A new estimator for weak lensing based on IM-Galaxy cross correlation

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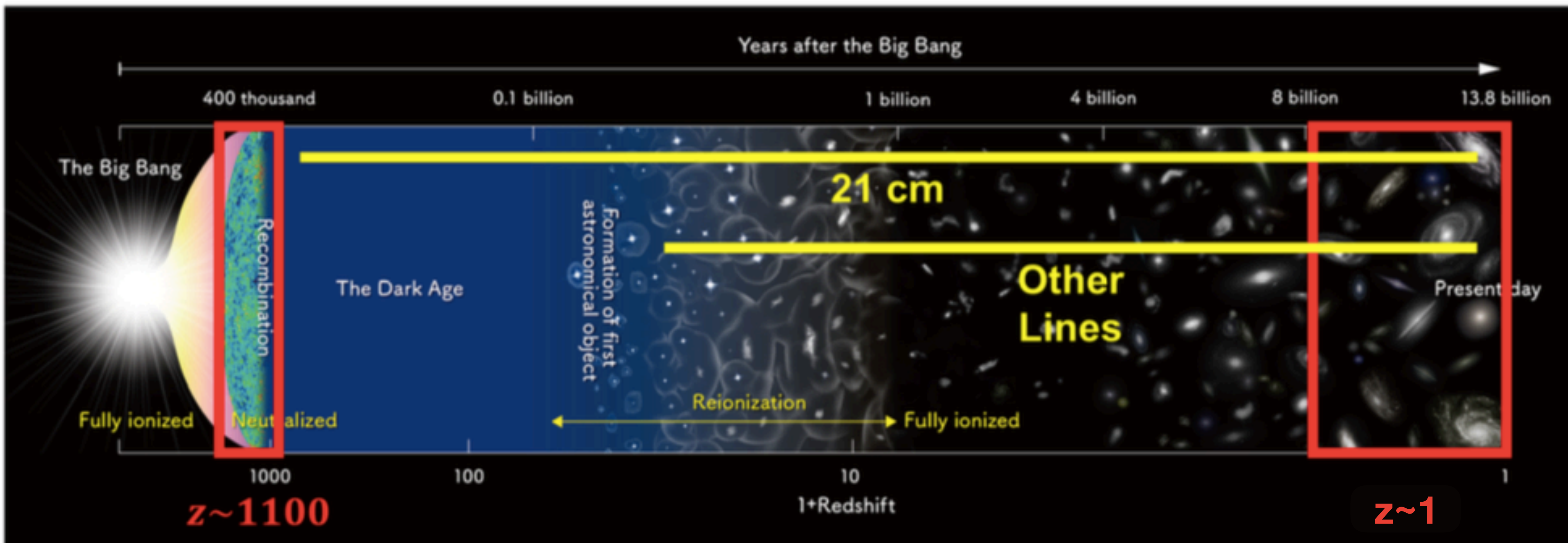
Motivation

- Future 21cm surveys will probe high redshifts
- Complementary to the CMB and galaxy surveys
- Test our models in a wider range of distances
- Weak lensing: probe of matter distribution and sensitive to the dynamics of the universe



Introduction to weak lensing of galaxies and intensity mapping

Lensing effect on observed galaxies

Shape correlation (cosmic shear)

