PICO systematics: angles, beams, …

E. Hivon

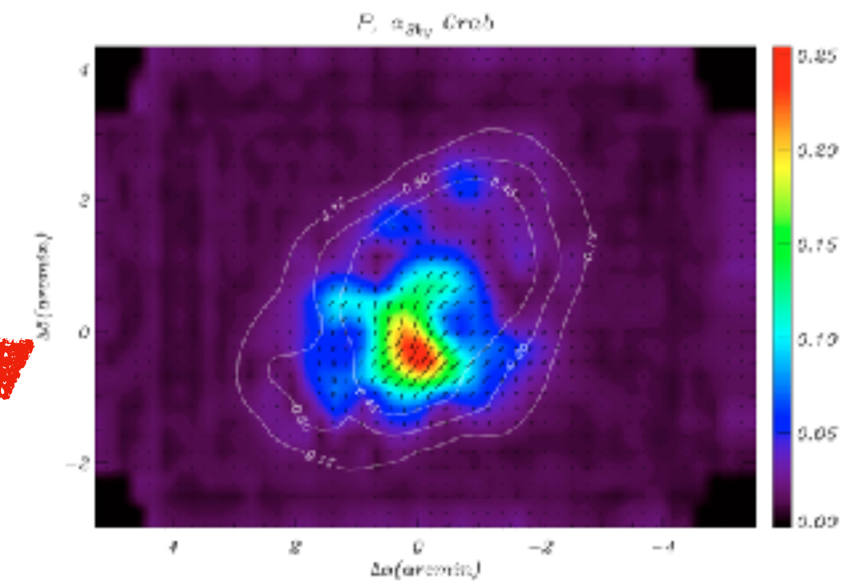
Institut d'Astrophysique de Paris

Polarisation rotation

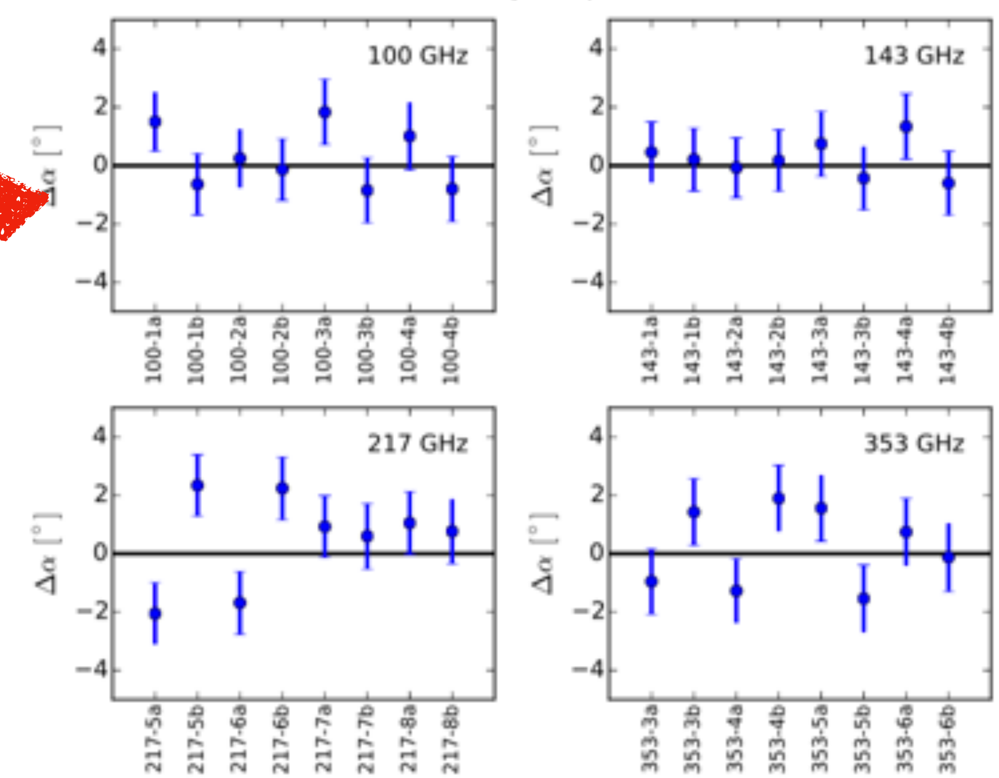
- $(Q \pm i\, U) \to (Q \pm i\, U)\ e^{\mp 2i\alpha}$
  - ✦ Can be on the sky (birefringence: different refractive index for 2 states of polarisation), see L. Pogosian talk
    - interaction with dust foreground (ν-dependent),
    - Faraday rotation due to magnetic field (ν-dependent),
    - interaction with pseudo-scalar field
    - ‣ α *may* depend on position, scale, frequency,…
  - ✦ Can be created by the instrument:
    - ‣ undetected rotation of the polarimeters (individual + global rotation)
      - relative rotation: measured to a few 0.1 arcmin on CMB ?
      - α may depend on frequency, but not on position nor scale

