Beam Systematics, Lensing, and Current & Future Experiments

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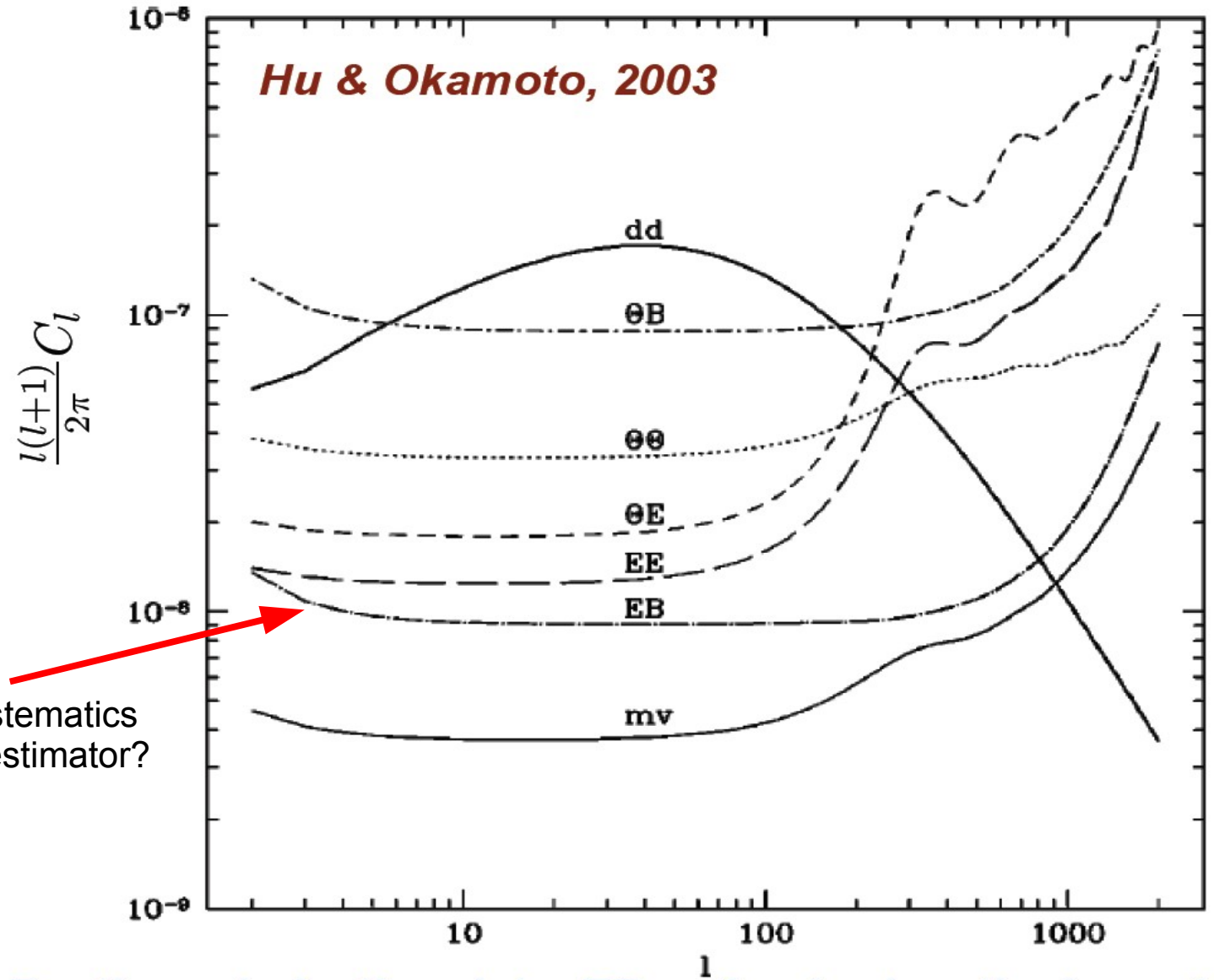
Overview

- Imperfect beams lead to spurious power spectra
  - TT, EE, BB, TE, TB, EB
- How does this affect reconstruction of the lensing power spectra?
  - It will affect the extraction of lensing parameters from data
  - How does the scan strategy affect reconstruction?
- How does this affect the different estimators for current/future experiments?
- References:
  - Shimon, Keating, Ponthieu, & Hivon PRD 77 083003
  - Miller, Shimon, & Keating PRD 79 063008
  - Miller, Shimon, & Keating PRD 79 103002

Lensing Reconstruction



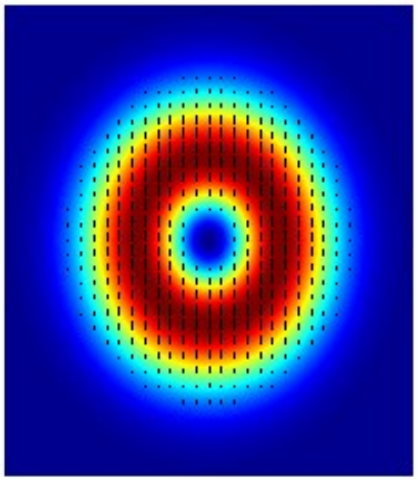
How do systematics affect this estimator?

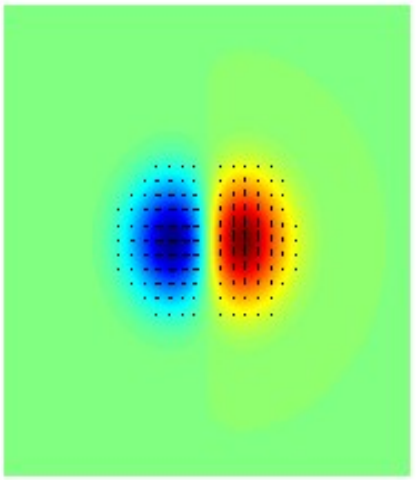
For the polarization data, EB estimator has the lowest noise

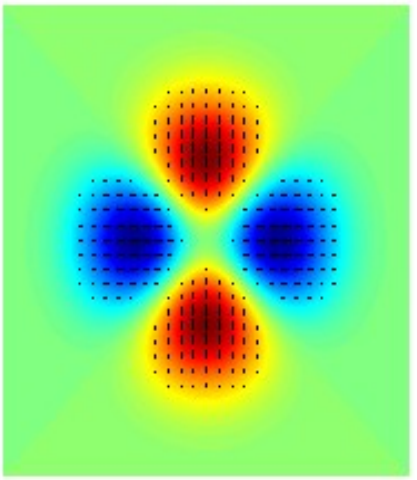
Systematic Beam Effects in Real Space

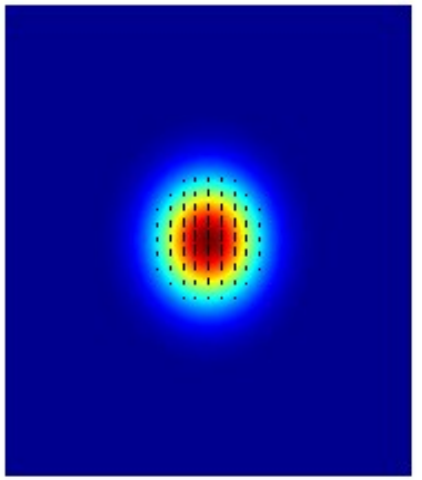
differential pointing (dipole effect)

differential gain (monopole effect)









differential FWHM (monopole effect)

differential ellipticity (quadrupole effect)

Irreducible

Systematic Beam Effects in Real Space

differential pointing
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differential gain
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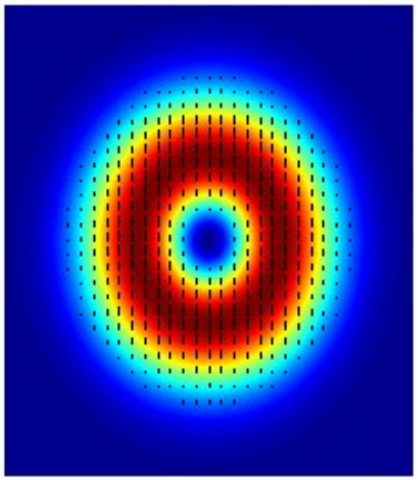
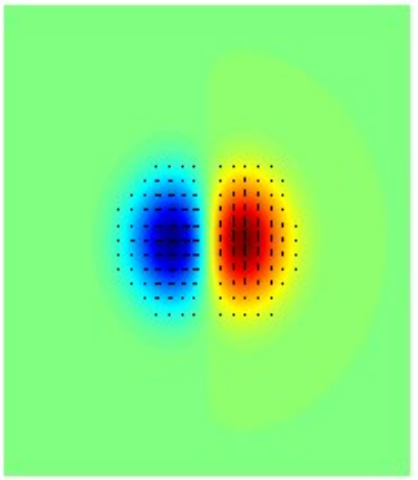
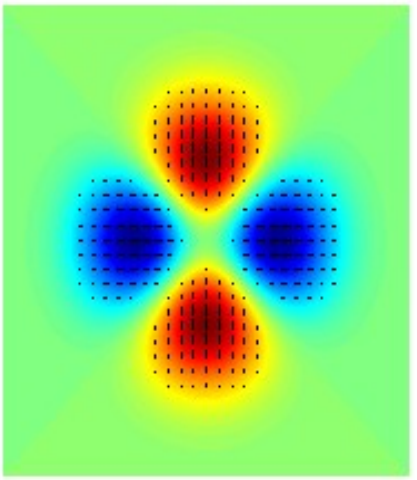
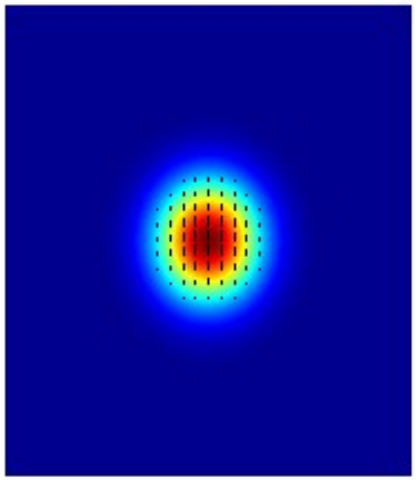








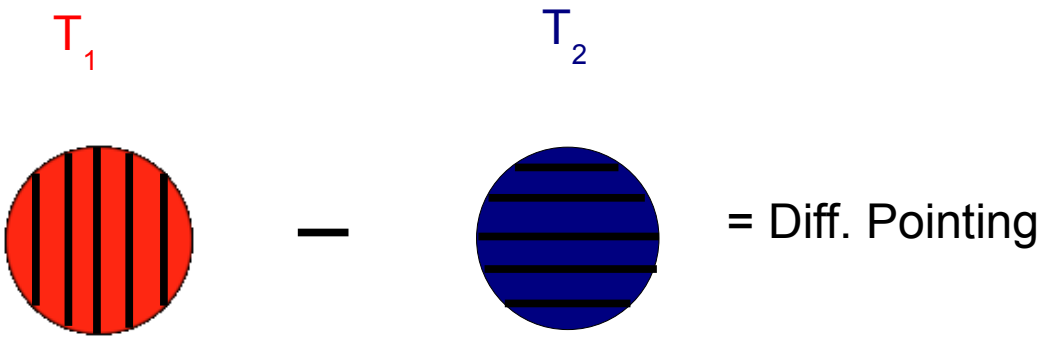
differential FWHM
(monopole effect)

