EXPLORING THE INFLATIONARY UNIVERSE WITH LYMAN-BREAK GALAXIES AND CMB LENSING

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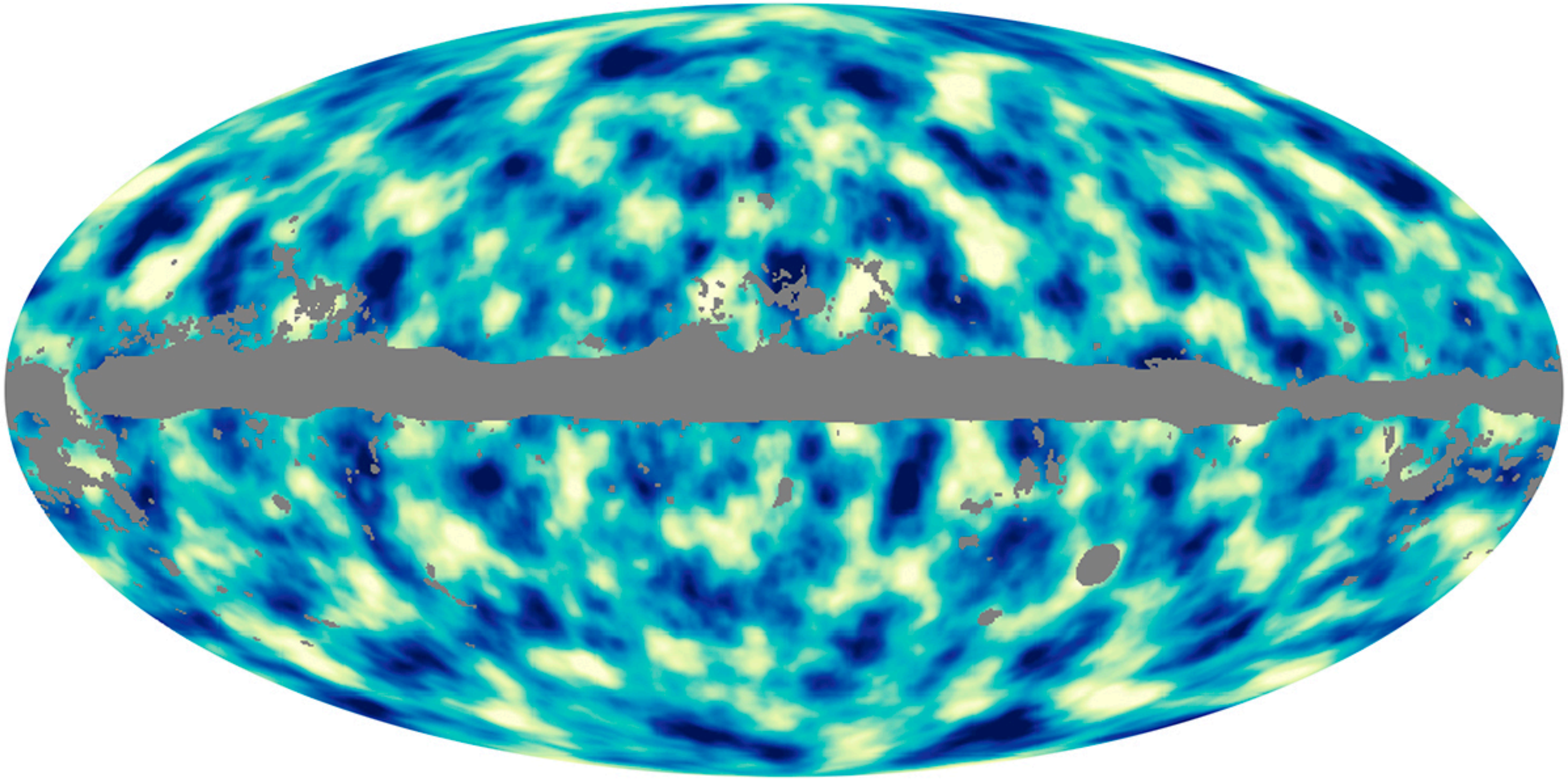
with Martin White, David Schlegel, Rebecca Bowler ++

