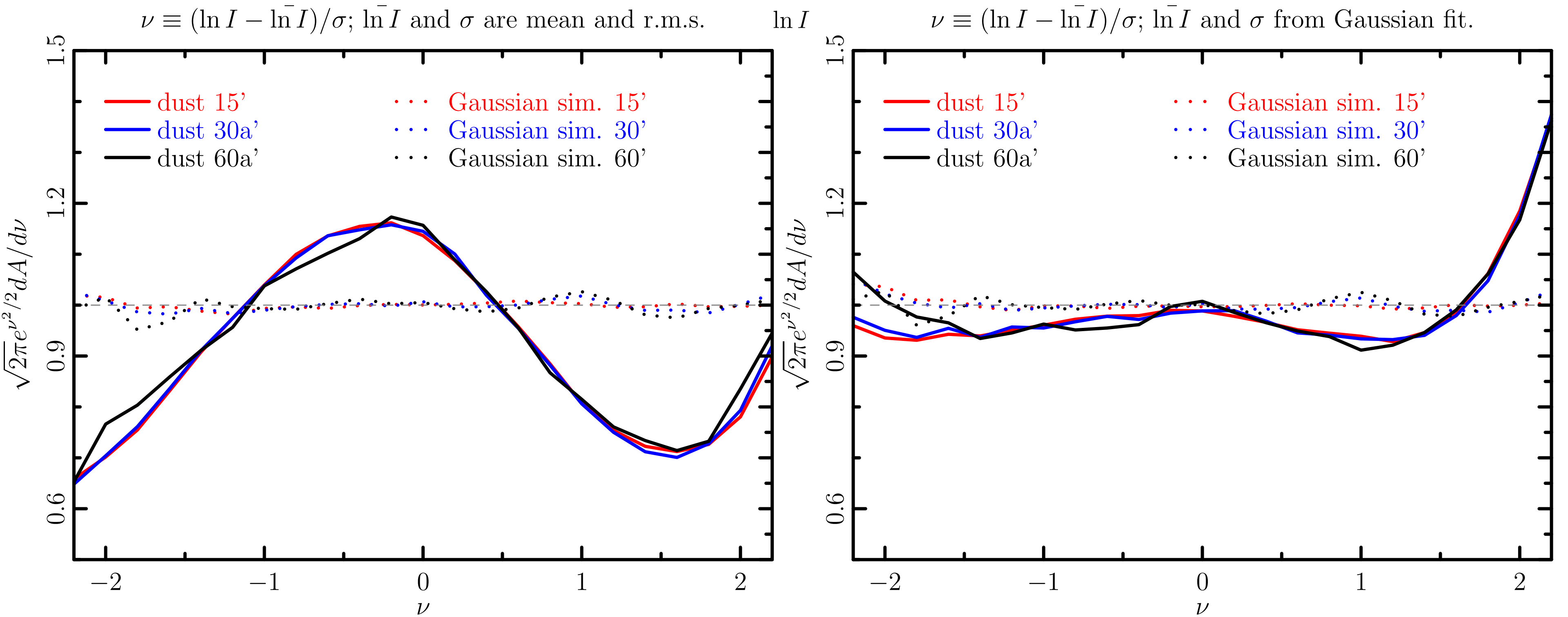
bcut=30deg

highly nonGaussian in I, wide variation in I with Galactic cut

properly mean, variance measures can mitigate

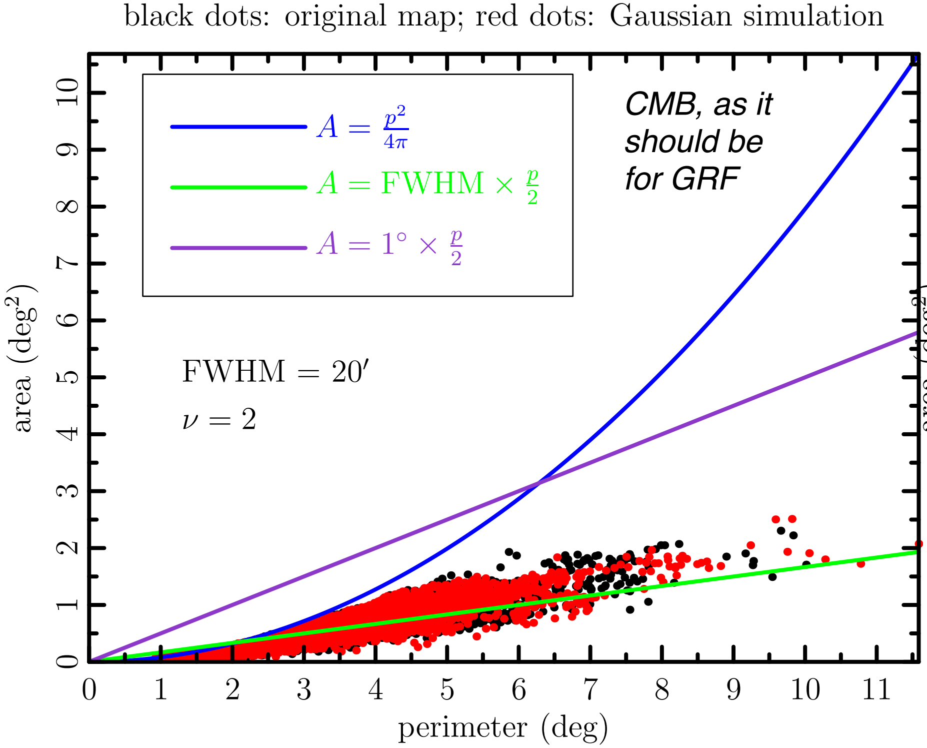
transform to Gaussianized 1-point PDF variables help with Minkowksi functionals