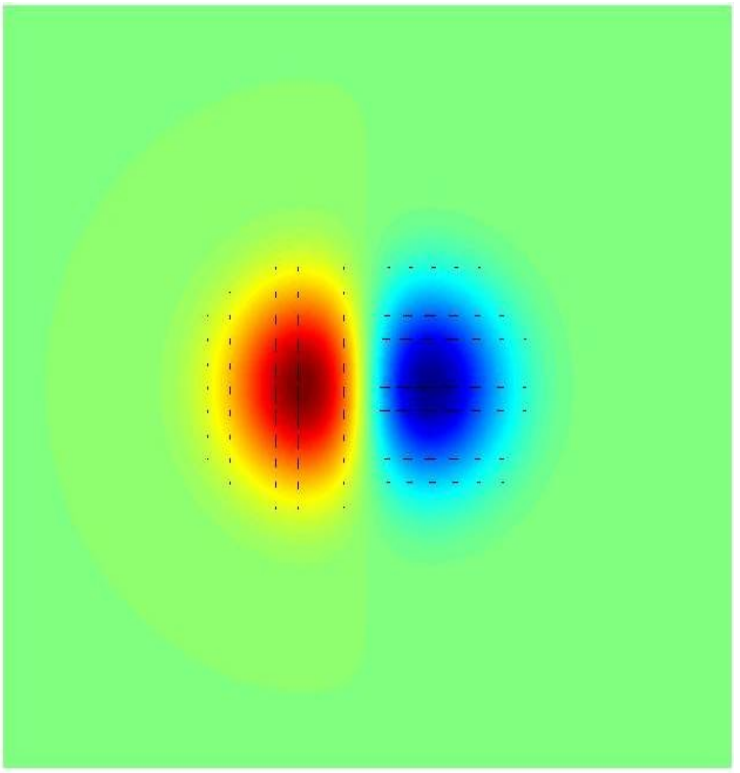
differential ellipticity
(quadrupole effect)

Irreducible

Now we will investigate how these systematic effects will affect the EB estimator

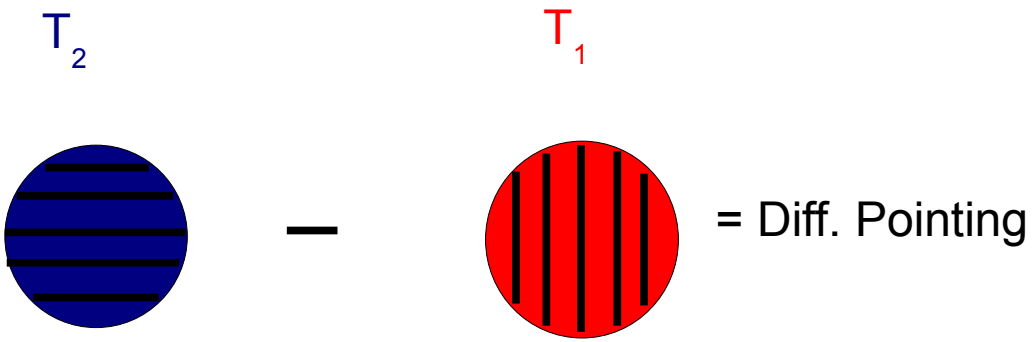
Reducible Beam Systematic Differential Pointing

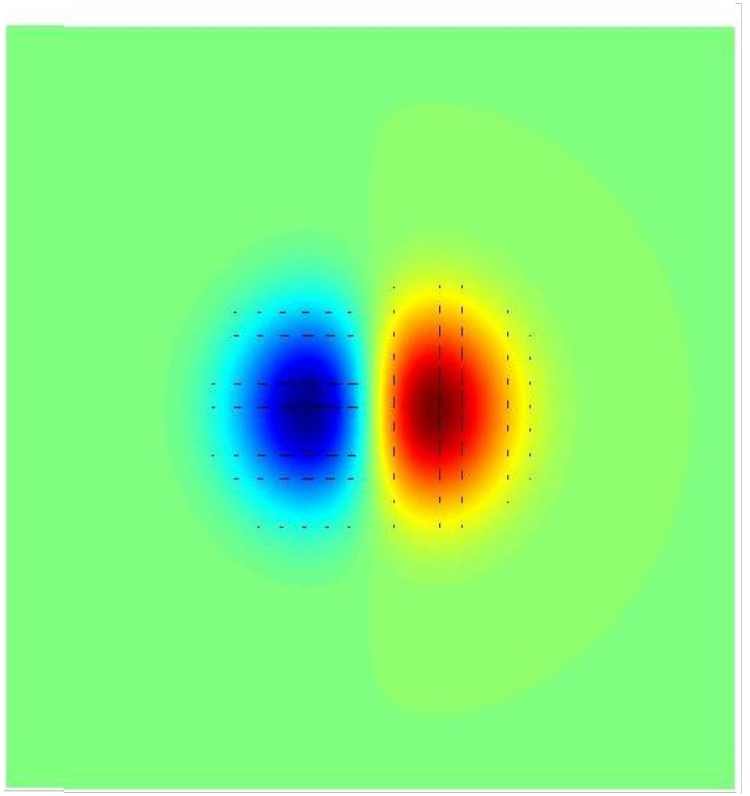




Reducible: Optimizing scan strategy will reduce systematic

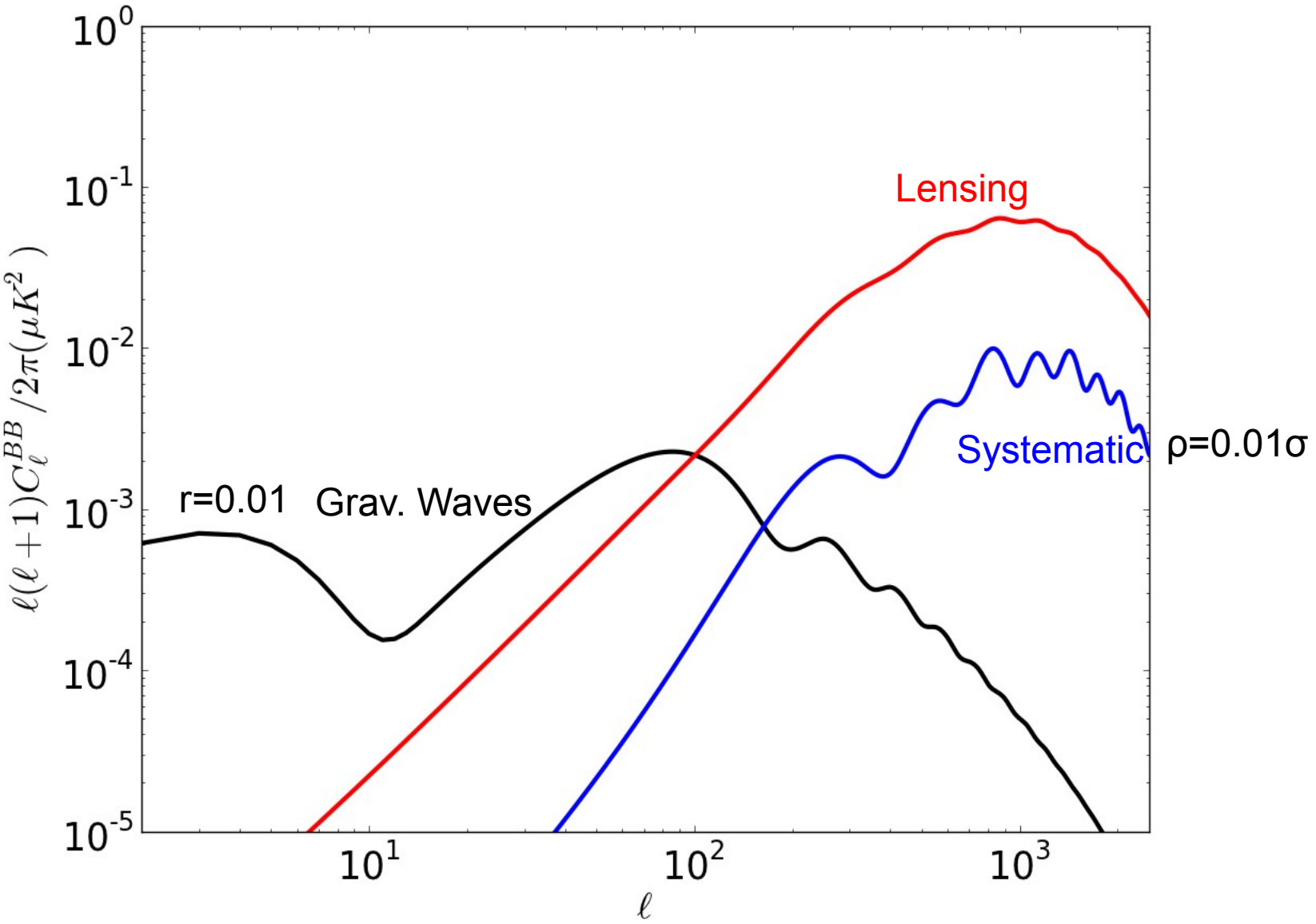
Reducible Beam Systematic: Differential Pointing





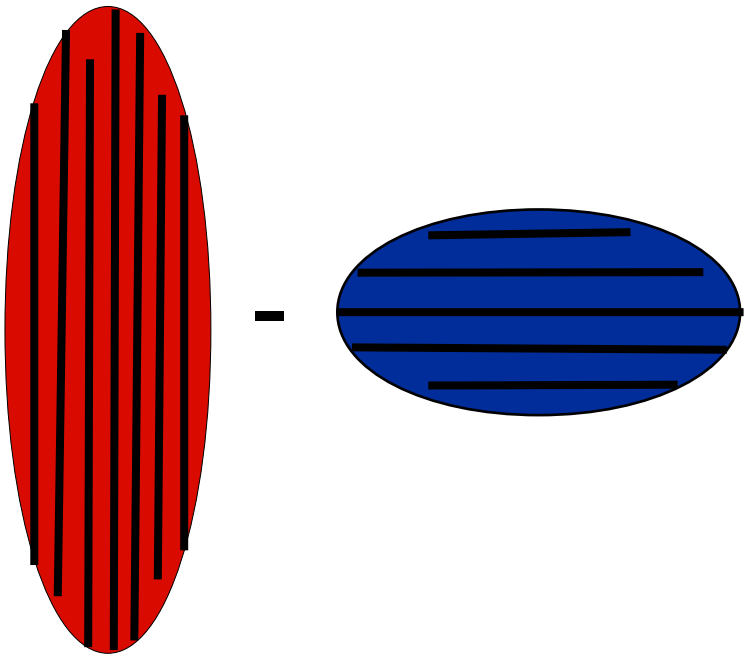
Reducible: Optimizing scan strategy will reduce systematic