(NECESSARY) OVERVIEW

- Why z>2 is interesting, including:
- Tomographic CMB lensing
- Small signatures require large volume, e.g. single-field inflation & f_{NL}

- "Established" high-z tracers: Lyman-break galaxies
- Detection forecasts for C_{kg} with forthcoming experiments
- Spectroscopic clustering estimates of N(z): DESI & PFS

- Accurate understanding of the biasing of high-z LBGs?
- Greater S/N by cleaning kappa with low-z surveys

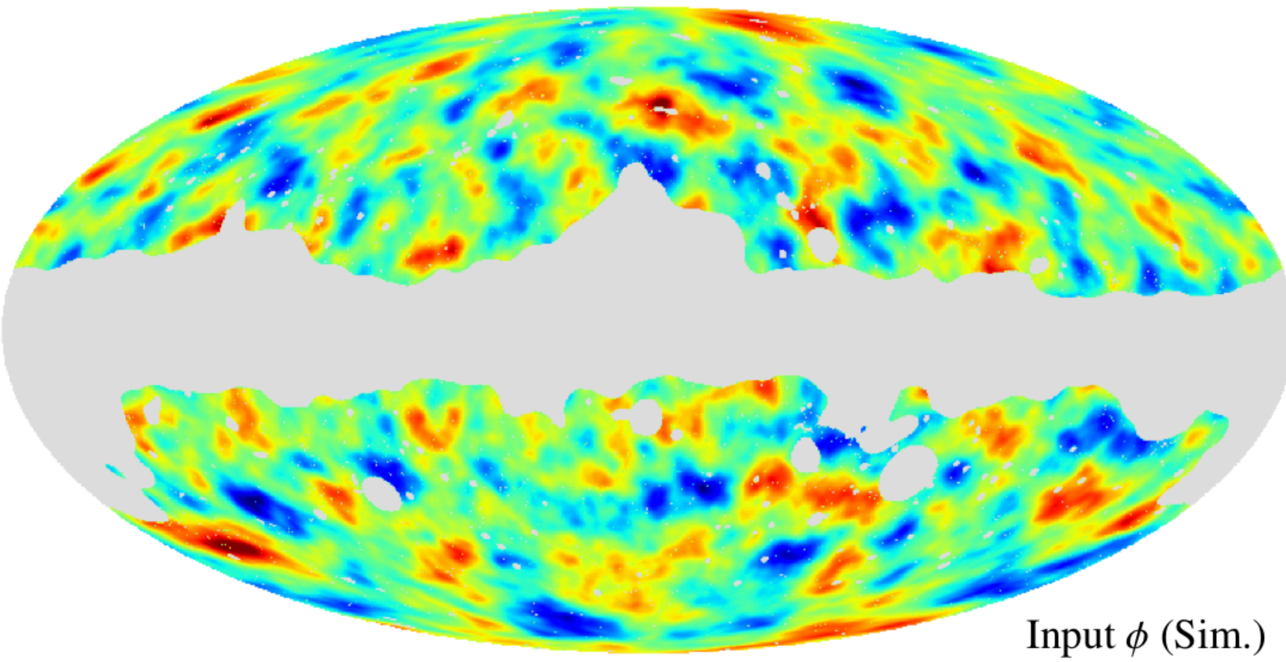


$$C_{XY}(\ell) = \int \frac{d\chi}{\chi^2}\, W_X(\chi) W_Y(\chi)\, P_{XY}\left(k_\perp = \frac{\ell + 1/2}{\chi},\ k_\parallel \simeq 0\right)$$