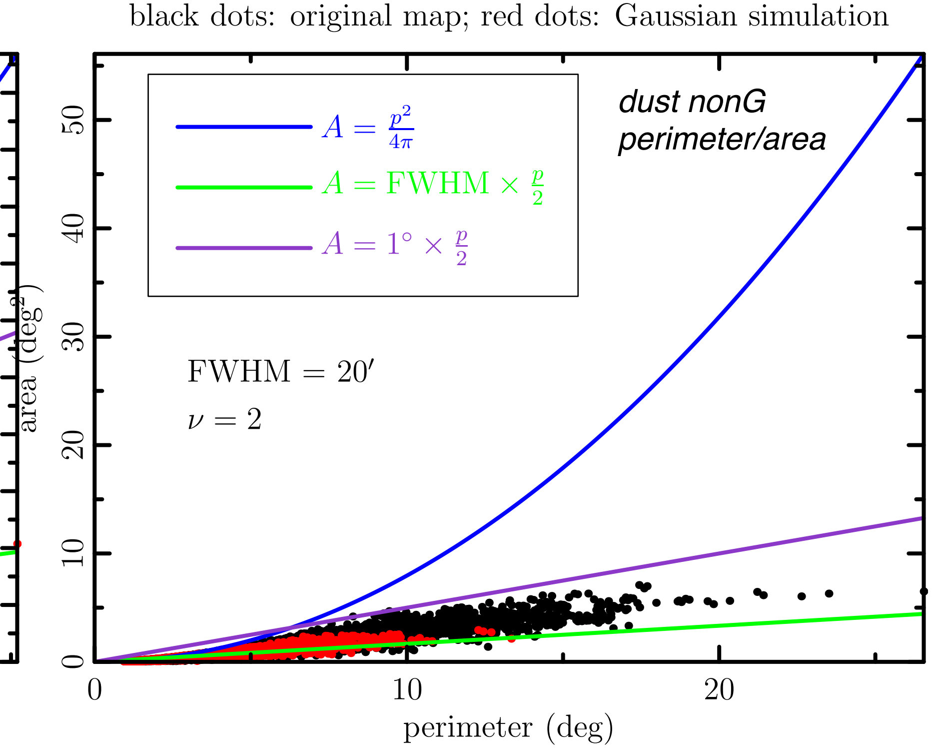


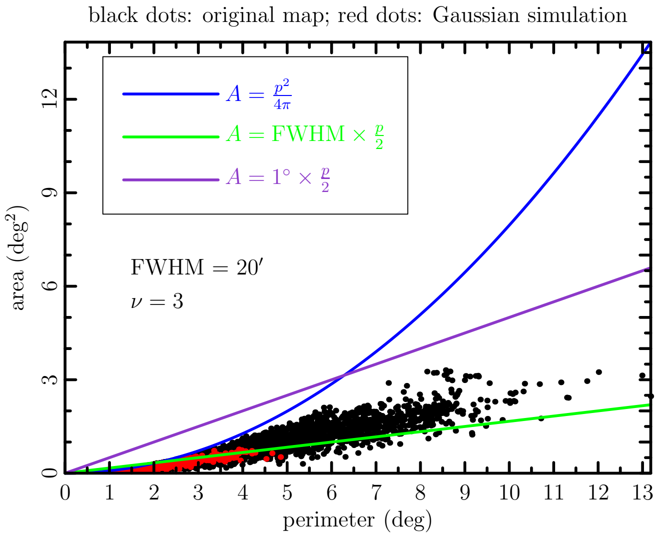


filaments: use Minkowki functionals - contour perimeters cf area as a filamentariness test

bcut 30deg







Stacking: CITA mini-industry Bond, Frolov, Huang dust/synch/CMB,
Alvarez, Stein, Codis + Connor Bevington, Bruno Régaldo-Saint Blancard for tSZ etc & to LIM w/ Ronan Kerr

Three key elements:

- **A** What to stack? (cosmic field u)
- **B** Where to stack? (selection of patches, e.g., peaks)
- **C** How to stack? (patch orientations)

"where" and "how" give constrained parameter(s) q;

	WMAP & Planck 2013	Planck 2015
What	T, Q, U, Q_r, U_r	$T, Q, U, Q_r, U_r, E, B, Q_T, U_T, \zeta_{\rm dv}, \ldots$
Where	T peaks	$T, E, B, Q^2+U^2, Q_T^2+U_T^2, \zeta_{\rm dv}\ldots$ peaks
How	unoriented	oriented and unoriented

For Gaussian fields,

$$\langle u|q;\mathrm{peak},\mathrm{orientation}\rangle = \langle u q^\dagger\rangle\langle q q^\dagger\rangle^{-1}\langle q|\mathrm{peak},\mathrm{orientation}\rangle.$$

Stacking: CITA mini-industry e.g., Bond, Frolov, Huang for dust/synch cf. CMB, good way to select regions or points (catalogues), see long wave gradients,etc

First derivative vanishes on the peak. Need to use the 2nd derivatives.

Intuitively (flat-sky limit):

$$Q_T \equiv \nabla^{-2}(\partial_y^2 - \partial_x^2)T,\ U_T \equiv -2\nabla^{-2}(\partial_x \partial_y)T$$

Slightly non-intuitive (on the sphere):

$$Q_T(\mathbf{n}) \pm i U_T(\mathbf{n}) \equiv \sum_{l,m}\left[\int T(\mathbf{n}')\, Y_{lm}^*(\mathbf{n}')\, d^2\mathbf{n}'\right]{}_{\pm 2}Y_{lm}(\mathbf{n})$$