B-mode Polarization Differential Pointing

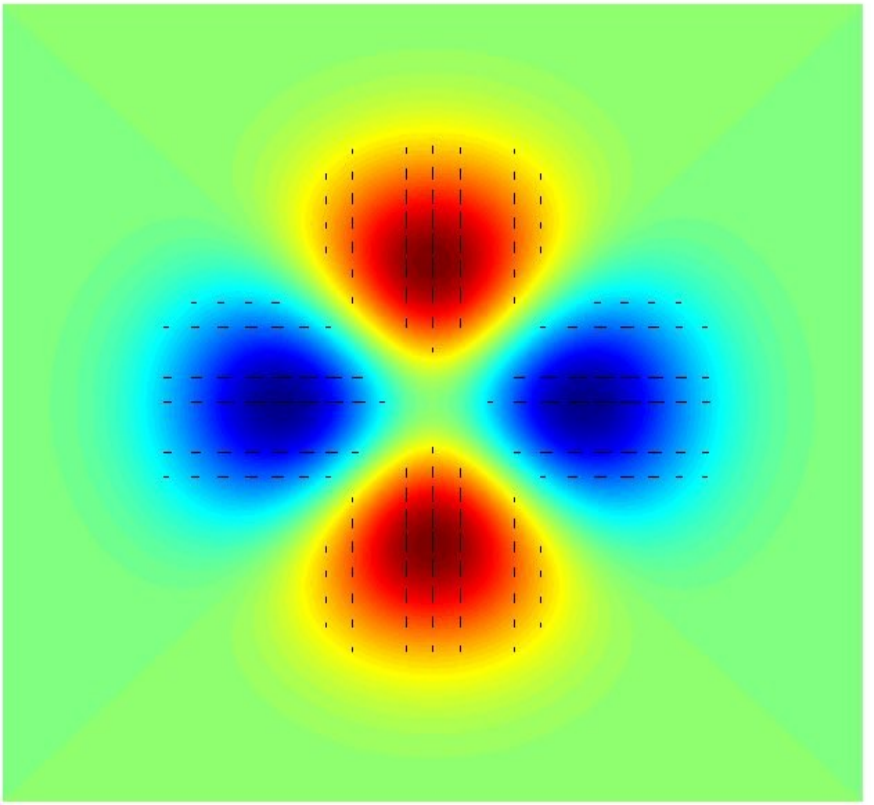


Irreducible Beam Systematic Differential Ellipticity

T_1 T_2

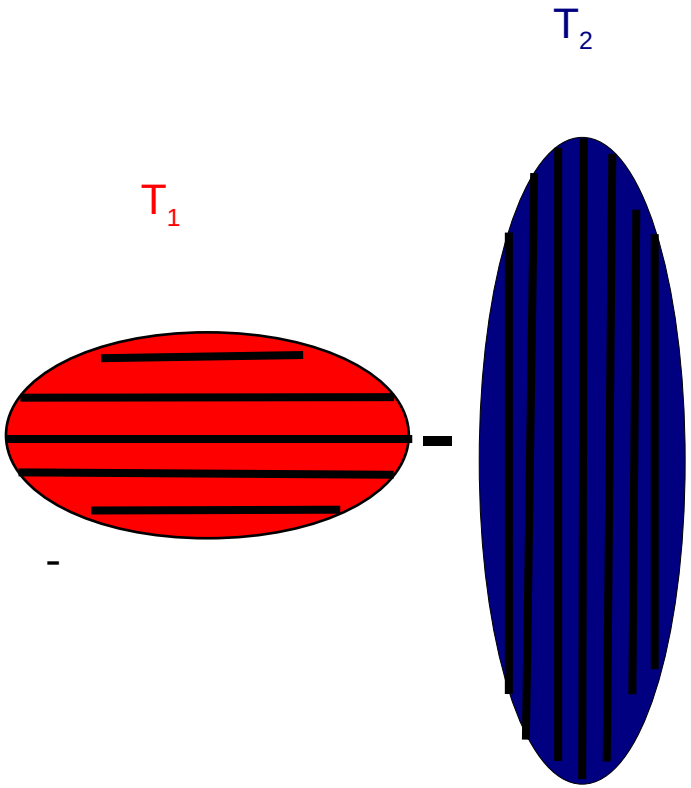


= Diff. Ellipticity

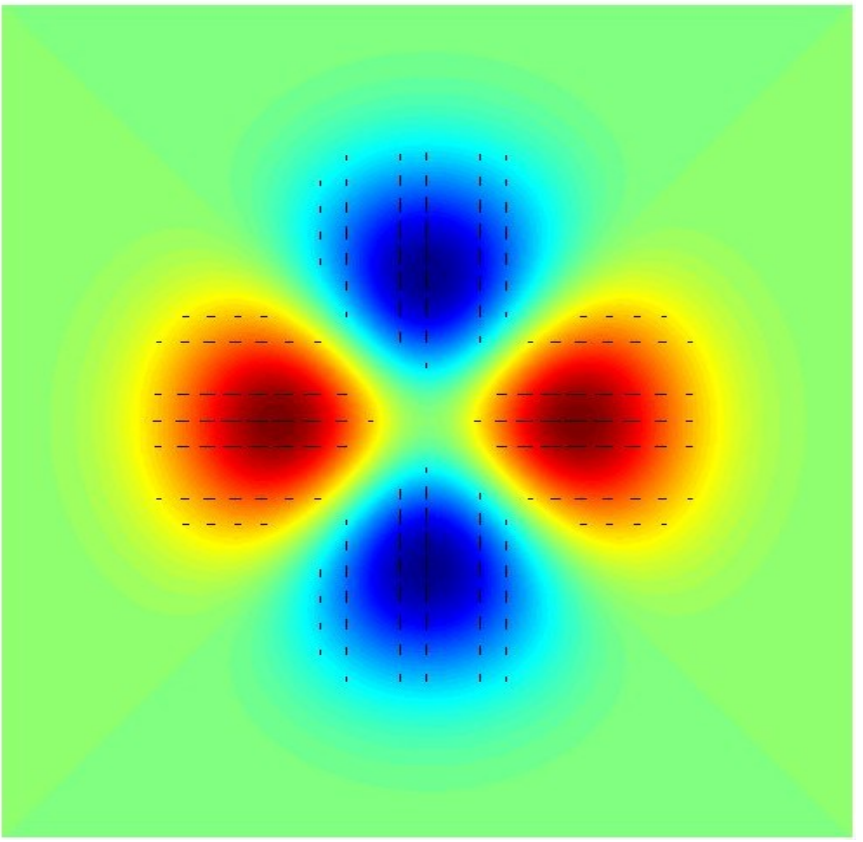


Irreducible: Optimizing scan strategy will NOT reduce systematic

Irreducible Beam Systematic Differential Ellipticity



= Diff. Ellipticity



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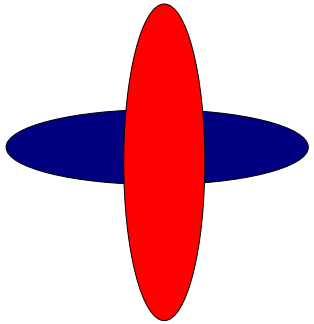
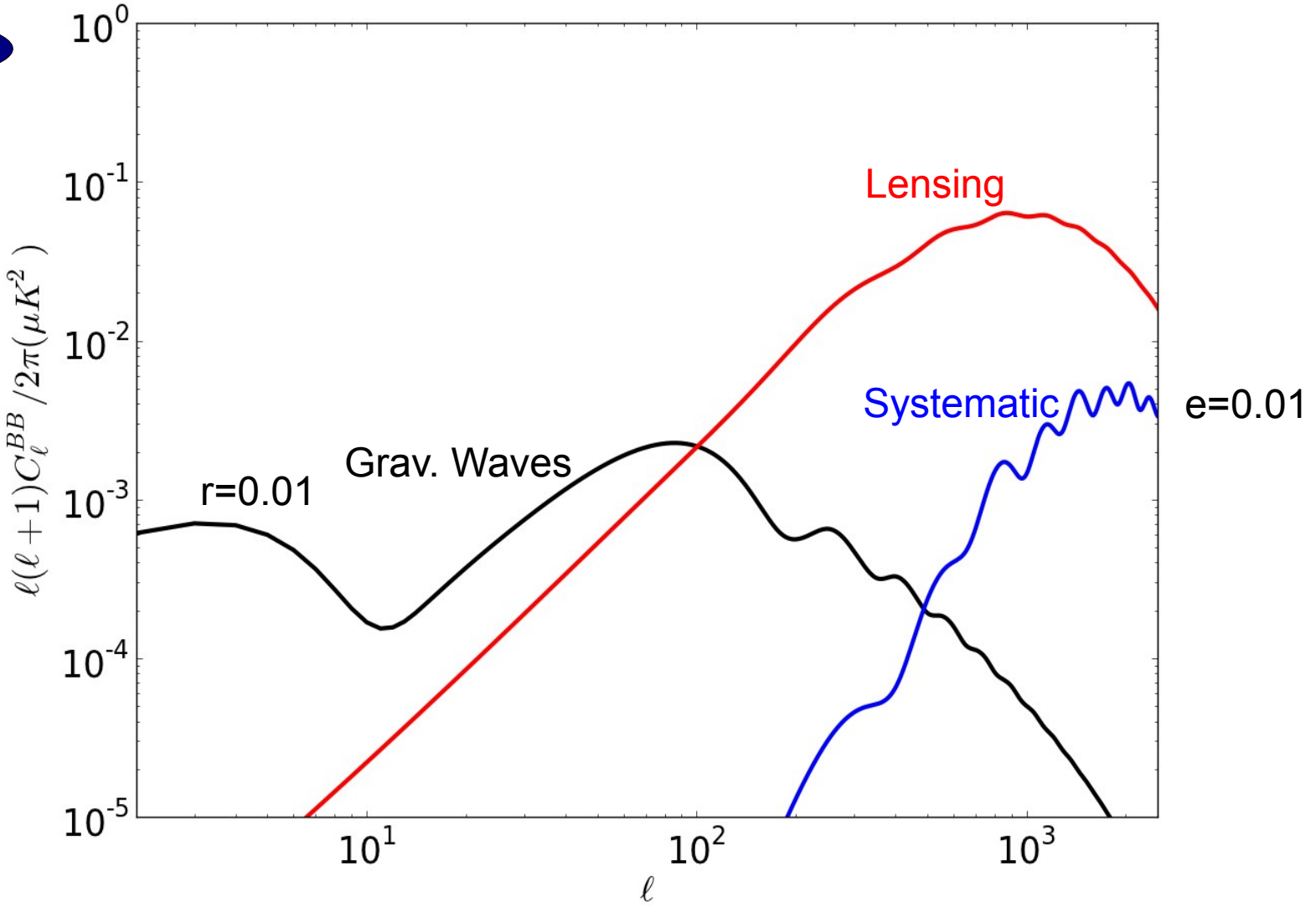
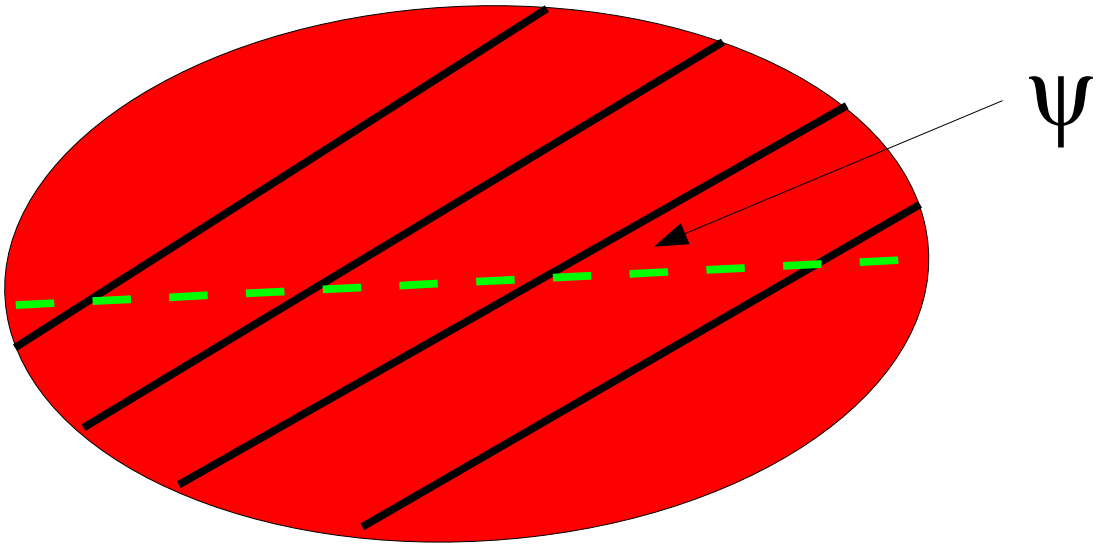
B-mode Polarization Differential Ellipticity