Possible angle calibrations

- Ground measurements
  - Planck:
    systematic error: ±0.9° (rel) ±0.3° (abs)
    Rosset++ 2010

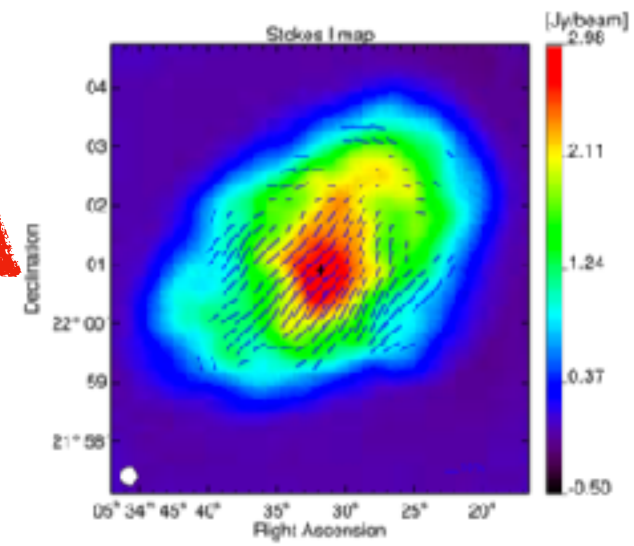


- Sky sources: Crab Nebula (Tau A) ?
  - measured with IRAM @ 89GHz
    (Aumont++ 2010)
  - Crab Nebula was used by Planck
    (Planck VIII 2016)