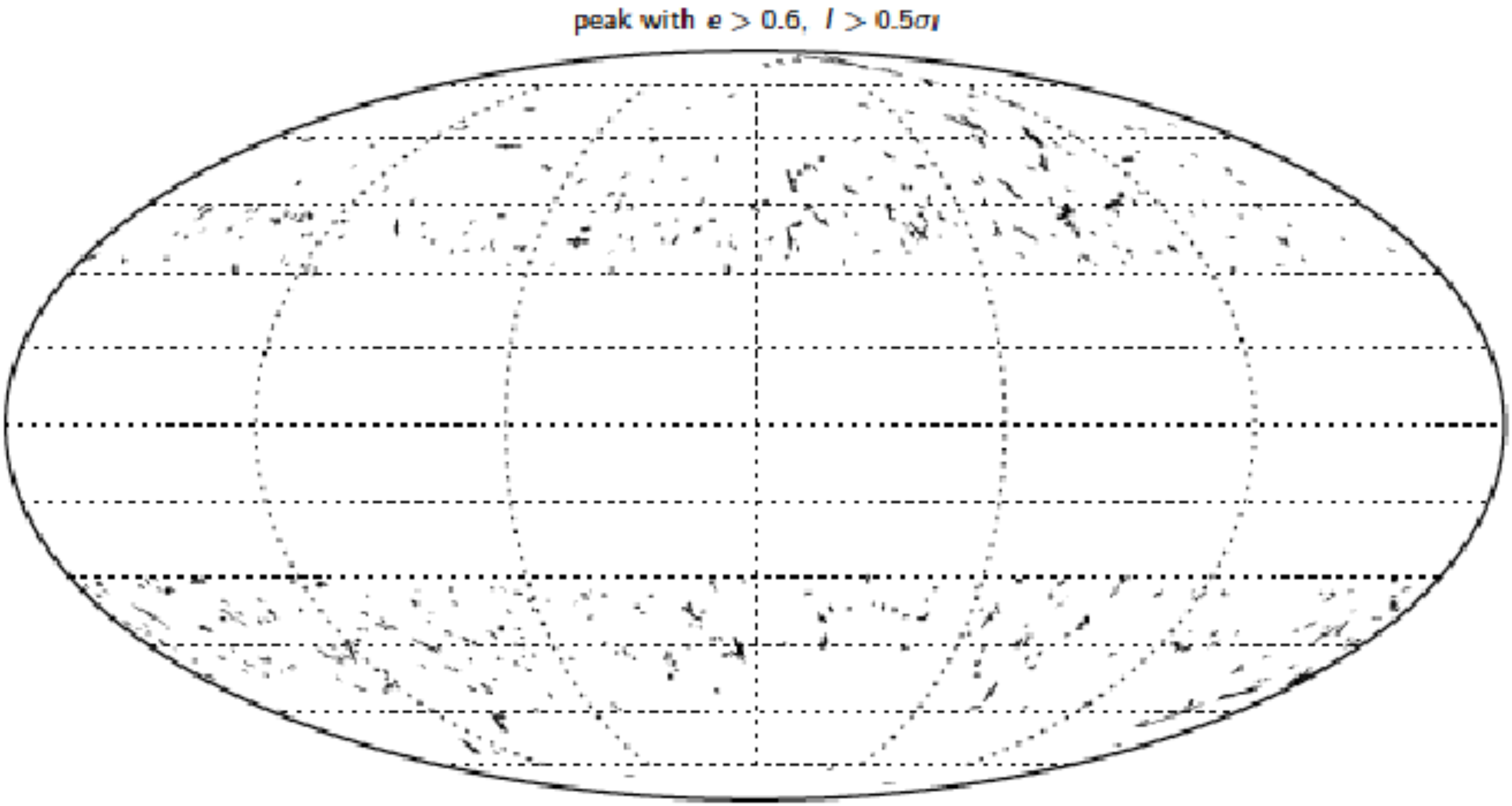
Orient the patch such that U_T **vanishes in the centre.**

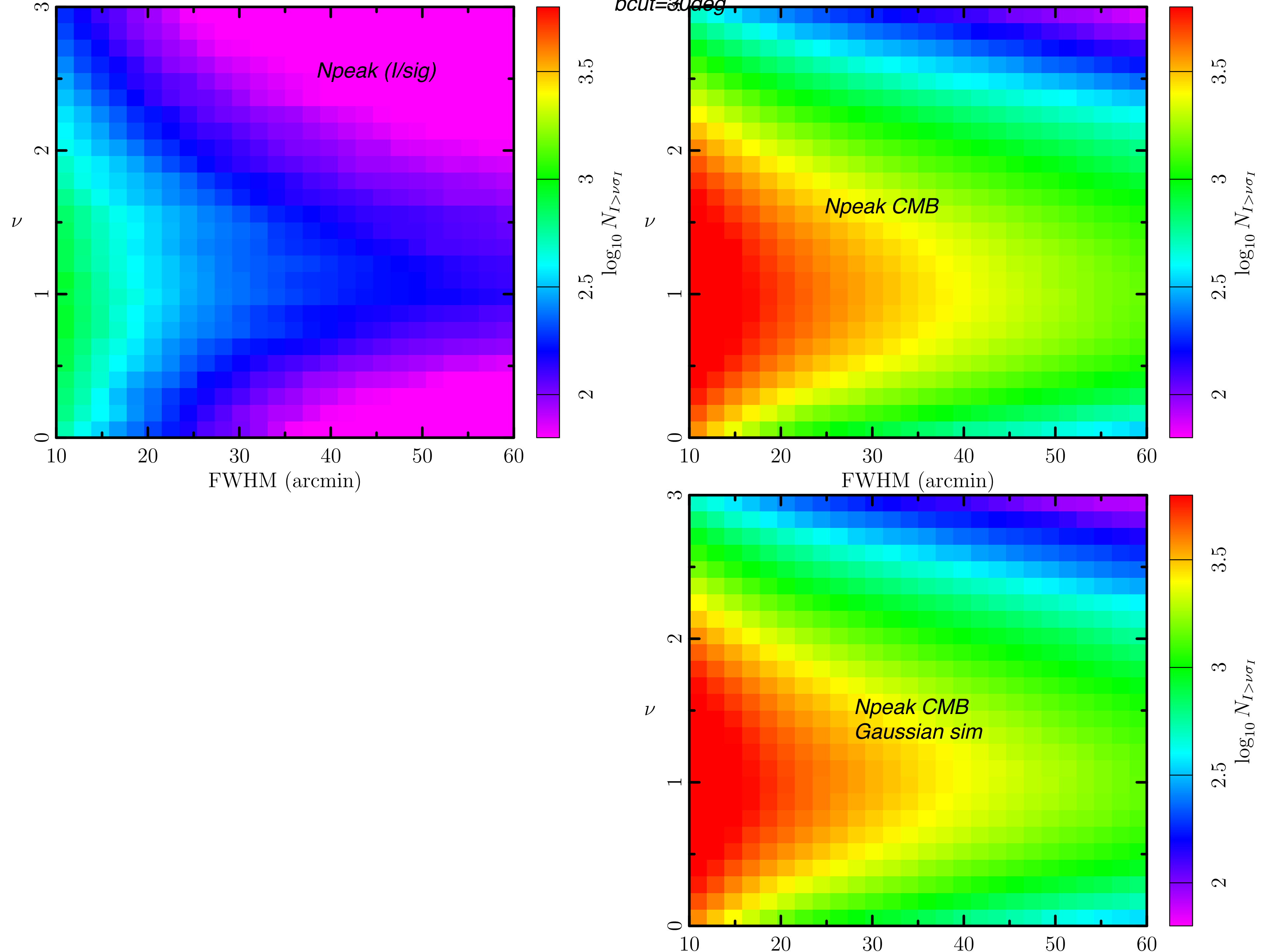
$\langle u|q;\mathrm{peak},\mathrm{orientation}\rangle(\varpi,\phi)$ decomposes to $\cos m\phi$, $m = 0, 2, 4$.