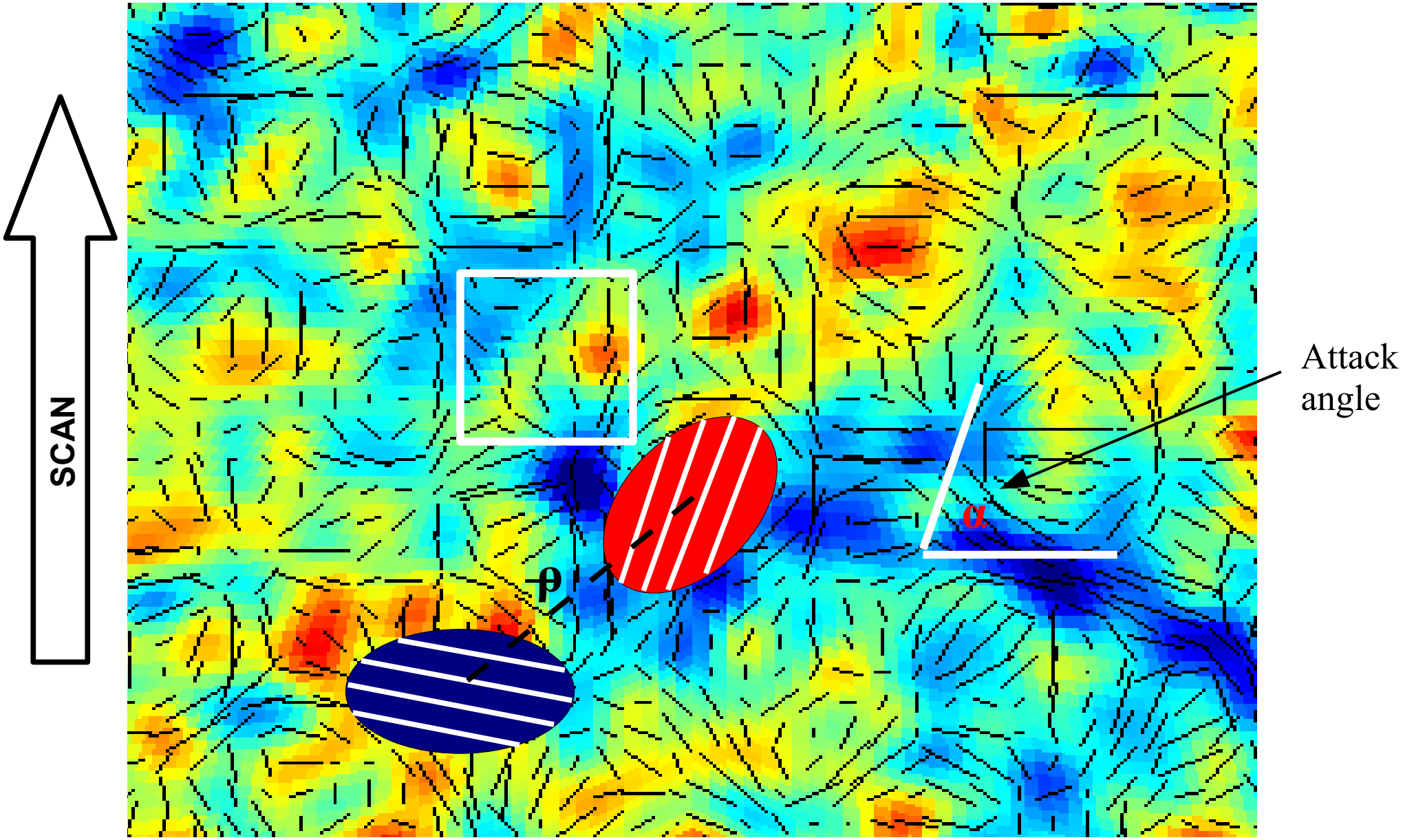


Imperfect Beams: Ellipticity

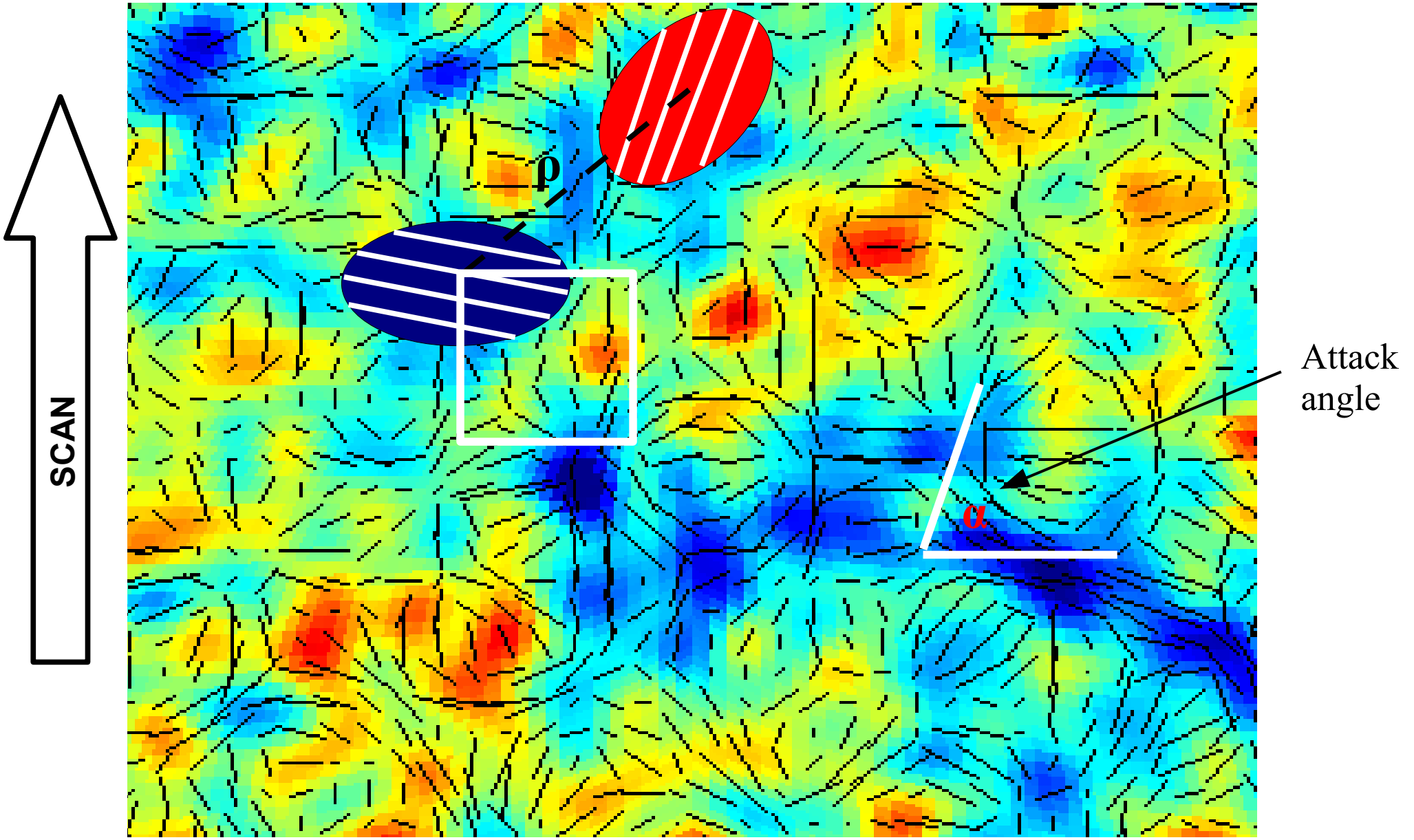


$$e = \frac{\sigma_x - \sigma_y}{\sigma_x + \sigma_y}$$

Imperfect Beams: A Theorist Builds a Bolometer



Imperfect Beams: A Theorist Builds a Bolometer



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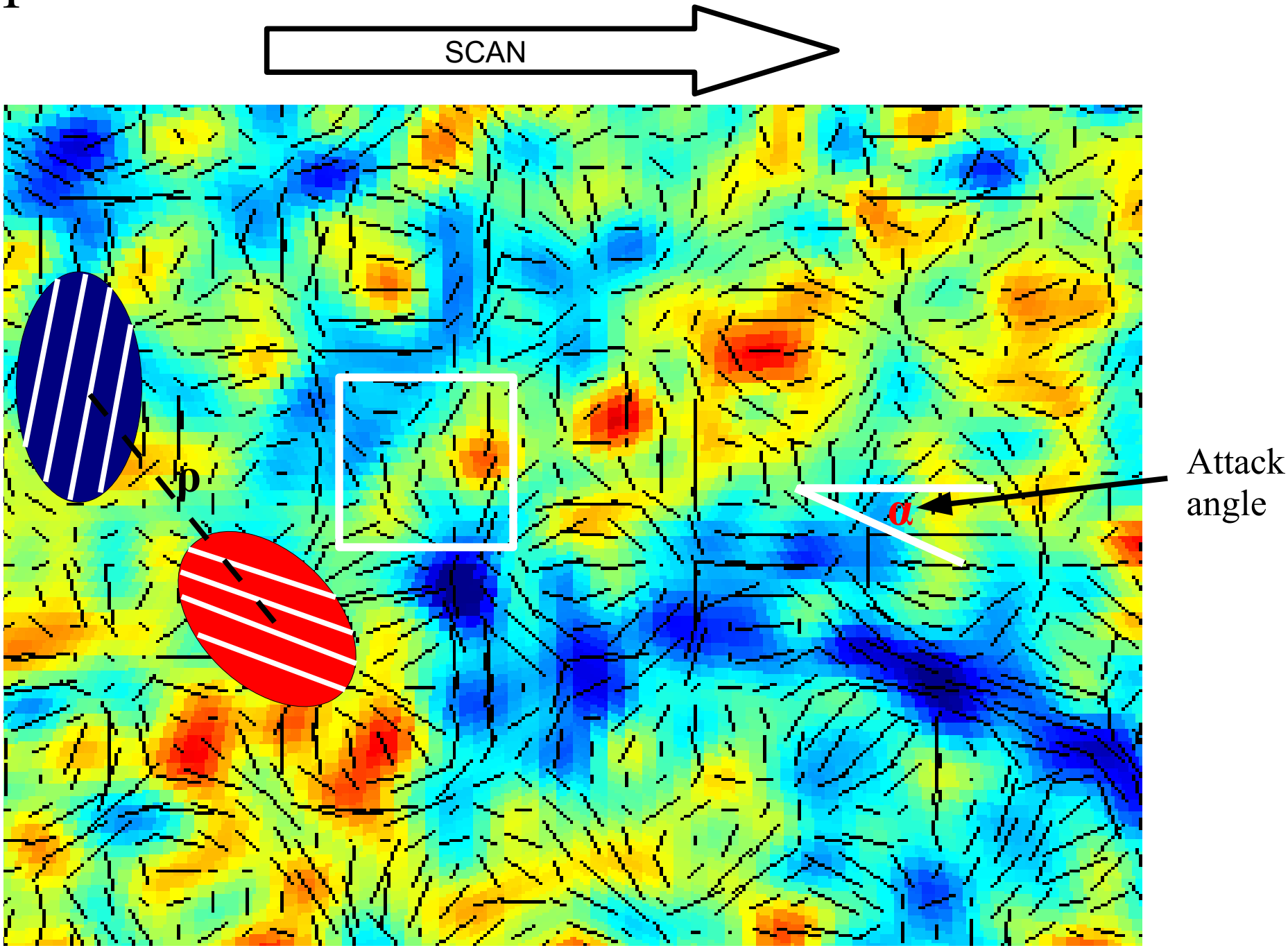