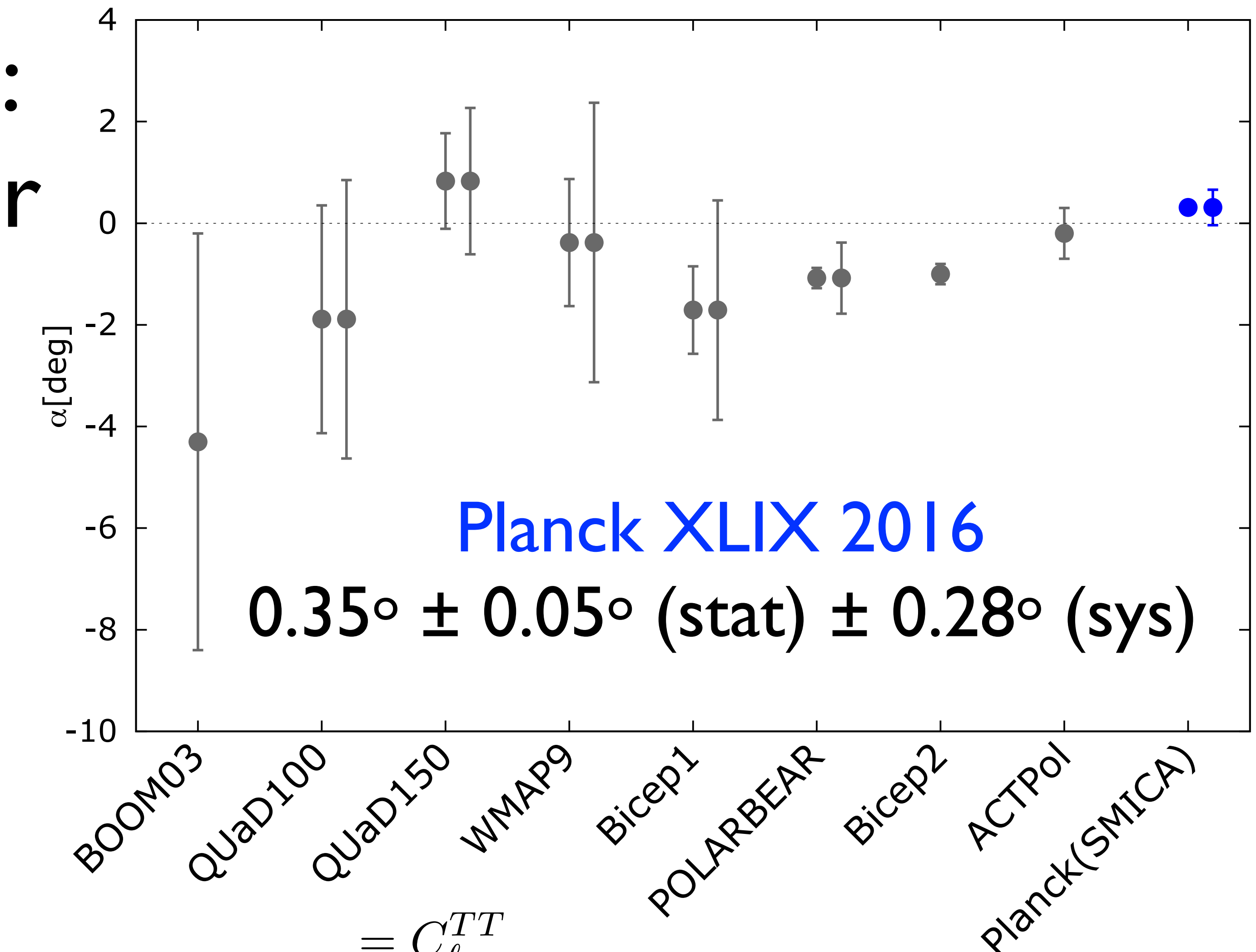
NEW!

  - measured with NIKA/IRAM @ 150GHz
    (Ritacco++ 2018)



Current constraints on cosmic birefringence (CB)