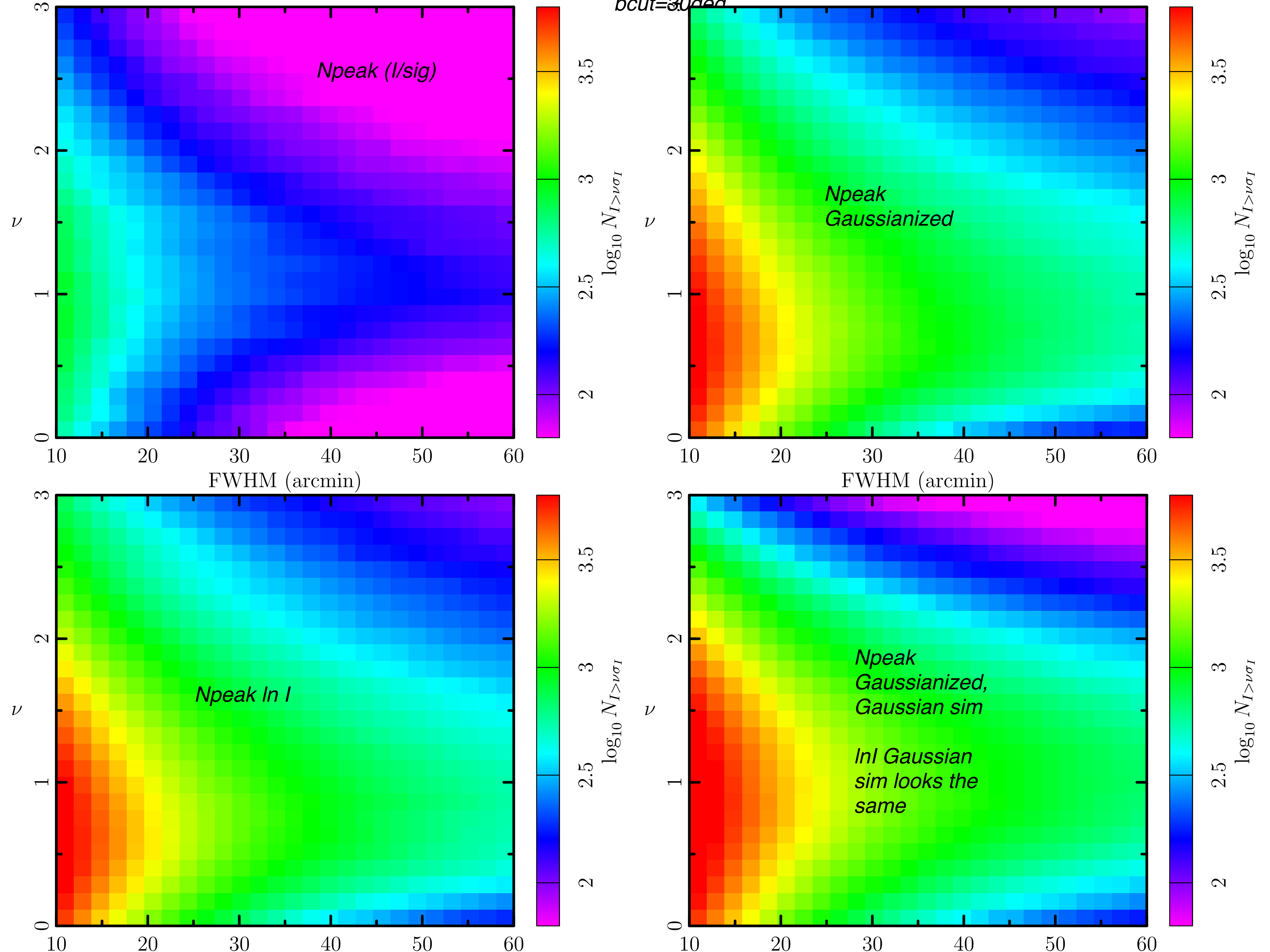
*using **QT, UT was great for CMB**, not for dust, synch - huge coherence with these anisotropic constraints, because so much power at low L. often use **Laplace(QT,UT), ie Hessian** to concentrate the constraint closer to the filter scale.*