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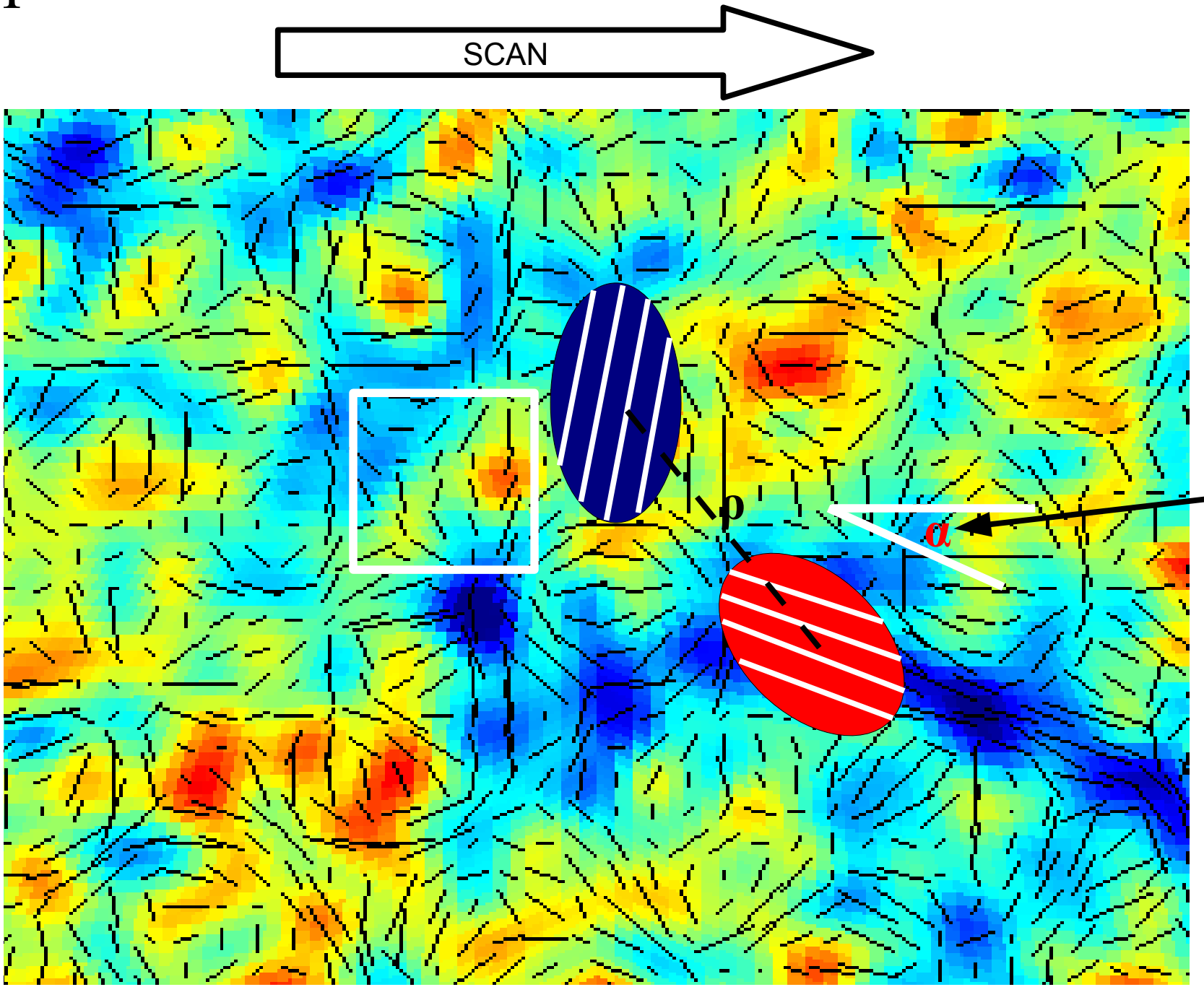


Scan Strategy Functions

Nearly ideal scanning

$$f_1 = \frac{1}{2}\left|\langle \exp(2i\alpha)\rangle\right|^2$$ "Quadrupole"

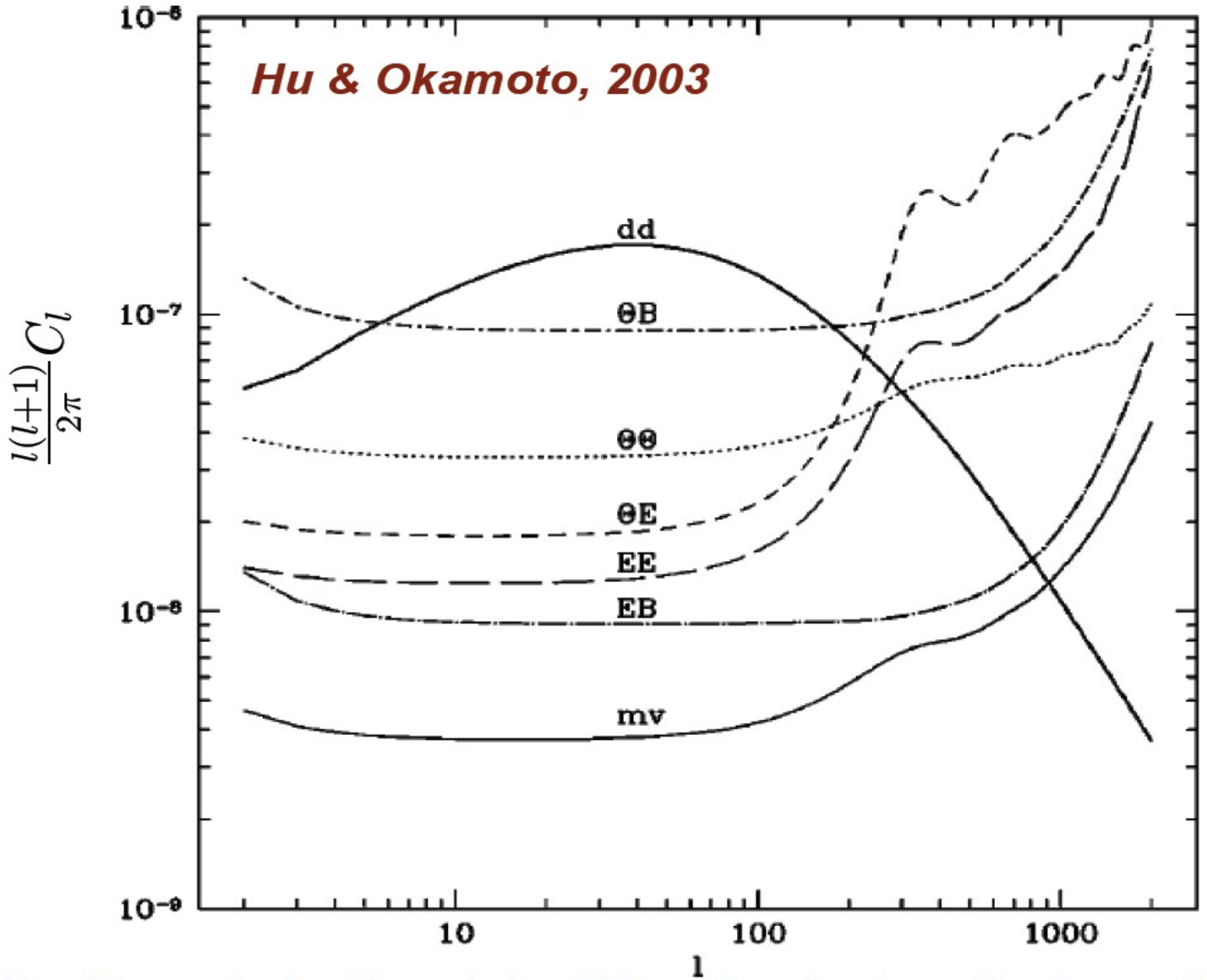
$$f_2 = \frac{1}{2}\left(\left|\langle \exp(i\alpha)\rangle\right|^2 + \left|\langle \exp(3i\alpha)\rangle\right|^2\right)$$ "Dipole"/"Octupole"

α: attack angle – angle between polarization sensitive direction of bolometer and a constant vector on the sky

Systematic Parameters

effect	parameter	definition
gain	g	$g_1 - g_2$
monopole	μ	$\frac{\sigma_1 - \sigma_2}{\sigma_1 + \sigma_2}$
dipole	ρ	$\rho_1 - \rho_2$
quadrupole	e	$\frac{\sigma_x - \sigma_y}{\sigma_x + \sigma_y}$
rotation	ε	$\frac{1}{2}(\varepsilon_1 + \varepsilon_2)$