- limited by systematics: knowledge of detector orientation



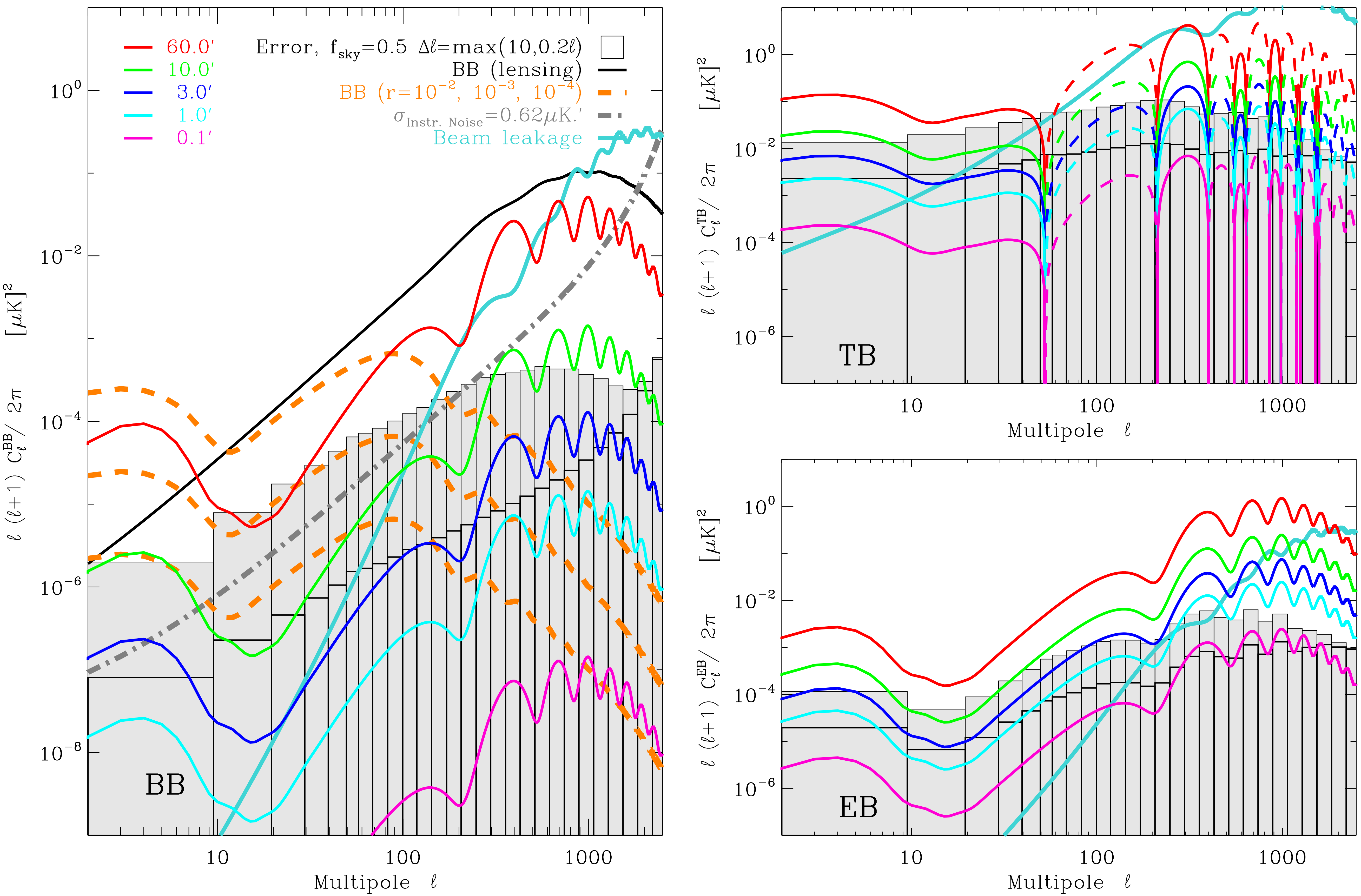
$$
\begin{aligned}
C_\ell^{TT} &\longrightarrow C_\ell^{TT} && = C_\ell^{TT} \\
C_\ell^{TE} &\longrightarrow \cos 2\psi\ C_\ell^{TE} && \sim \left(1 - 2\psi^2\right)\ C_\ell^{TE} \\
C_\ell^{EE} &\longrightarrow \cos^2 2\psi\ C_\ell^{EE} + \sin^2 2\psi\ C_\ell^{BB} && \sim C_\ell^{EE} - 4\psi^2\ \left(C_\ell^{EE} - C_\ell^{BB}\right) \\
C_\ell^{BB} &\longrightarrow \sin^2 2\psi\ C_\ell^{EE} + \cos^2 2\psi\ C_\ell^{BB} && \sim C_\ell^{BB} + 4\psi^2\ \left(C_\ell^{EE} - C_\ell^{BB}\right) \\
C_\ell^{TB} &\longrightarrow \sin 2\psi\ C_\ell^{TE} && \sim 2\psi\ C_\ell^{TE} \\
C_\ell^{EB} &\longrightarrow \sin 2\psi \cos 2\psi \left(C_\ell^{EE} - C_\ell^{BB}\right) && \sim 2\psi\ \left(C_\ell^{EE} - C_\ell^{BB}\right)
\end{aligned}
$$