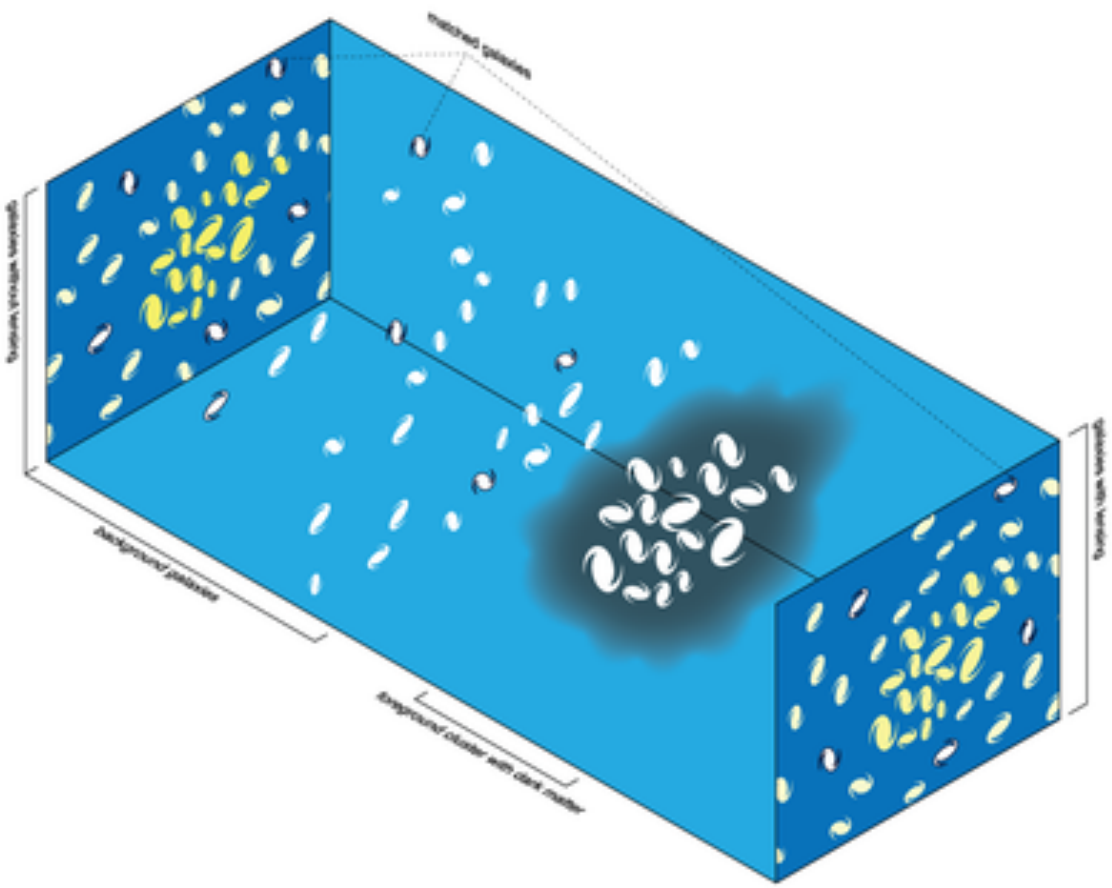
↓

Needs precise shape measurements

Number density of galaxies

$$\Delta^{galaxy}(\hat{n}, z) = b(z)\delta(\hat{n}, z) + (2 - 5s)\nabla^2\phi$$

magnification bias



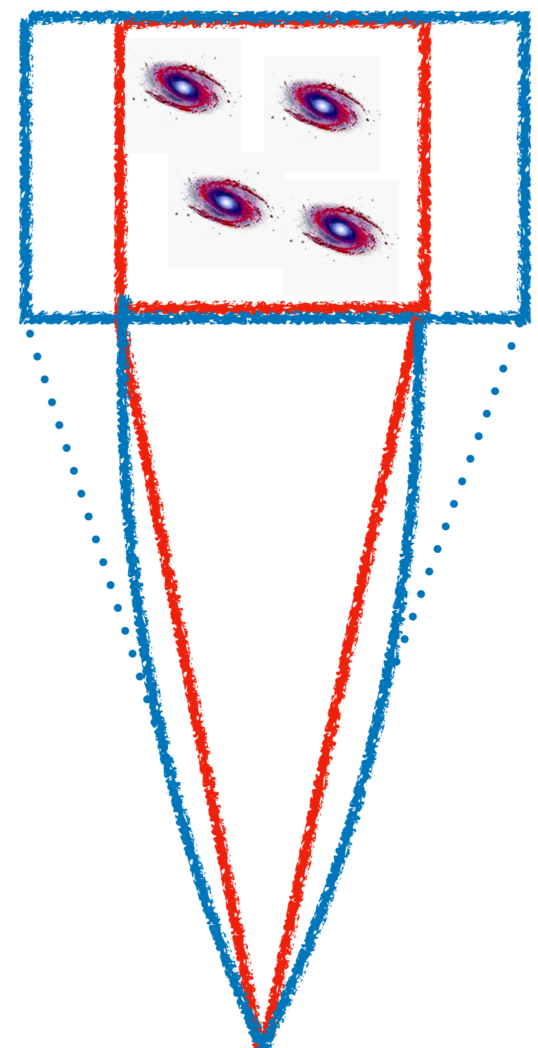


Diagram credit: Michael Sachs

Lensing effect on intensity mapping

Lensing conserves surface brightness

$$\frac{dB}{d\Omega}[W/m^2 d\Omega]$$

$$\Delta^{IM}(\hat{n}, z) = b(z)\delta(\hat{n}, z)$$

No first order lensing term added to IM

Remapping of temperature fluctuations

↓

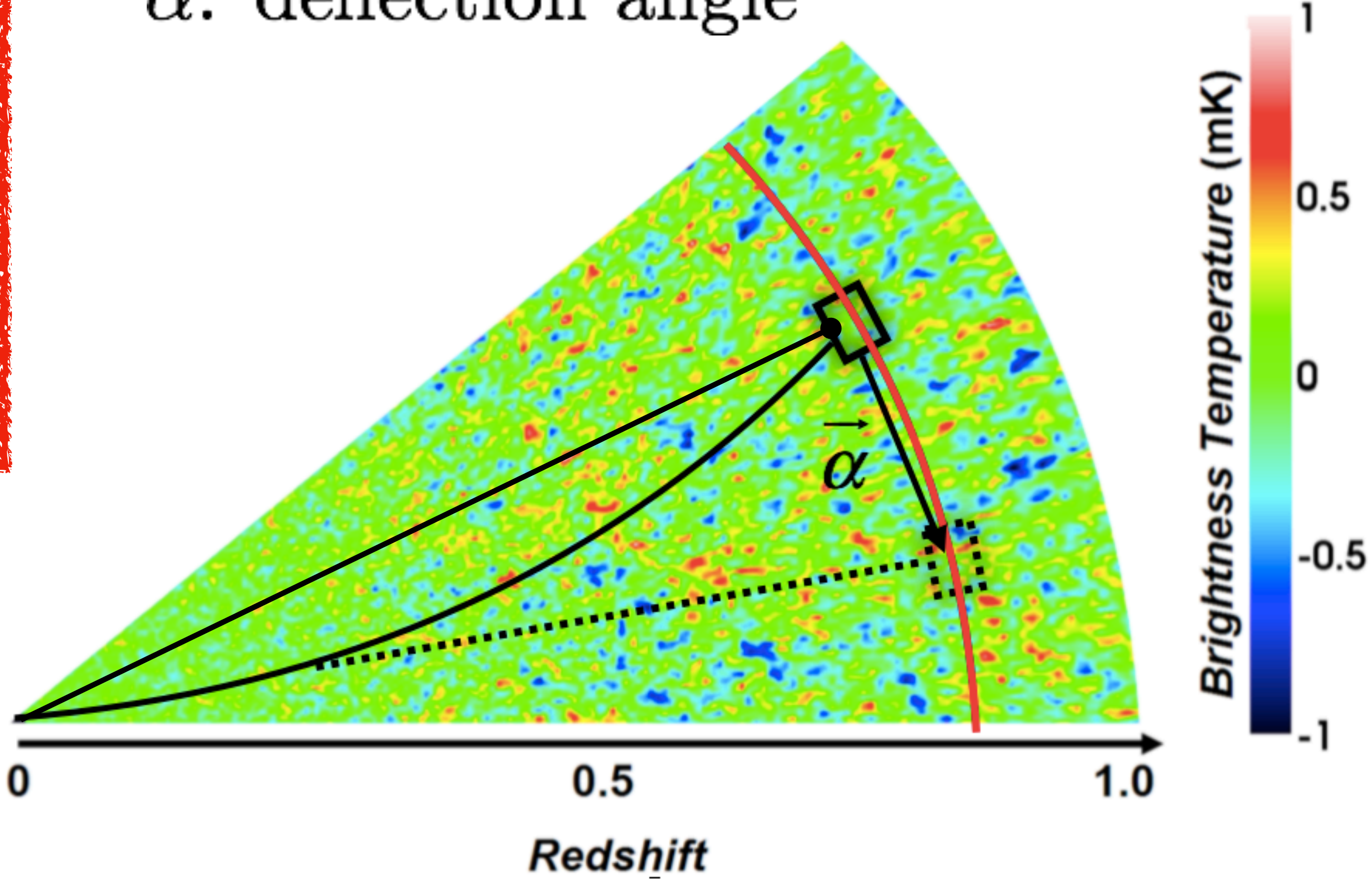
Second and higher order lensing terms

$$\Delta^{HI}(\hat{n}) \rightarrow \Delta^{HI}(\hat{n} + \nabla\phi)$$

$$\vec{\alpha} = \nabla\phi$$