Lensing Reconstruction



For the polarization data, EB estimator has the lowest noise

Systematic Power Spectra: E/B

effect	parameter	ΔC_l^E	ΔC_l^B
gain	g	$g^2 f_1 \star C_l^T$	$g^2 f_1 \star C_l^T$
monopole	μ	$4\mu^2 (l\sigma)^4 f_1 \star C_l^T$	$4\mu^2 (l\sigma)^4 f_1 \star C_l^T$
pointing	ρ	$c_\theta^2 C_l^T J_2^2(l\rho)$ $+J_1^2(l\rho) C_l^T \star f_2$	$s_\theta^2 C_l^T J_2^2(l\rho)$ $-J_1^2(l\rho) C_l^T \star f_2$
quadrupole	e	$I_1^2(z) c_\psi^2 C_l^T$	$I_1^2(z) s_\psi^2 C_l^T$
rotation	ε	$4\varepsilon^2 C_l^B$	$4\varepsilon^2 C_l^E$

$$z = \ell^2 \sigma^2 e$$

For ellipticity: $c_\psi = cos(2\psi)$ $s_\psi = sin(2\psi)$

I(z) = modified Bessel function

Systematic Power Spectra: EB

effect	parameter	ΔC_l^{EB}
gain	g	0
monopole	μ	0
pointing	ρ	$s_\theta c_\theta J_2^2(l\rho) C_l^T$
quadrupole	e	$I_1^2(z) s_\psi c_\psi C_l^T$
rotation	ε	$2\varepsilon C_l^E$

$$z = \ell^2 \sigma^2 e$$

For ellipticity: $c_\psi = cos(2\psi)$

$s_\psi = sin(2\psi)$

I(z) = modified Bessel function

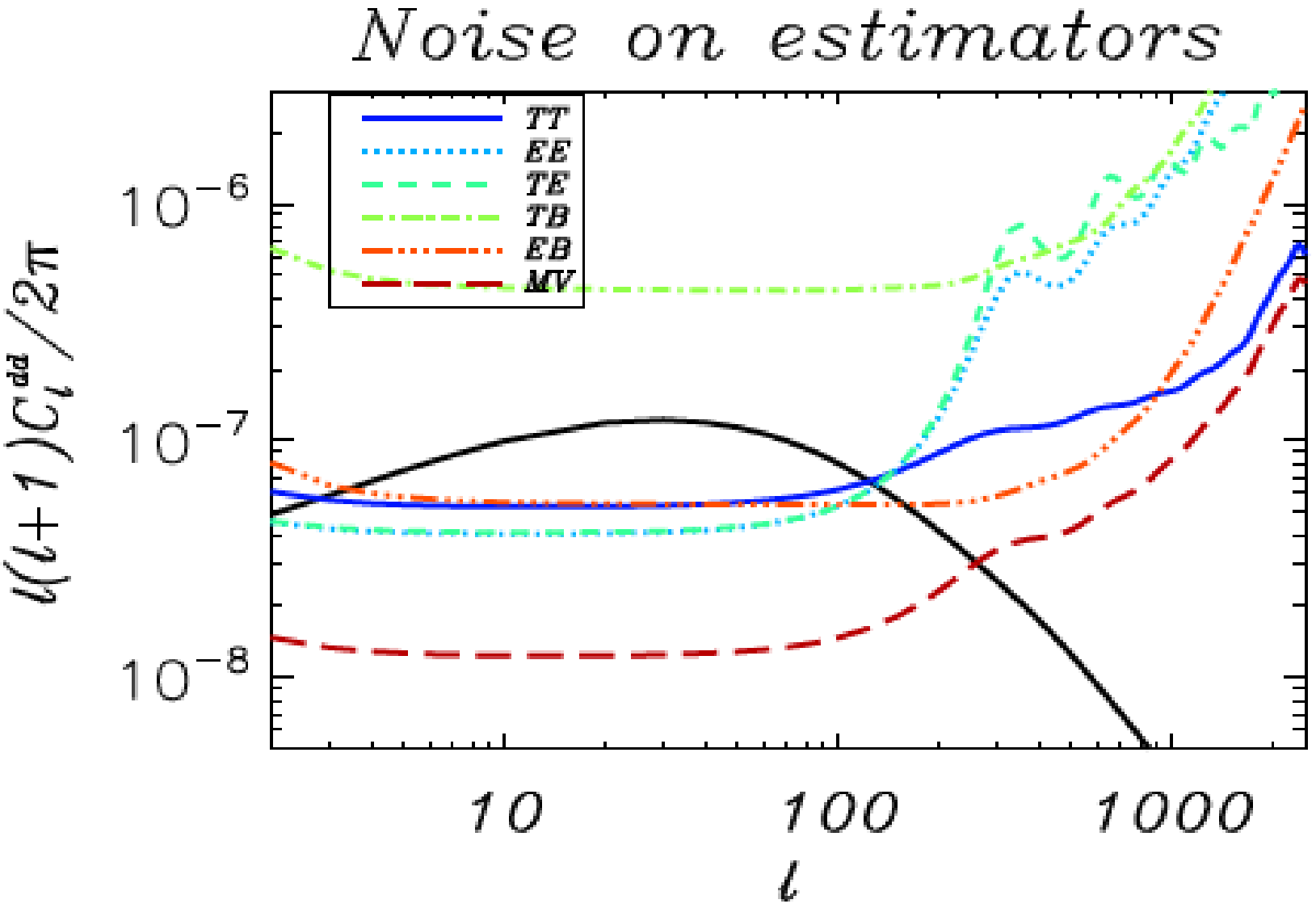
Effect of Scan Strategy on Systematics

- Differential gain and beamwidth couple to the "quadrupole" of the scan strategy
- Differential pointing couples to the "dipole" and "octupole" of the scan strategy
- If we remove the "dipole", "quadrupole", and "octupole" from the scan strategy, then we remove the effects of differential gain, beamwidth, and pointing
- Differential ellipticity and rotation are irreducible, therefore the scan strategy has no effect on systematics
- If we are given a scan strategy, we can construct the f functions

Experiments

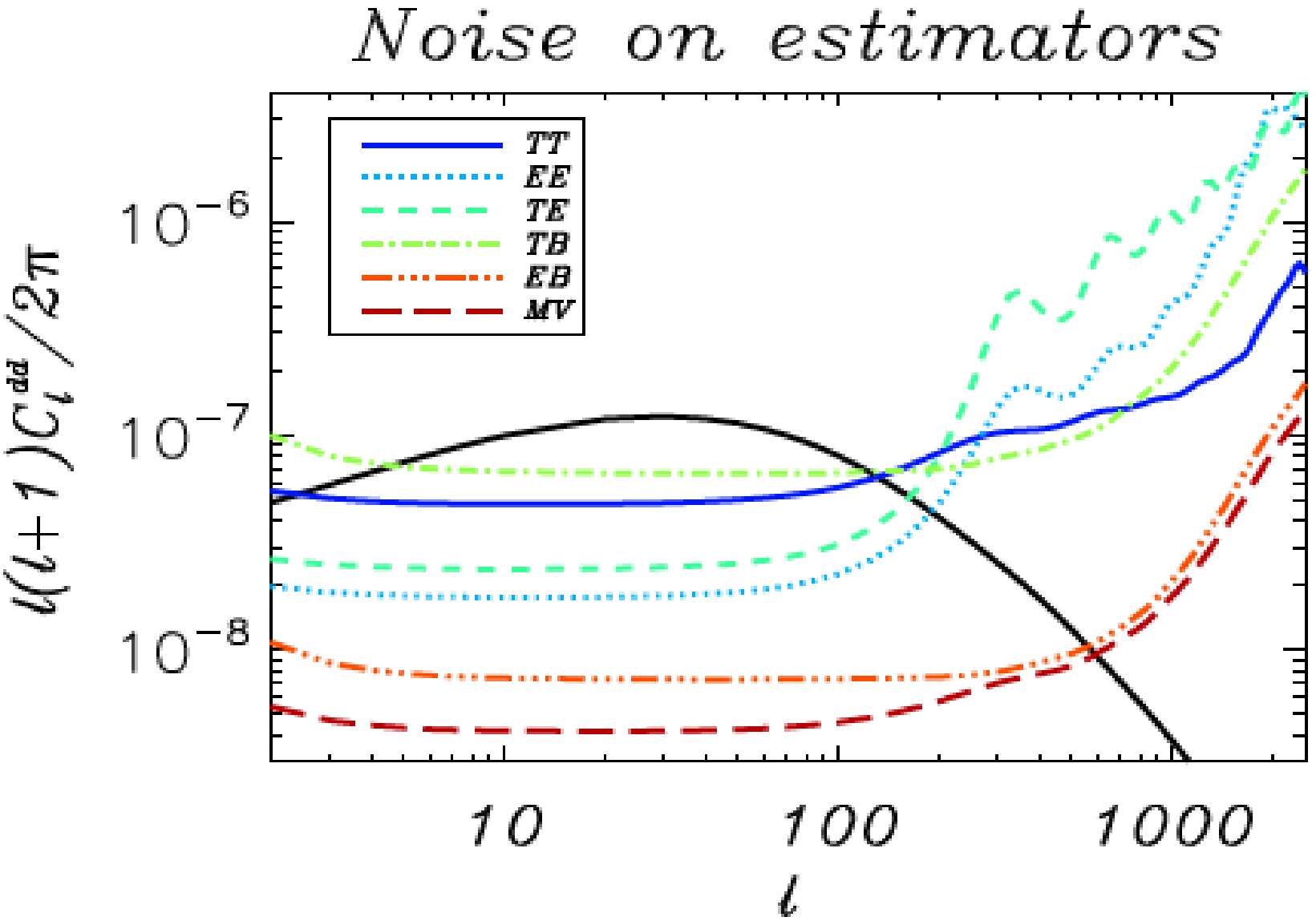
	f_{sky}	ν (GHz)	θ_b	$\Delta_T(\mu K)$	$\Delta_E(\mu K)$
Current Reference Experiment	0.03	90	$6.7'$	1.13	1.6
		150	$4'$	1.70	2.4
		220	$2.7'$	8.0	11.3
CMBPol	0.65	150	$5'$	0.22	0.32