Rotation affects *BB* and therefore *r*

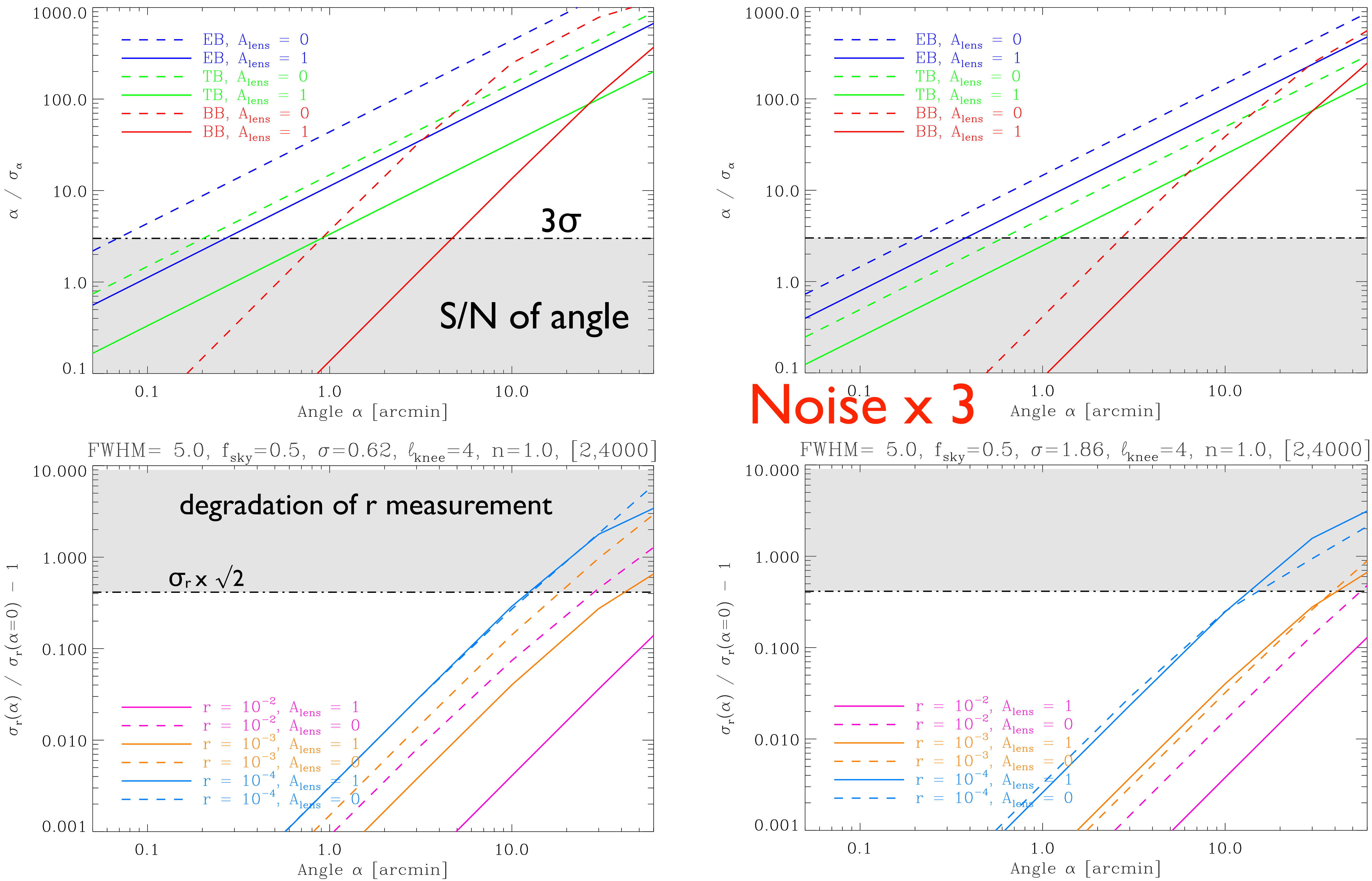
TB and *EB* can monitor the rotation

Hypotheses

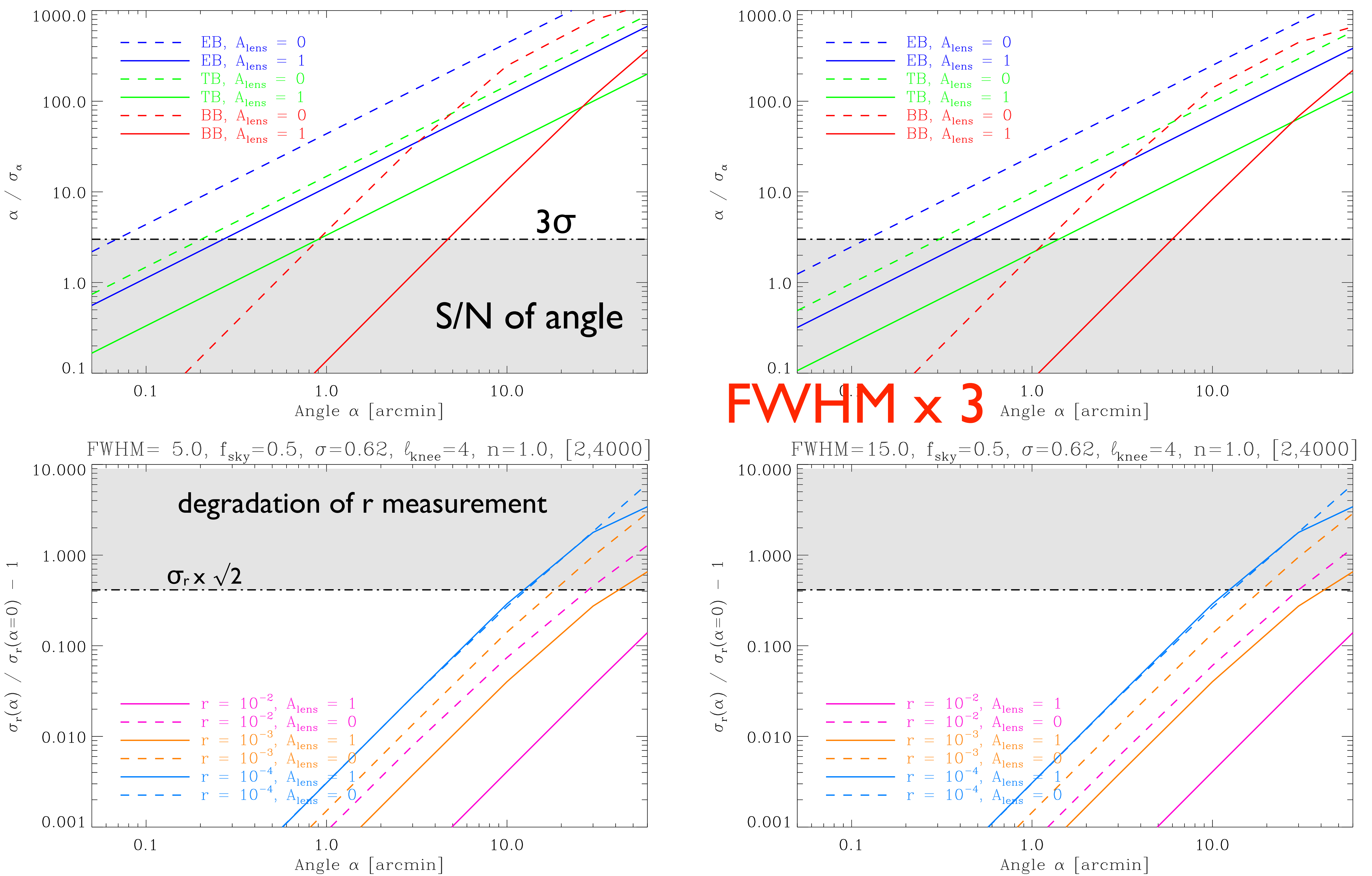
- Planck based $C(\ell)$
  - $\tau = 0.078$
- Instrument:
  - Beam FWHM = 5'
  - Noise $N(\ell) = N_0\ (\ell + (\ell_{knee}/\ell)^n)$
    - 0.62μK.arcmin on CMB Q and U
    - $\ell_{knee} = 4$, n=1, based on CORE studies
  - $f_{sky} = 0.5$, no residual foreground
- Perfect delensing