ϕ: lensing potential

α: deflection angle



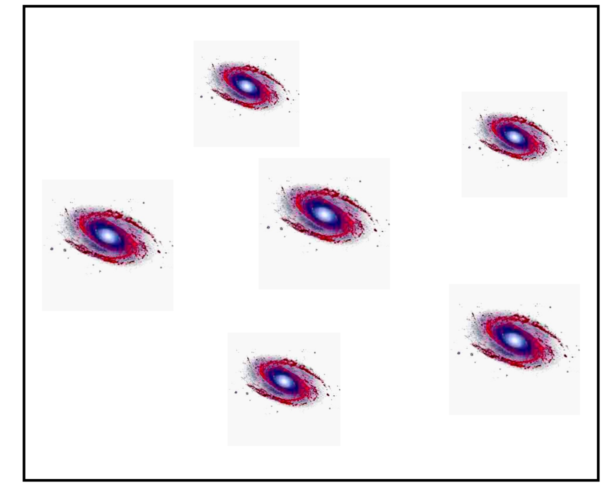
Standard estimator for detecting magnification bias

Standard estimator: galaxy-galaxy cross correlation

$$\Delta^{galaxy}(\hat{n}, z) = b(z)\delta(\hat{n}, z) + (2-5s)\nabla^2\phi$$

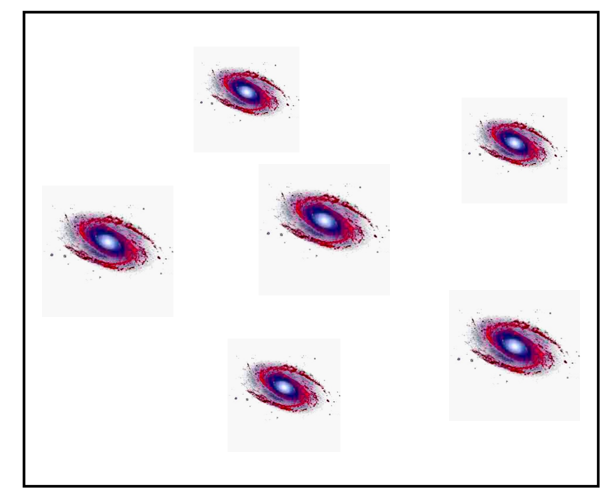
Contamination from density term

z_b



$$\begin{aligned} E_\ell^{\rm st} &= C_\ell^{g,g}(z_b, z_f) \\ &= b_g(z_b) b_g(z_f) C_\ell^{\delta\delta}(z_b, z_f) \\ &+ \frac{1}{2} b_g(z_f)(2-5s(z_b)) C_\ell^{\phi\delta}(z_b, z_f) \\ &+ \frac{1}{2} b_g(z_b)(2-5s(z_f)) C_\ell^{\delta\phi}(z_b, z_f) \\ &+ \frac{1}{4}(2-5s(z_b))(2-5s(z_f)) C_\ell^{\phi\phi}(z_b, z_f) \end{aligned}$$