Lensing Reconstruction Current Experiment

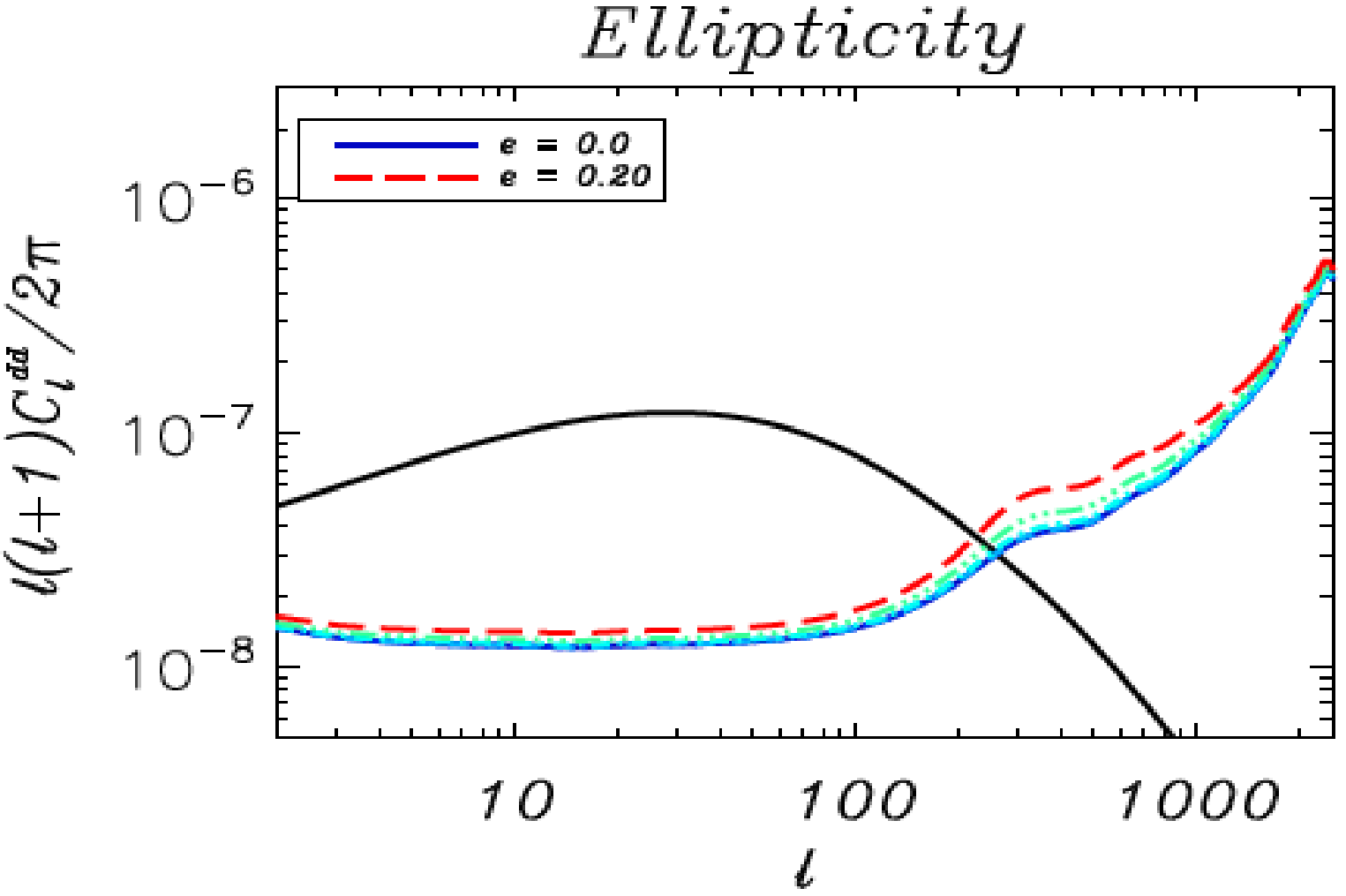


Lensing Reconstruction

CMBPol

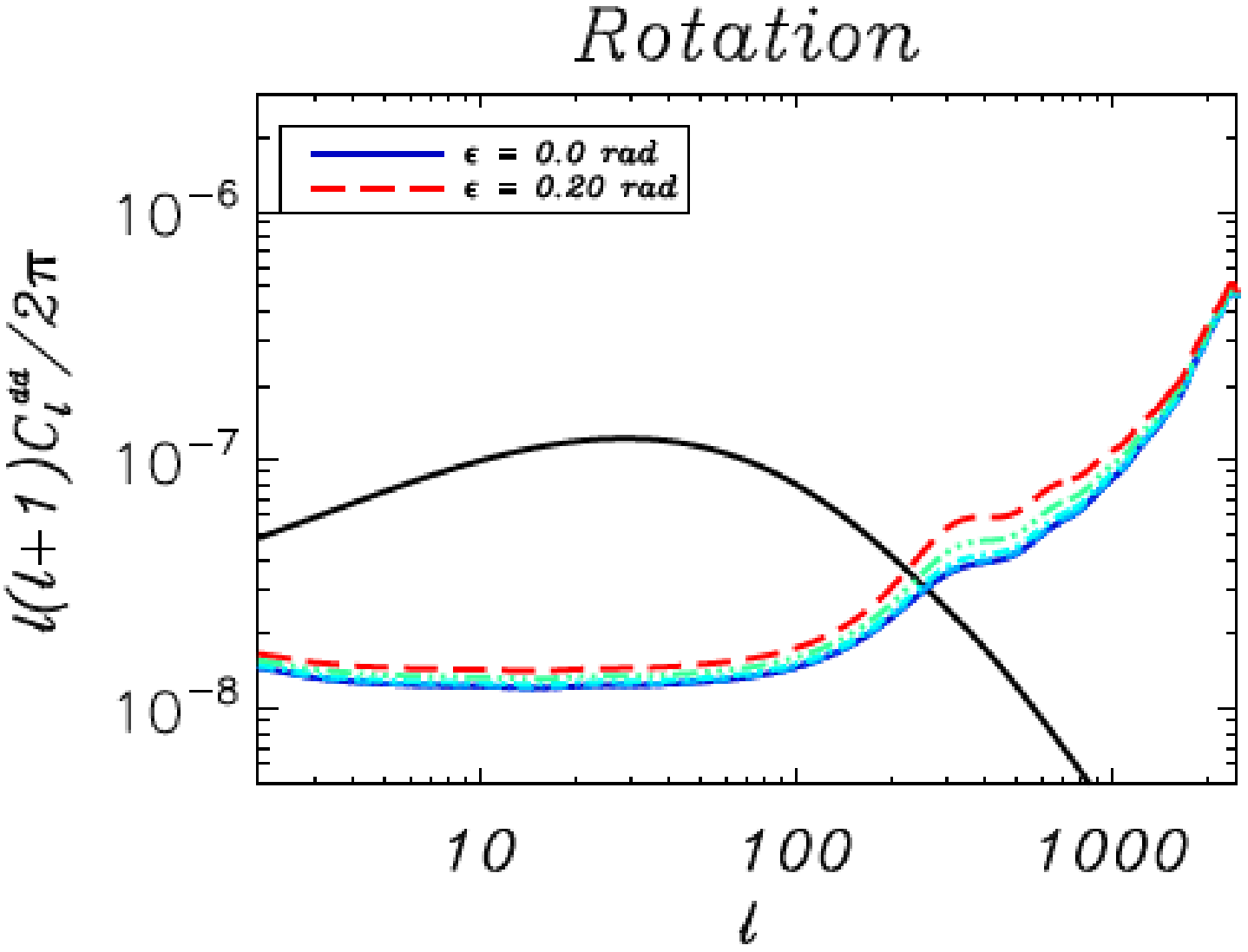


Lensing Reconstruction With Systematics
Current Experiment



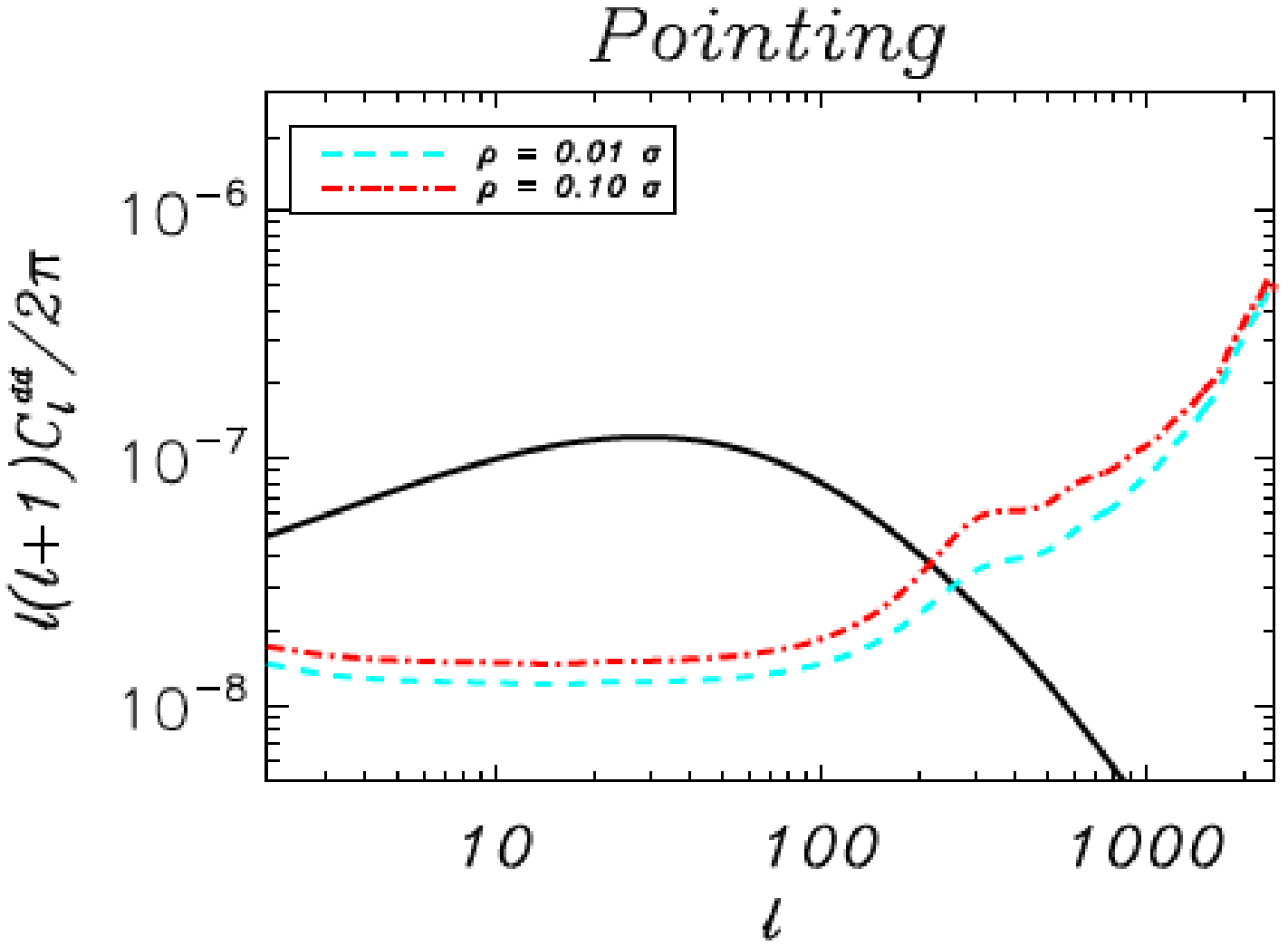
e = 0.0, 0.01, 0.02, 0.05, 0.10, 0.20

Lensing Reconstruction: Rotation



ε = 0.0, 0.01, 0.02, 0.05, 0.10, 0.20 radian

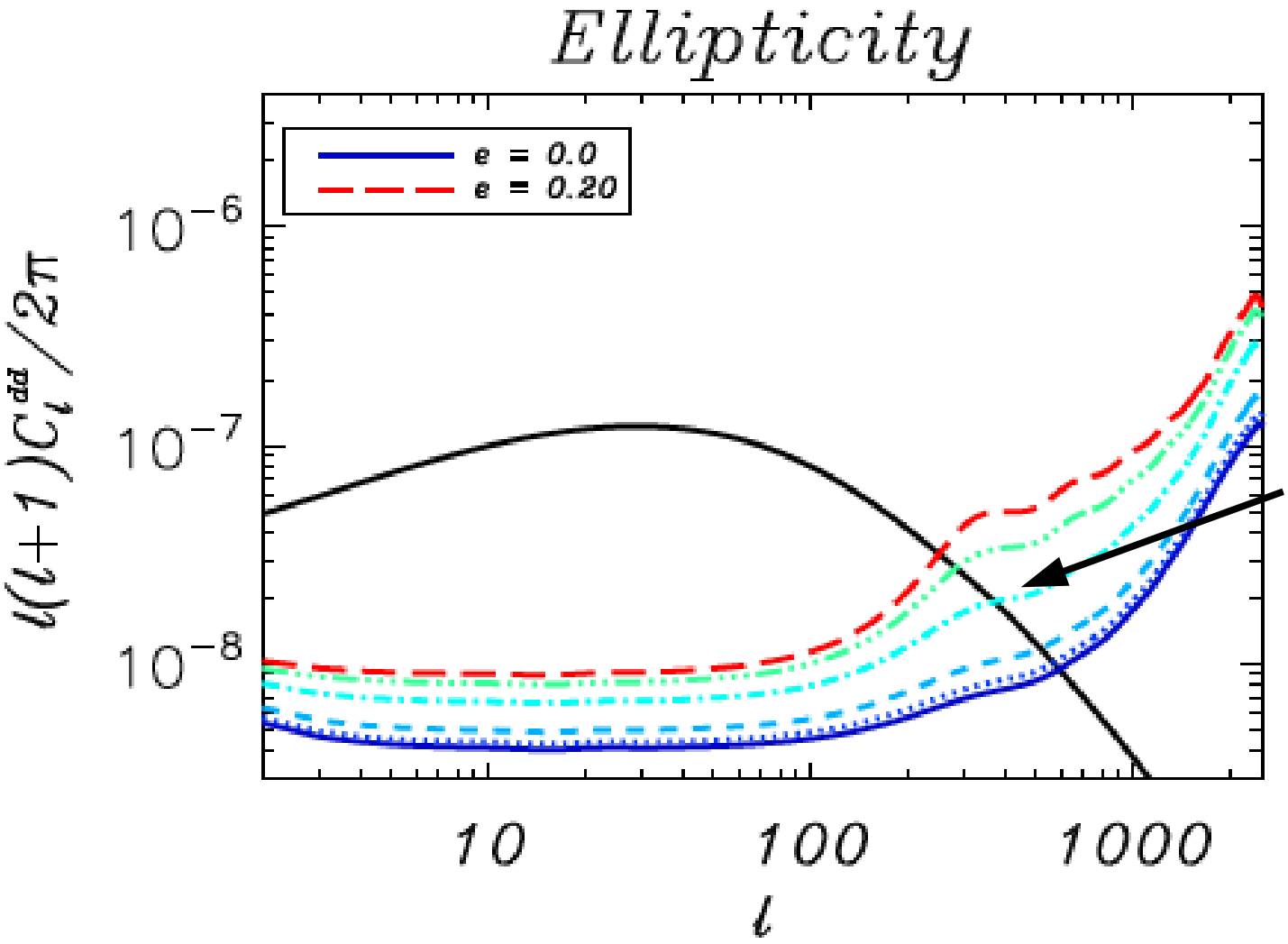
Lensing Reconstruction: Pointing



ρ = 0.01σ, 0.10σ

Lensing Reconstruction With Systematics

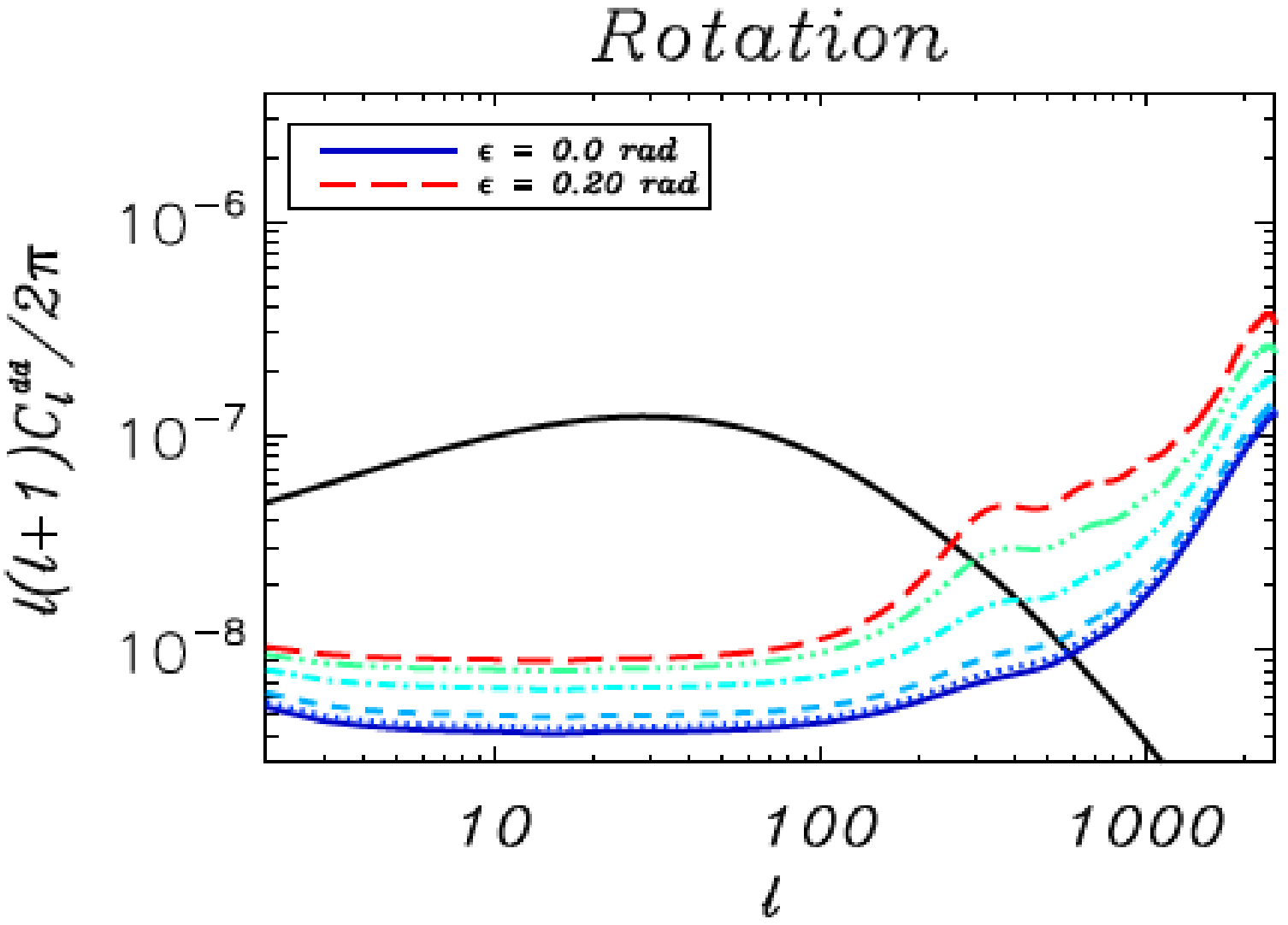
CMBPol



We care about this part of the power spectrum for lensing parameters