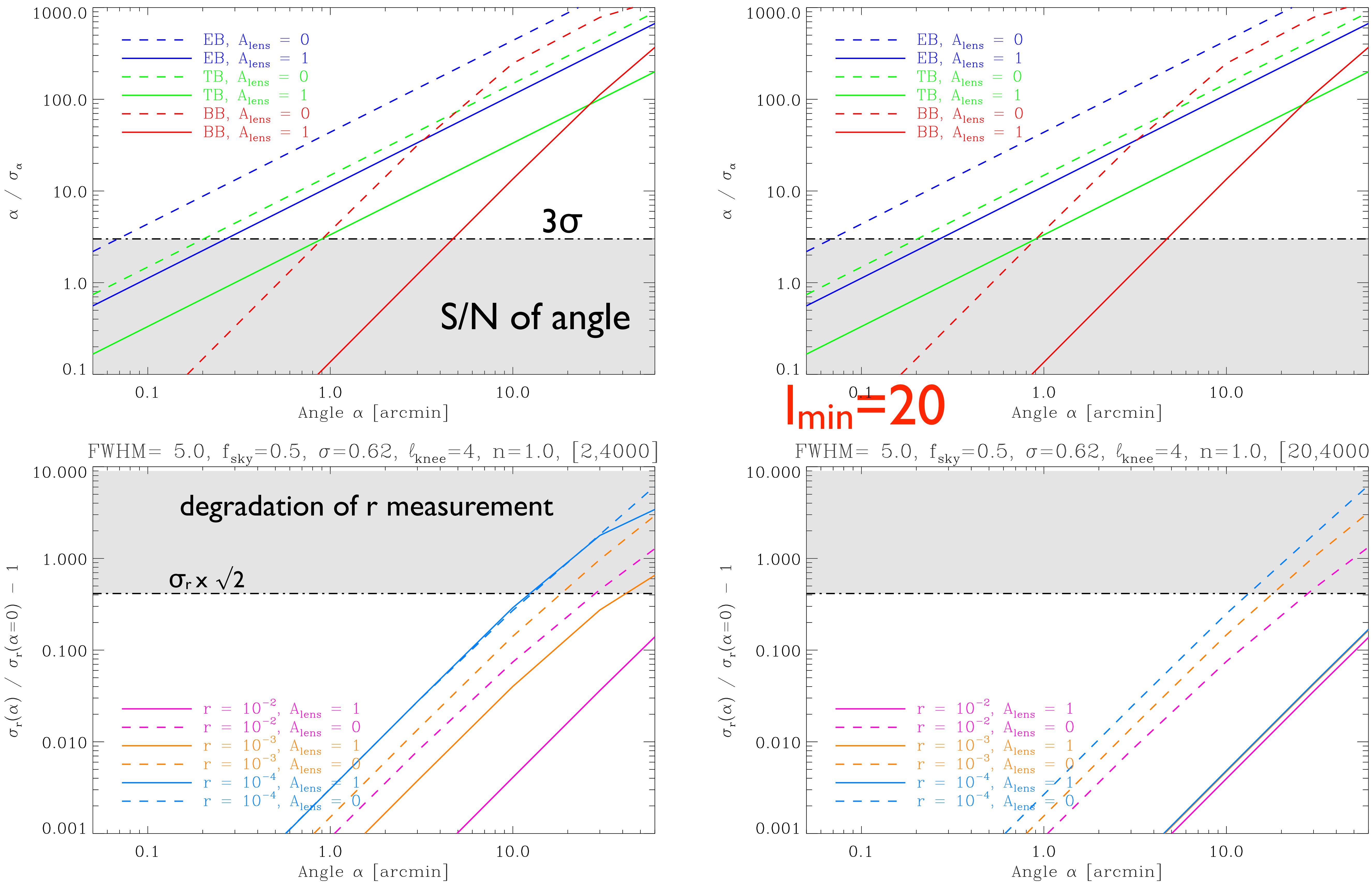
60.0′
10.0′
3.0′
1.0′
0.1′
Error, f_{sky}=0.5 $\Delta\ell$=max(10,0.2ℓ)
BB (lensing)
BB (r=10^{-2}, 10^{-3}, 10^{-4})
$\sigma_{\rm Instr.\ Noise}$=0.62$\mu$K.′
Beam leakage
BB
TB
EB
$\ell\ (\ell+1)\ C_\ell^{BB}/\ 2\pi\ \ [\mu K]^2$
$\ell\ (\ell+1)\ C_\ell^{TB}/\ 2\pi\ \ [\mu K]^2$
$\ell\ (\ell+1)\ C_\ell^{EB}/\ 2\pi\ \ [\mu K]^2$
Multipole ℓ