z_f

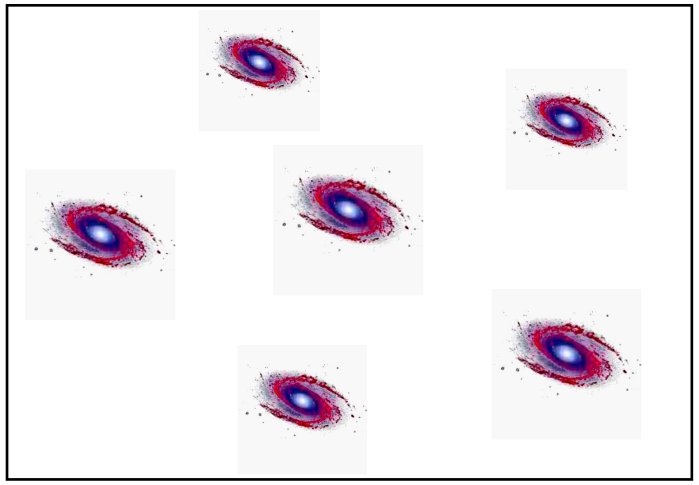


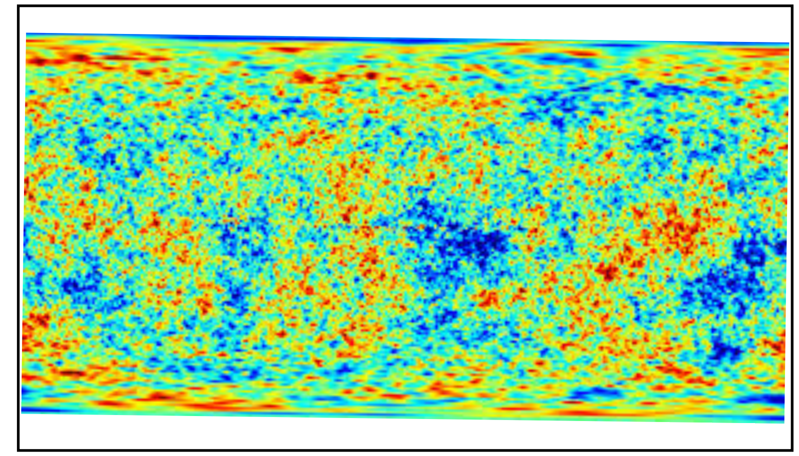
Lensing terms

Introduction to the new estimator

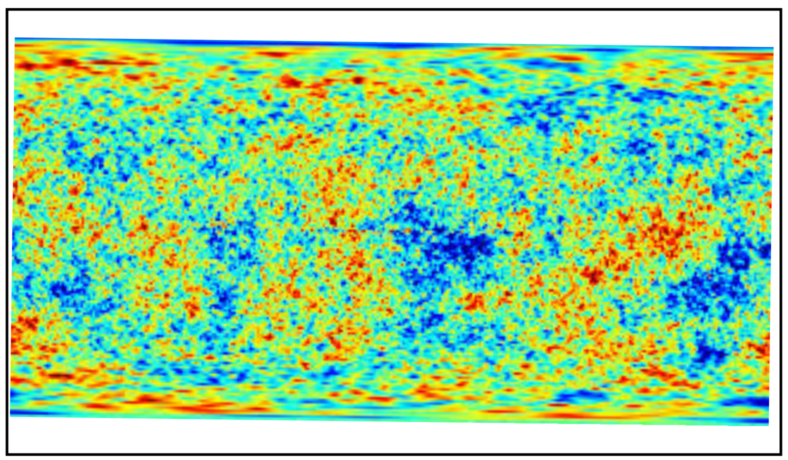
Idea of new estimator

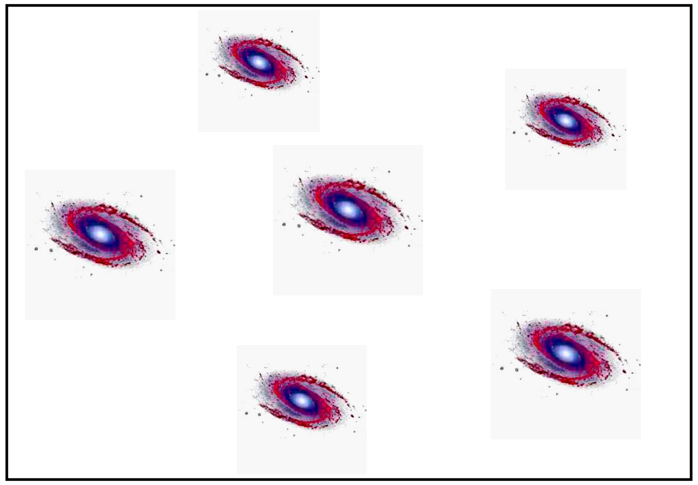
z_b





z_f





$$C_\ell^{\mathrm{IM-g}}(z_f, z_b)$$

$$C_\ell^{\mathrm{g-IM}}(z_f, z_b)$$

density + lensing term

density

New estimator: $E^{\times}$

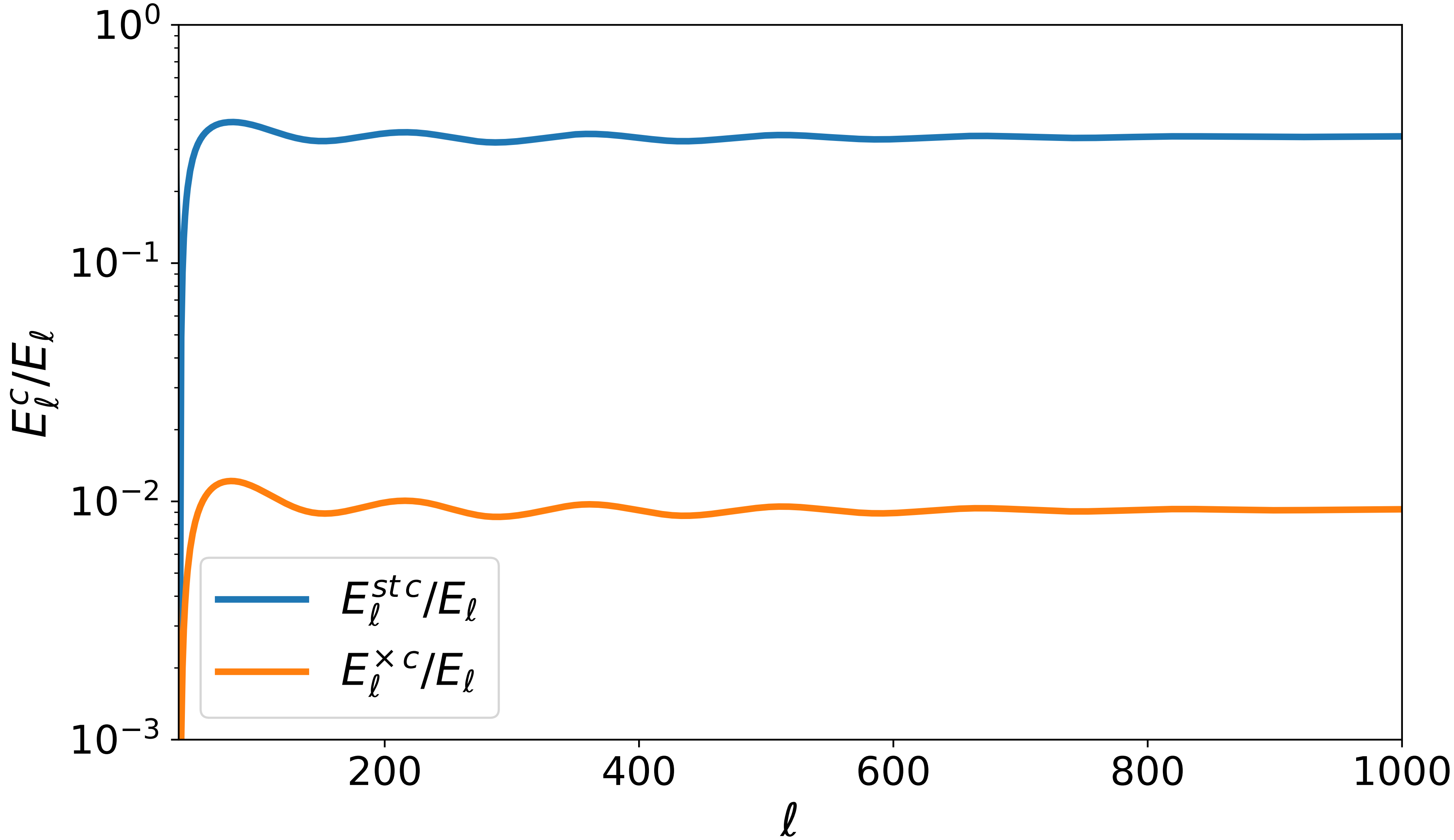
Contamination: reduced by a factor proportional to bias difference