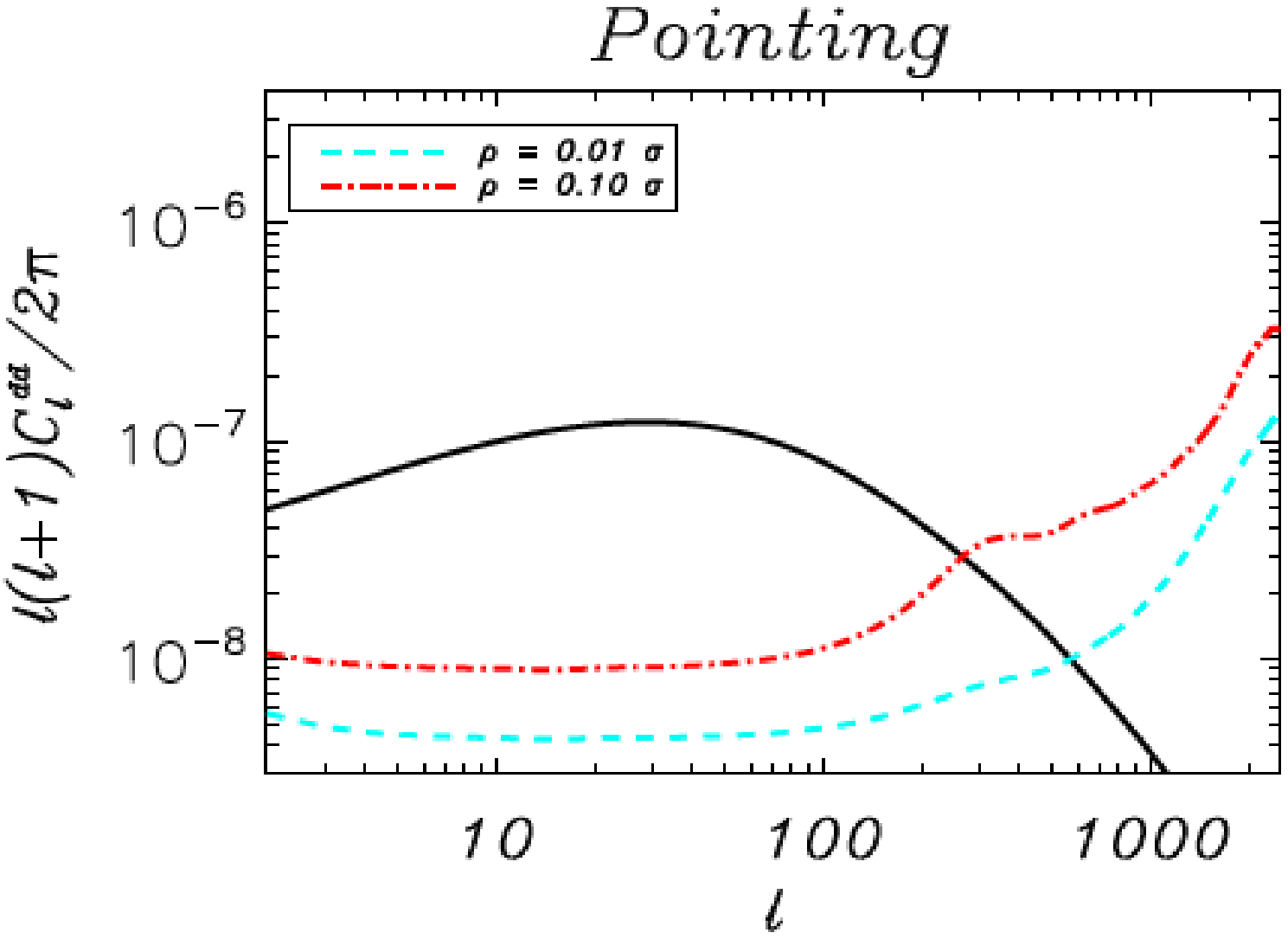
e = 0.0, 0.01, 0.02, 0.05, 0.10, 0.20

Lensing Reconstruction: Pointing



e = 0.0, 0.01, 0.02, 0.05, 0.10, 0.20 radian

Lensing Reconstruction: Pointing



ρ = 0.01σ, 0.10σ

Conclusions

- Beam systematics will lead to spurious polarization and power spectra.
- This will affect the reconstruction of the lensing potential.
- Future experiments will be very susceptible to the effect of beam systematics.
- We need to put a lot of work into limiting beam systematics for future experiments.
- For non-polar sites, we can get very good coverage with just sky rotation.