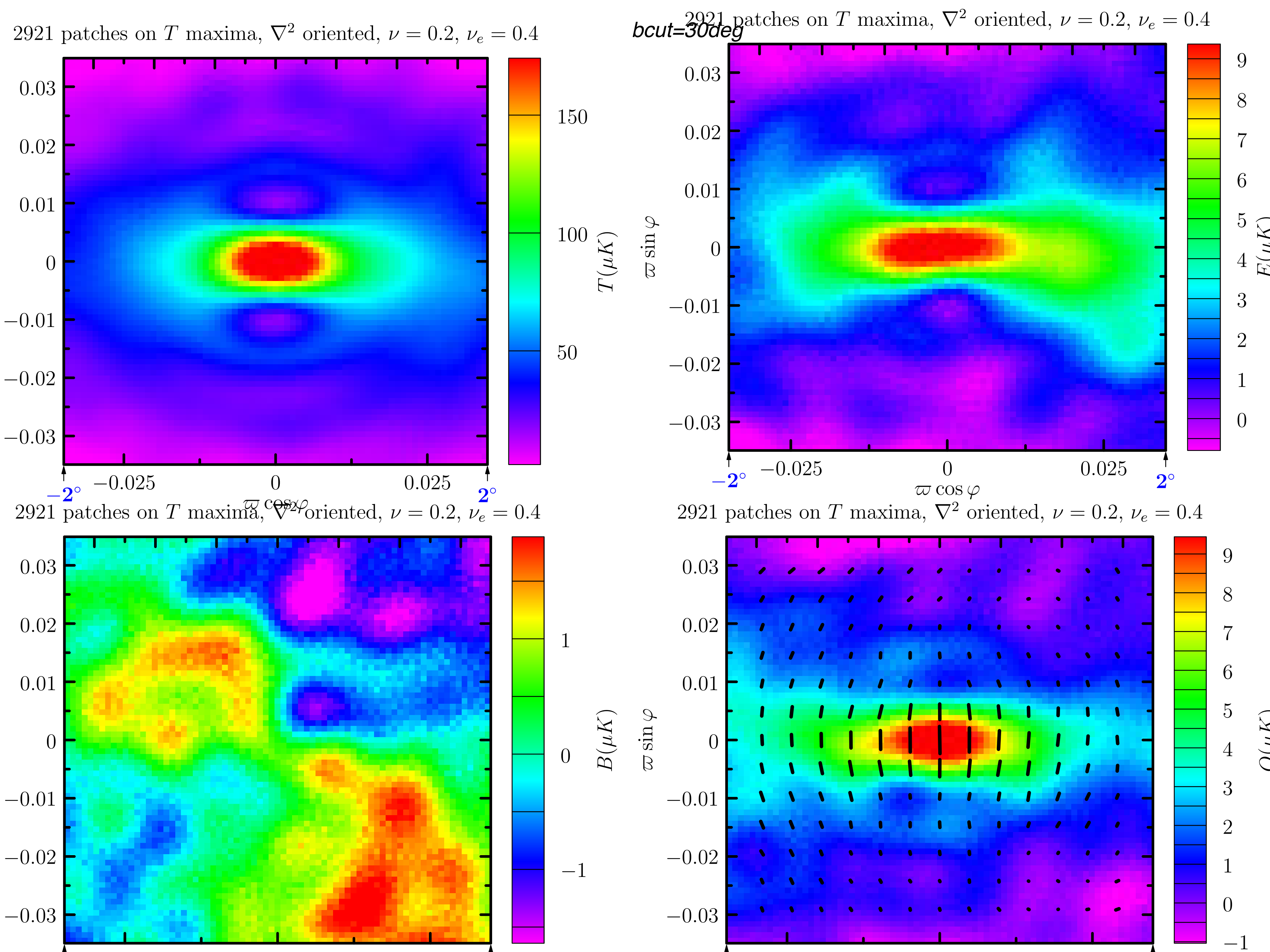
use a dipole to decide which side to stack on => asymmetric oriented stacks shows better "superclustering", filaments, membranes, etc.