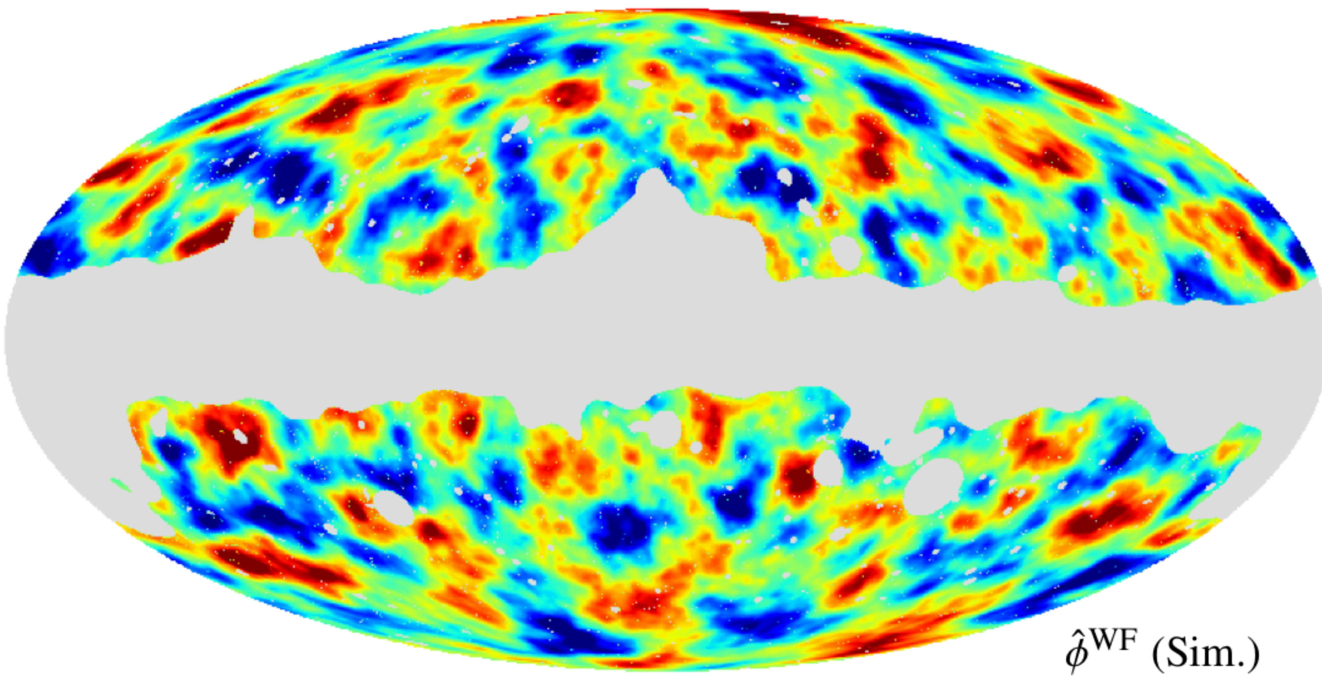
$$W^\kappa(\chi) = \frac{3}{2}\Omega_m(1+z)\left(\frac{H_0}{c}\right)^2\ \frac{\chi(\chi_\star - \chi)}{\chi_\star}$$