EB, A_lens = 0
EB, A_lens = 1
TB, A_lens = 0
TB, A_lens = 1
BB, A_lens = 0
BB, A_lens = 1
3σ
S/N of angle
α / σ_α
Angle α [arcmin]
Noise x 3
FWHM= 5.0, f_sky=0.5, σ=0.62, ℓ_knee=4, n=1.0, [2,4000]
FWHM= 5.0, f_sky=0.5, σ=1.86, ℓ_knee=4, n=1.0, [2,4000]
degradation of r measurement
σ_r x √2
σ_r(α) / σ_r(α=0) − 1
r = 10^-2, A_lens = 1
r = 10^-2, A_lens = 0
r = 10^-3, A_lens = 1
r = 10^-3, A_lens = 0
r = 10^-4, A_lens = 1
r = 10^-4, A_lens = 0



EB, A_lens = 0
EB, A_lens = 1
TB, A_lens = 0
TB, A_lens = 1
BB, A_lens = 0
BB, A_lens = 1
α / σ_α
3σ
S/N of angle
Angle α [arcmin]
FWHM x 3
FWHM= 5.0, f_sky=0.5, σ=0.62, ℓ_knee=4, n=1.0, [2,4000]
FWHM=15.0, f_sky=0.5, σ=0.62, ℓ_knee=4, n=1.0, [2,4000]
degradation of r measurement
σ_r x √2
σ_r(α) / σ_r(α=0) − 1
r = 10^-2, A_lens = 1
r = 10^-2, A_lens = 0
r = 10^-3, A_lens = 1
r = 10^-3, A_lens = 0
r = 10^-4, A_lens = 1
r = 10^-4, A_lens = 0



EB, A_lens = 0
EB, A_lens = 1
TB, A_lens = 0
TB, A_lens = 1
BB, A_lens = 0
BB, A_lens = 1
3σ
S/N of angle
α / σ_α
Angle α [arcmin]
l_min=20
FWHM= 5.0, f_sky=0.5, σ=0.62, ℓ_knee=4, n=1.0, [2,4000]
FWHM= 5.0, f_sky=0.5, σ=0.62, ℓ_knee=4, n=1.0, [20,4000]
degradation of r measurement
σ_r x √2
σ_r(α) / σ_r(α=0) − 1
r = 10^-2, A_lens = 1
r = 10^-2, A_lens = 0
r = 10^-3, A_lens = 1
r = 10^-3, A_lens = 0
r = 10^-4, A_lens = 1
r = 10^-4, A_lens = 0

Conclusion and limitations

- TB and EB can detect and measure polarisation rotation at level (~0.1 arcmin) well below those affecting *r* measurements in BB (> 1 arcmin)
- But:
  - ✦ Delensing
    - Cleaned *B* map ? (eg LENSFLOW, Millea++ 2017)
      - level of residual lensing ?
      - increased noise ?
  - ✦ At low-ℓ:
    - Interaction with foregrounds,
      - cut sky
        - ★ need for optimal C(l) at large scale,
        - ★ non-gaussian error bars, correlated error bars
      - need for proper FG modelling, and component separation.
    - Large scale noise correlation (1/f noise).
  - ✦ At intermediate and high-ℓ:
    - interaction with other systematics (eg, beam related),
      those can be computed numerically and/or (semi)-analytically,
      assuming the input features (beam map, calibration, …) are known well enough

Core simulation with 2 Planck beams