bcut=30deg high ellipticity 'catalogue' with an intensity cut

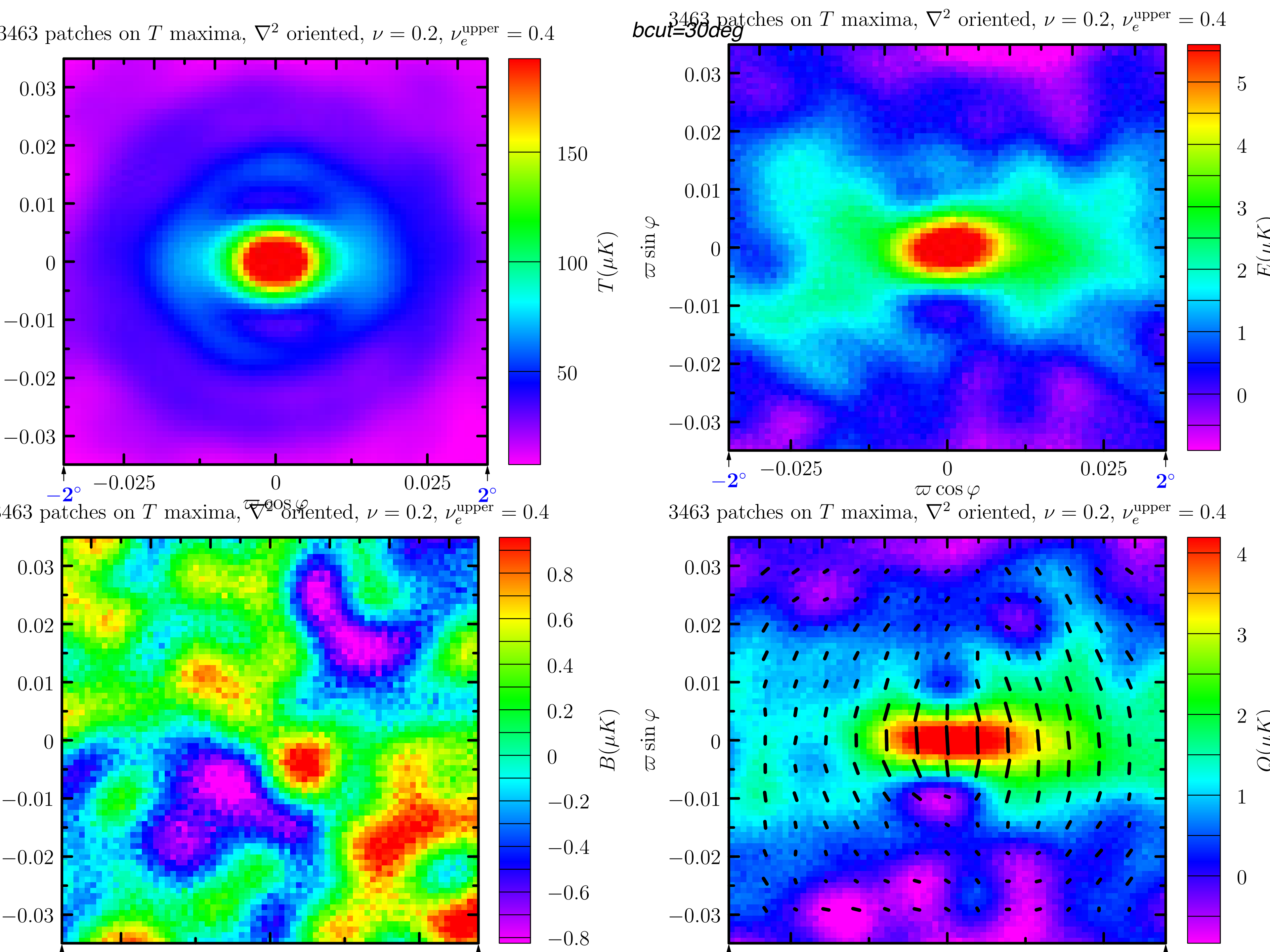


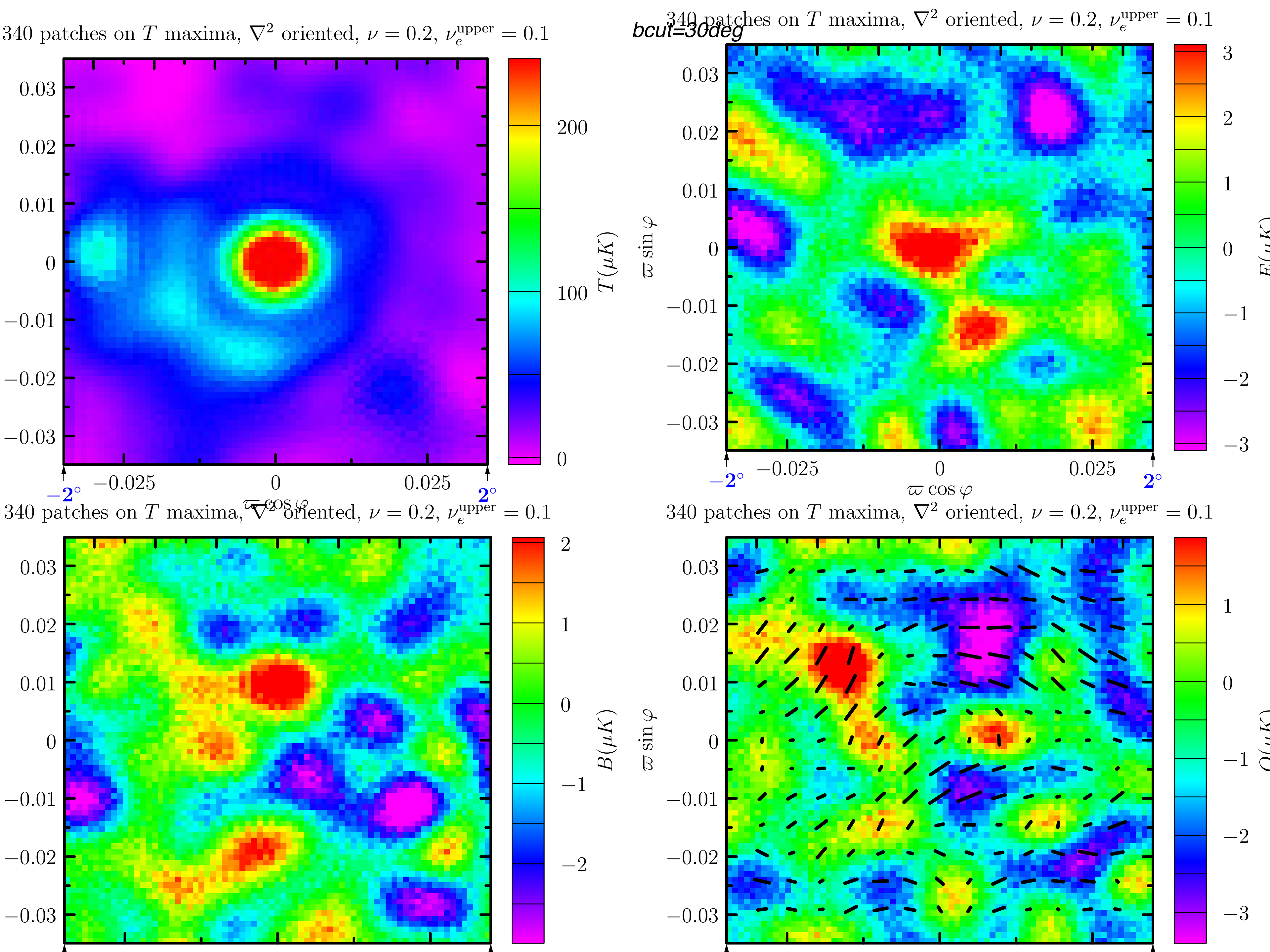

bcut=30deg
Npeak (I/sig)
Npeak CMB
Npeak CMB
Gaussian sim
FWHM (arcmin)
FWHM (arcmin)
ν
$\log_{10} N_{I>\nu\sigma_I}$


bcut=30deg
Npeak (I/sig)
Npeak
Gaussianized
Npeak ln I
Npeak
Gaussianized,
Gaussian sim
lnI Gaussian
sim looks the
same
FWHM (arcmin)
ν
$\log_{10} N_{I>\nu\sigma_I}$