$$
\begin{aligned}
E^{\times} &= C_\ell^{g\text{-HI}}(z_b, z_f) - C_\ell^{\text{HI-}g}(z_b, z_f) \\
&= \left[b_g(z_b) b_{\text{HI}}(z_f) - b_{\text{HI}}(z_b) b_g(z_f)\right] C_\ell^{\delta\delta}(z_b, z_f) \\
&+ \frac{1}{2} b_{\text{HI}}(z_f)(2 - 5s(z_b)) C_\ell^{\phi\delta}(z_b, z_f) \\
&- \frac{1}{2} b_{\text{HI}}(z_b)(2 - 5s(z_f)) C_\ell^{\delta\phi}(z_b, z_f)
\end{aligned}
$$

Lensing terms

Contamination

DESxHIRAX $z_b = 1.25$ $z_f = 1.0$



~ 40 % for $E^{\rm st}$

~ 1 % for $E^{\times}$

Variance

$$V(\hat{E}^{\rm st}) = \frac{1}{(2\ell+1)f_{sky}}[C_\ell^{\rm g-g}(z_f)C_\ell^{\rm g-g}(z_b) + C_\ell^{\rm g-g}(z_f,z_b)^2]$$

$$V(\hat{E}^{\times}) = \frac{1}{(2\ell+1)f_{sky}}\Big[C^{\rm HI-HI}(z_f)C^{\rm g-g}(z_b) + C^{\rm HI-HI}(z_b)C^{\rm g-g}(z_f) - 2C^{\rm HI-g}(z_f)C^{\rm HI-g}(z_b) - 2C^{\rm g-g}(z_f,z_b)C^{\rm HI-HI}(z_f,z_b) + C^{\rm HI-g}(z_f,z_b)^2 + C^{\rm g-HI}(z_f,z_b)^2\Big]$$

$$\left[b_g(z_b)b_{\rm HI}(z_f) - b_{\rm HI}(z_b)b_g(z_f)\right]^2 C_\ell^{\delta\delta}(z_b)C_\ell^{\delta\delta}(z_f)$$