$$W^g(\chi) \propto H(z)\,\frac{dN}{dz}$$

Fig. 3 of Planck XV: Gravitational lensing



Input kappa map

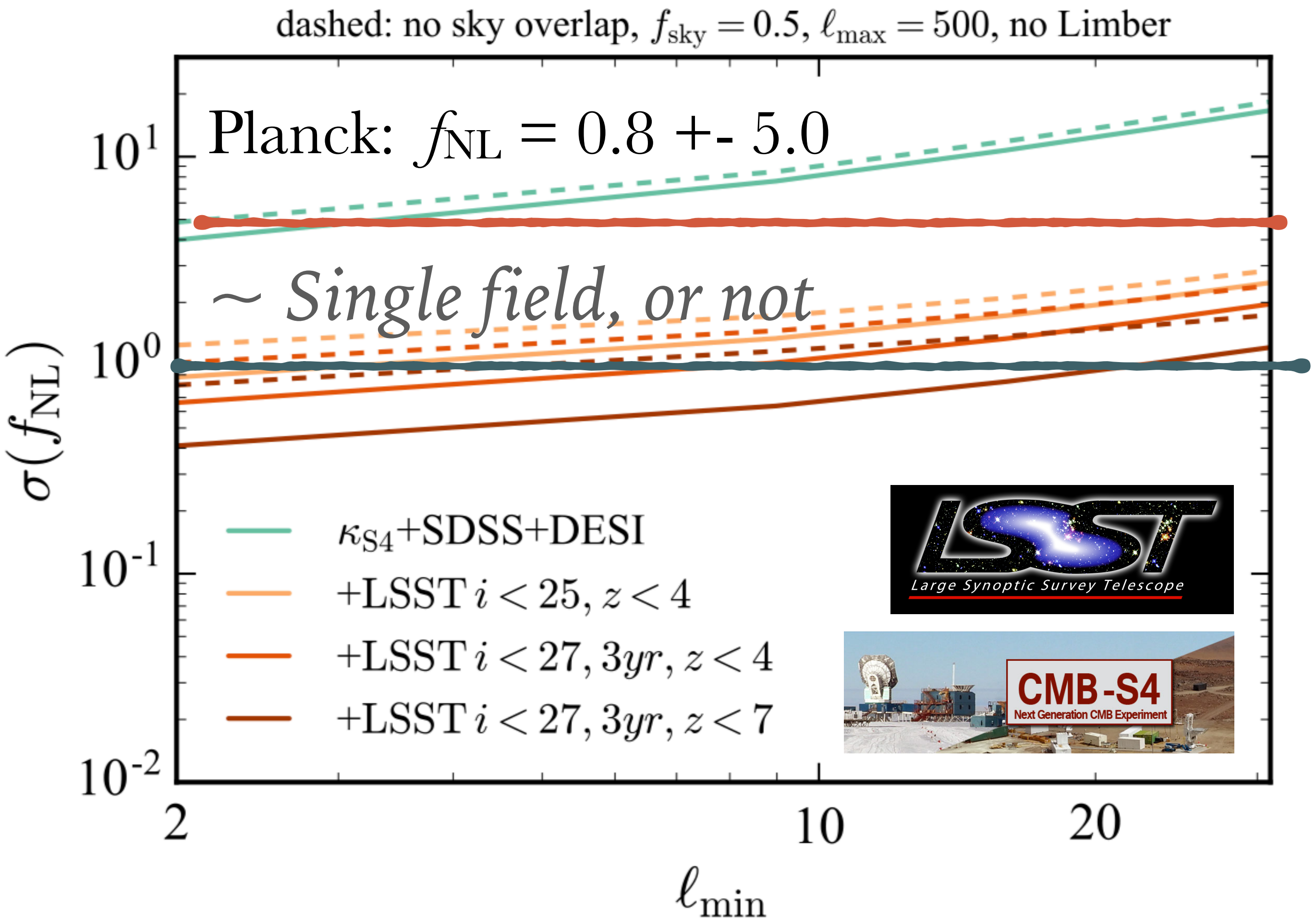


(WF filtered) Planck recovered

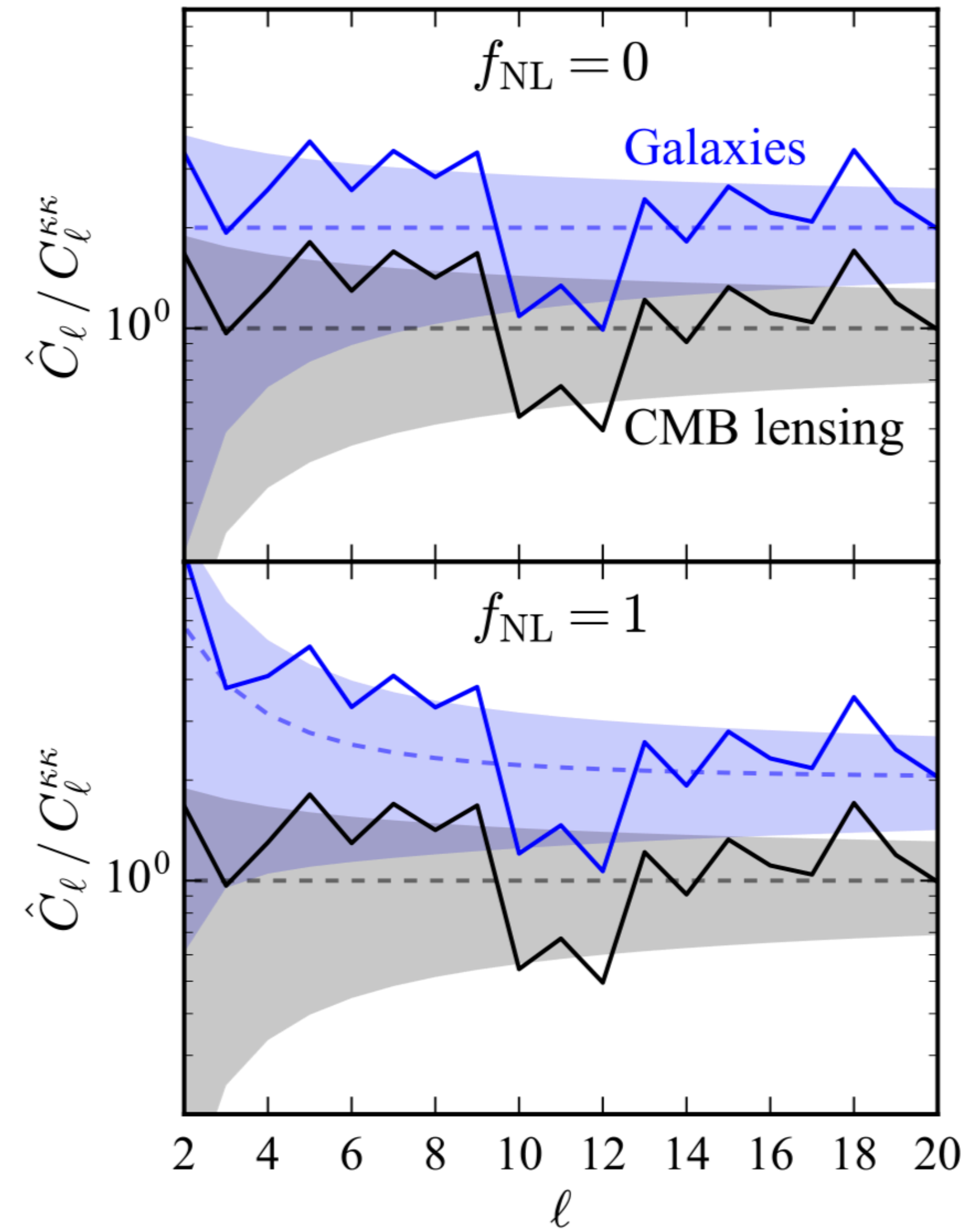
Planck (S/N) ~ 40

— *CMB-S4 (S/N) ~ 400 - 500 for L =1500; Driven by many, many, more bolometers.*

— *Dominated by (~ fore-ground free) EB with iterative reconstruction accounting for x2.5 gain*



Schmittfull & Seljak (2017)



$$\Phi_{\rm NG}(\boldsymbol{x}) = \phi(\boldsymbol{x}) + f_{\rm NL}(\phi^2(\boldsymbol{x}) - \langle\phi^2\rangle).$$

$$\Delta b(k) = 2(b-1) f_{\rm NL}\delta_c \frac{3\Omega_m}{2a\, g(a) r_H^2 k^2}$$