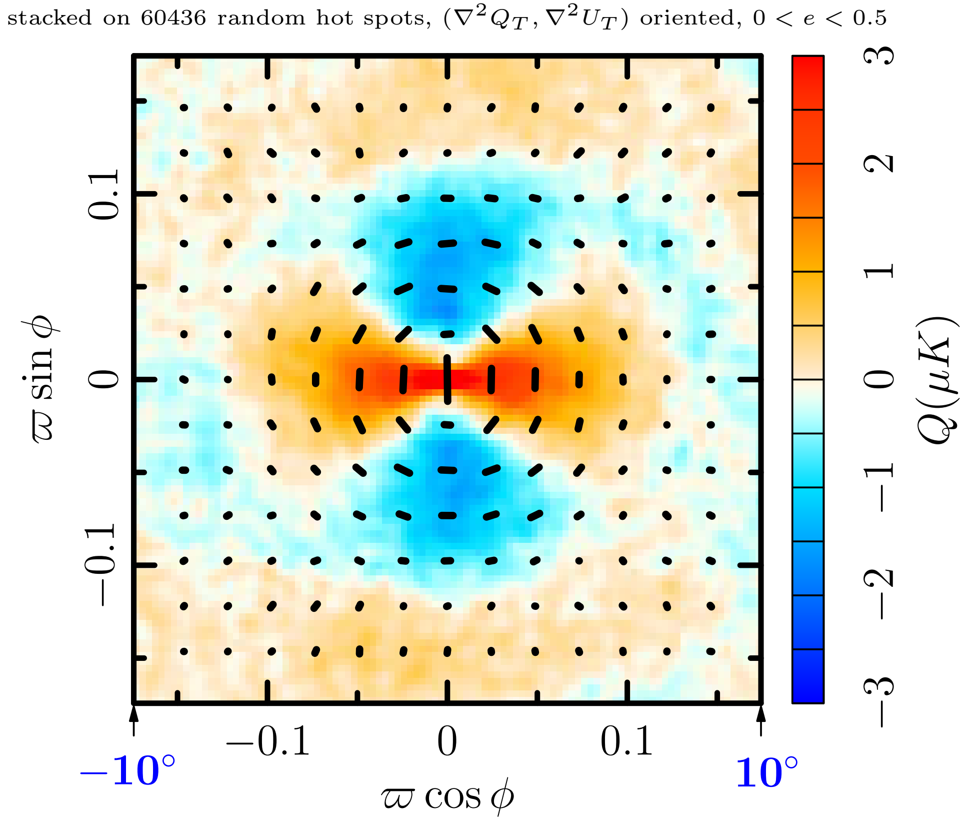


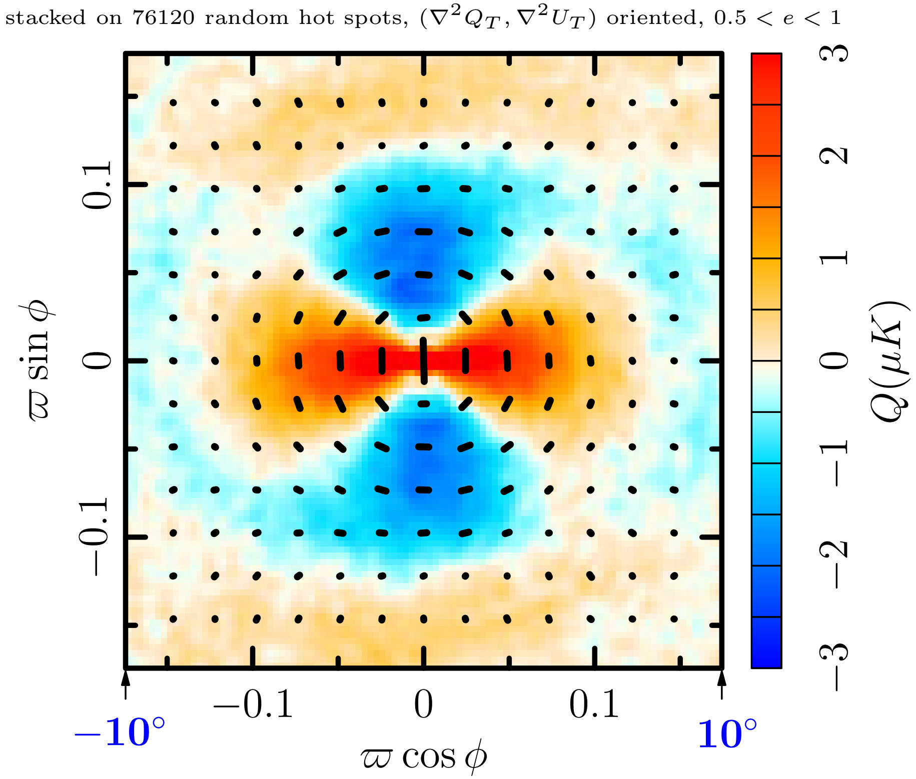
2921 patches on T maxima, ∇^2 oriented, $\nu = 0.2$, $\nu_e = 0.4$
bcut=30deg
$T(\mu K)$
$E(\mu K)$
$B(\mu K)$
$Q(\mu K)$
$\varpi \cos\varphi$
$\varpi \sin\varphi$
-2°
2°


3463 patches on T maxima, ∇^2 oriented, $\nu = 0.2$, $\nu_e^{\rm upper} = 0.4$
$T(\mu K)$
$\varpi \cos\varphi$
$-2°$
$2°$
bcut=30deg
3463 patches on T maxima, ∇^2 oriented, $\nu = 0.2$, $\nu_e^{\rm upper} = 0.4$
$\varpi \sin\varphi$
$E(\mu K)$
$\varpi \cos\varphi$
$-2°$
$2°$
3463 patches on T maxima, ∇^2 oriented, $\nu = 0.2$, $\nu_e^{\rm upper} = 0.4$
$B(\mu K)$
3463 patches on T maxima, ∇^2 oriented, $\nu = 0.2$, $\nu_e^{\rm upper} = 0.4$
$\varpi \sin\varphi$
$Q(\mu K)$


340 patches on T maxima, ∇^2 oriented, $\nu = 0.2$, $\nu_e^{\rm upper} = 0.1$
$T(\mu K)$
$\varpi \cos\varphi$
$-2°$
$2°$
bcut=30deg
340 patches on T maxima, ∇^2 oriented, $\nu = 0.2$, $\nu_e^{\rm upper} = 0.1$
$\varpi \sin\varphi$
$E(\mu K)$
$\varpi \cos\varphi$
$-2°$
$2°$
340 patches on T maxima, ∇^2 oriented, $\nu = 0.2$, $\nu_e^{\rm upper} = 0.1$
$B(\mu K)$
340 patches on T maxima, ∇^2 oriented, $\nu = 0.2$, $\nu_e^{\rm upper} = 0.1$
$\varpi \sin\varphi$
$Q(\mu K)$