Signal-to-noise-ratio

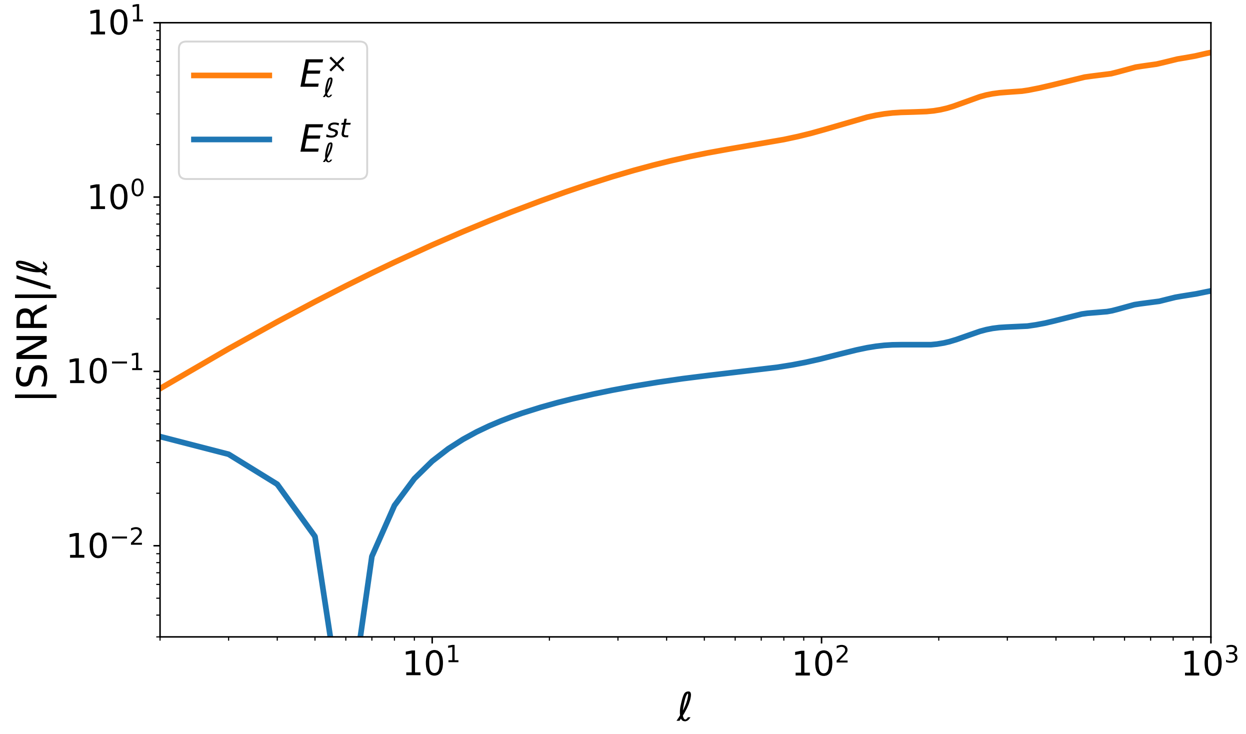
DESxHIRAX $z_b = 1.3$ $z_f = 0.8$

Cosmic variance limited

$$\mathrm{SNR}^{\mathrm{total}} = \sqrt{\sum_{\ell} (\mathrm{SNR}_{\ell})^2}$$

$E^{\times}$ ~ 357

E^{st} ~ 15

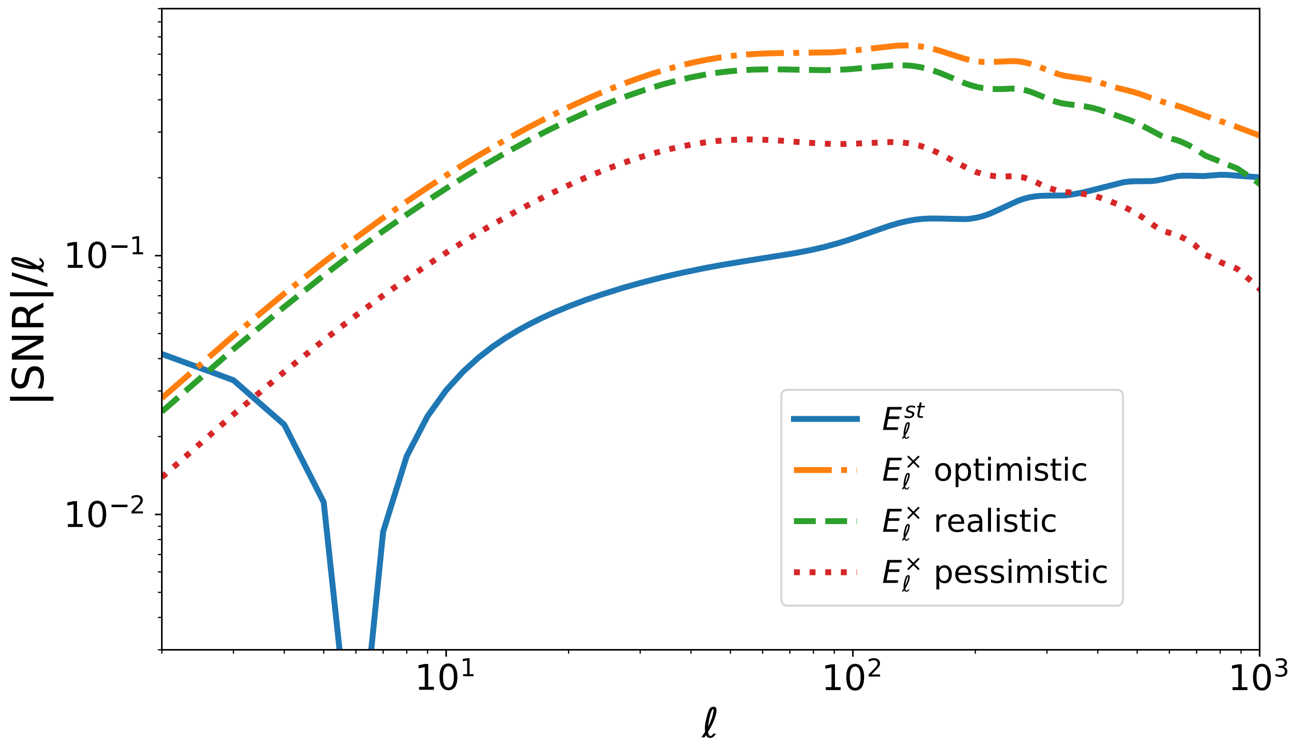


Shot noise + thermal noise

Optimistic case

$E^{\times}$ ~ 11

E^{st} ~ 8



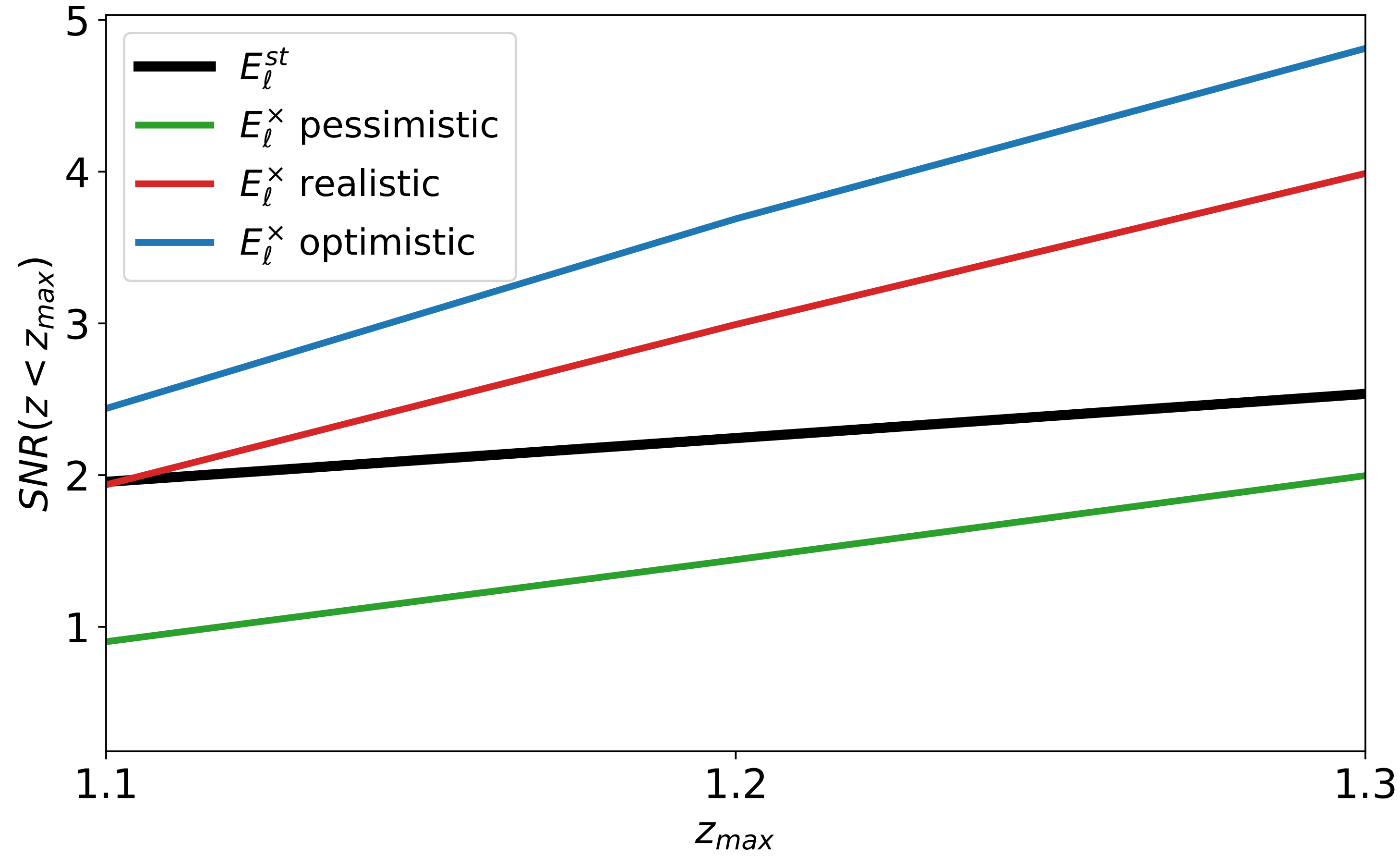
Fisher forecast

DESxHIRAX

z =[0.8, 1.3]

DES

z =[0.2, 1.3]