bcut=30deg

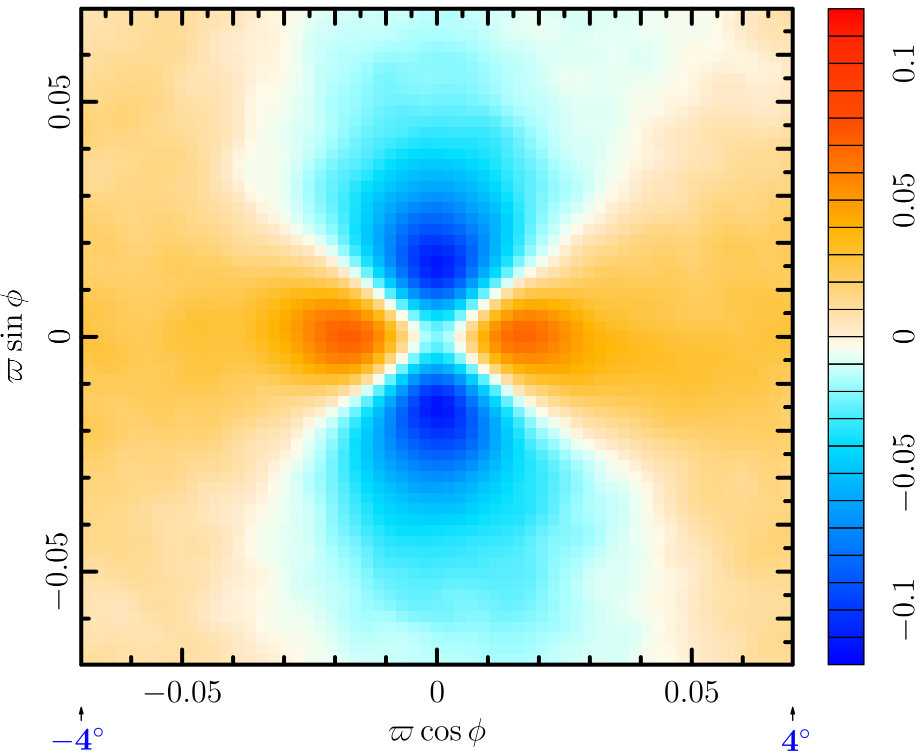




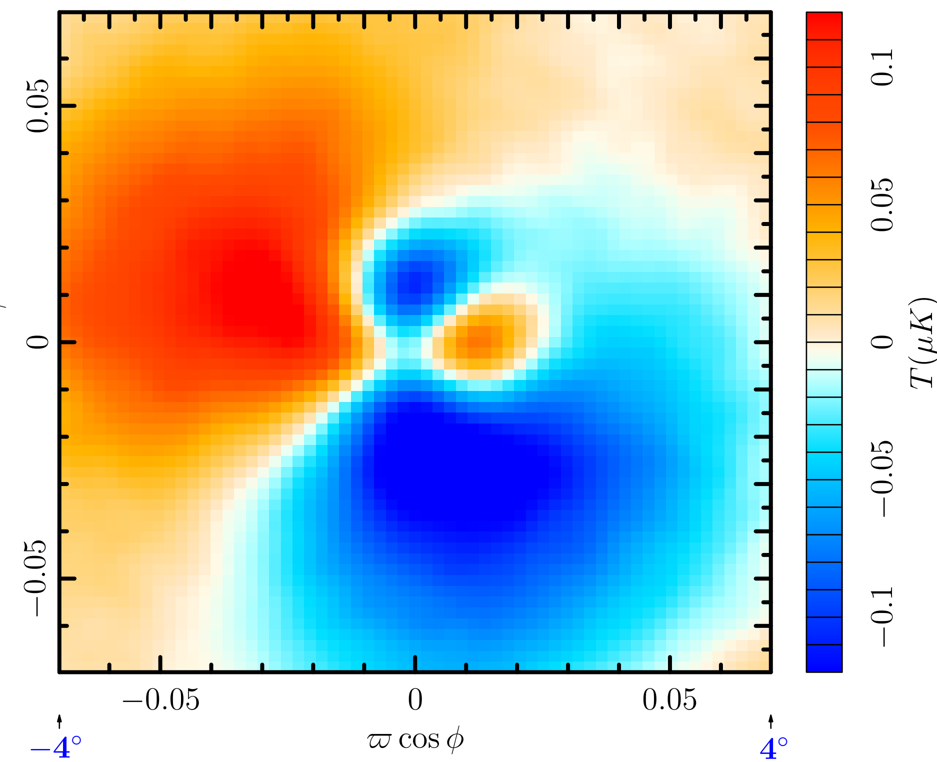
field points with T>0. could do this with NHI eg "catalogue of peaks"

90% mask

7779 cols (FWHM 1°), Hessian oriented

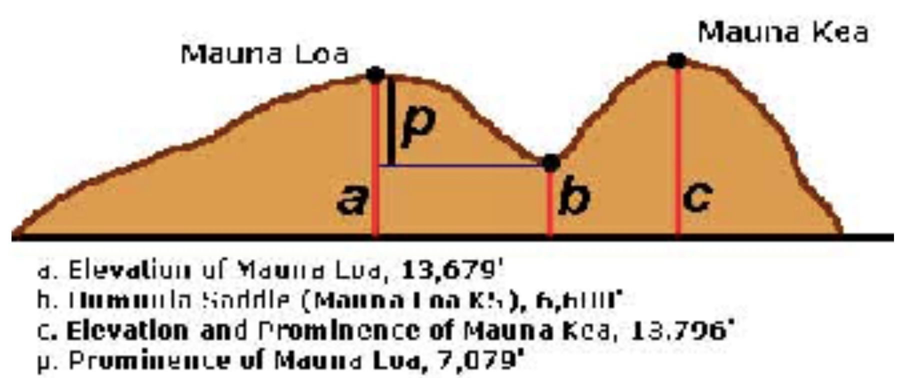


7779 cols (FWHM 1°), Hessian oriented with N/E selection (tophat $\theta < 2°$)



I-saddle stack

stacked + Hessian
+ direction info
*<ln **I** | **I-saddle***
broken symm>



1. *the log-transform of the df matrix and how the maps look*
2. *how EE, BB power spectra look in e, b*
3. *how IE, IB, EB look ieb cf IEB*

for these not yet done in ieb, but chose a strong bcut> 30deg Galactic mask for these results

filament-ariness is characterized by anisotropic coherence of stacks, but not straight (squeezed 3-point turned out not to be that useful for filaments - Planck with Tuhin Ghosh - projected filaments are curved, and Interstellar web is more complex. power pre decade rises above scale invariance at low L => huge fluctuations for GRF. Many ideas in Planck 2015, pip XXX, and some in Planck 2018 landS

4. PDF, Minkowski functionals
5. filaments - perimeter cf. area of contours (with care because of noise).
6. field point stacks as anisotropy changes
7. peak (hot spot) catalogue properties with scale. n_pk of dust cf. CMB (nu, nu_e similar to p pol fraction)
CUTS for filament strengths
8. stacks for high ellipticity peaks cf. low
9. stacks on P, P_T etal
10. stacks on everything else, saddle points are fun, etc