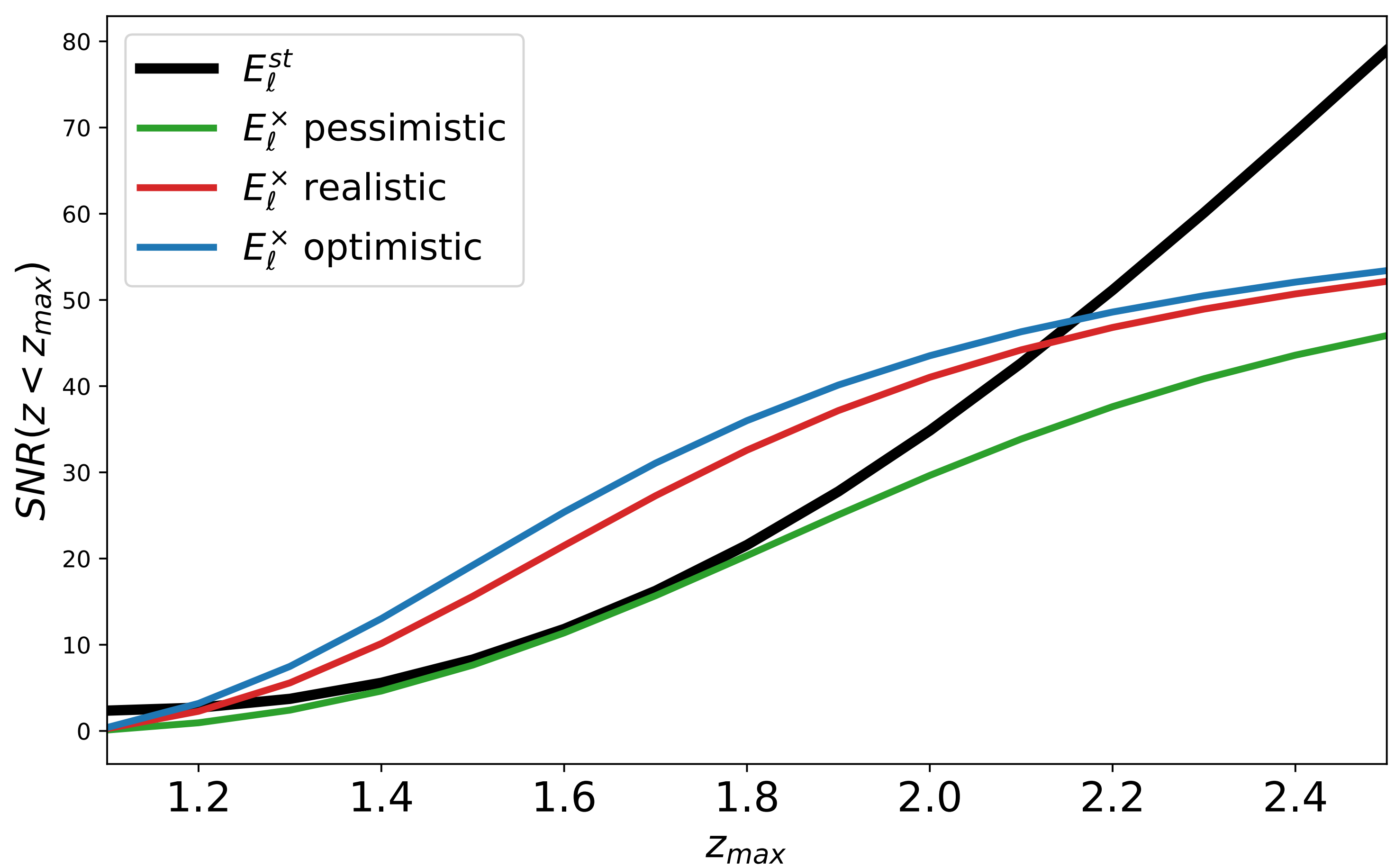


EuclidxHIRAX

z =[0.8, 2.5]

Euclid

z =[0.2, 2.5]

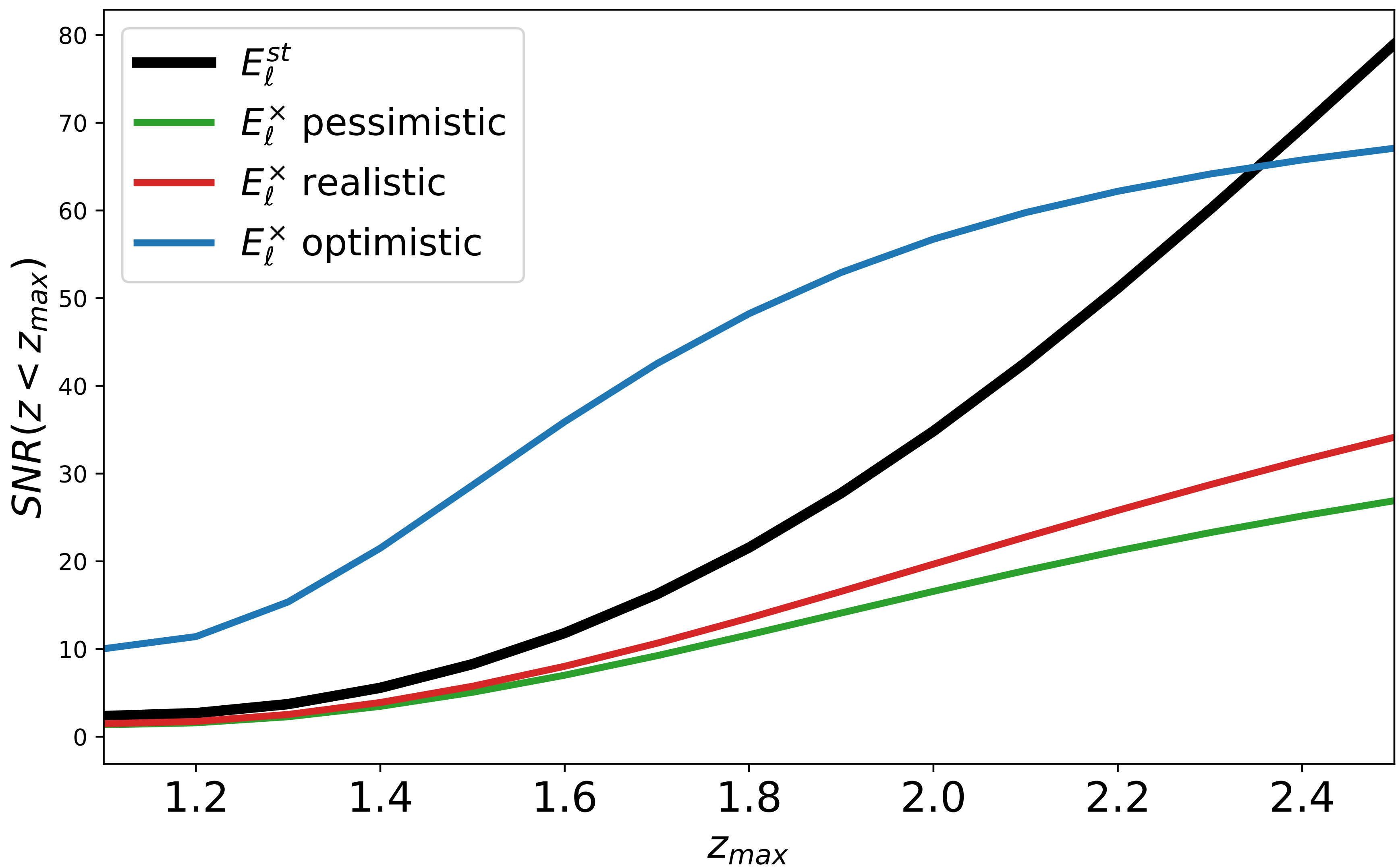


EuclidxSKAMID

$z \in [0.35, 2.5]$

SKA phase1 looks at redshift after reionization
SKA1-MID probes $z \in [0.35, 3]$

In optimistic case: EuclidxSKA improves magnificently
In realistic and pessimistic case: we are killed by thermal noise



Conclusion

- The new estimator we introduce reduces contamination and allows closer bins to be used for signal detection
- It increases signal-to-noise ratio by a factor of ~3 in the redshift range of z=1.4 to z=2 for EucildxHIRAX
- Reduces systematics since it’s built up by the cross correlation of data from two different surveys


Thank you for your attention