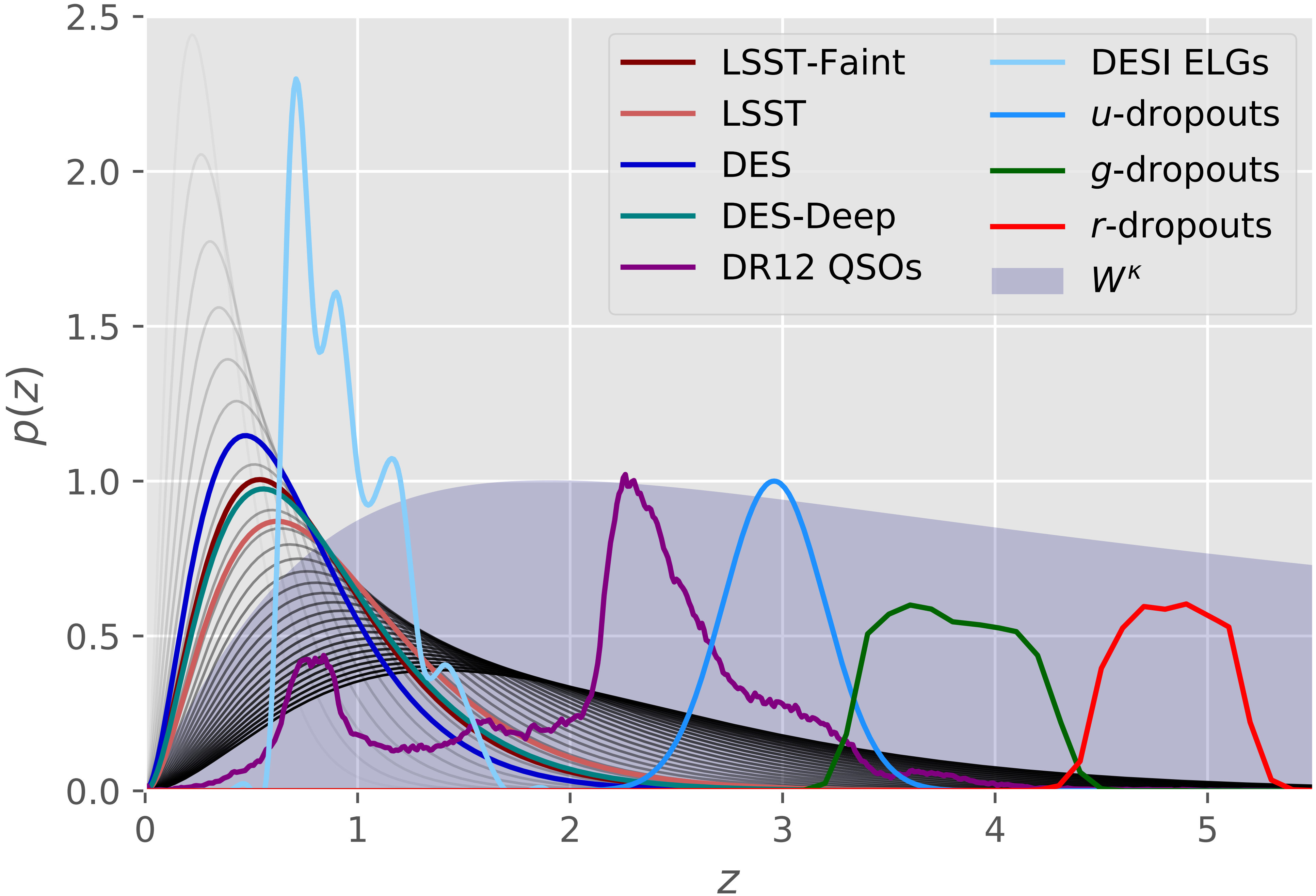
Dalal ++

— *Much larger volume;*

— *Break curvature-Dark Energy degeneracy (x2 in DE)*

— *Motivates (sparse) RSD at high z?*

— *More linear at high redshift, but the targeted objects are highly biased (b ~ 9 at z~6) and (non-primordial) scale-dependent tracers of the matter (e.g. Modi++).*



Sample	$z_{\rm eff}$	Δz	$\bar{n}_\theta$	$\bar{n}_\Theta$	Contaminant	b	$f_{\rm sat}$	Ref.
ELGs	1.13	1.09	–	2400				[60]
QSOs	2.10	1.60	–	31.7	Gal. stars			[61]
Lyα								
Hα emitters		–		4350				[62]
u-dropouts	2.96	0.52	6160	5763	G and K stars	2.9		[63]
g-dropouts	3.80	0.58	4980	283	Early-types	6.66		[16]

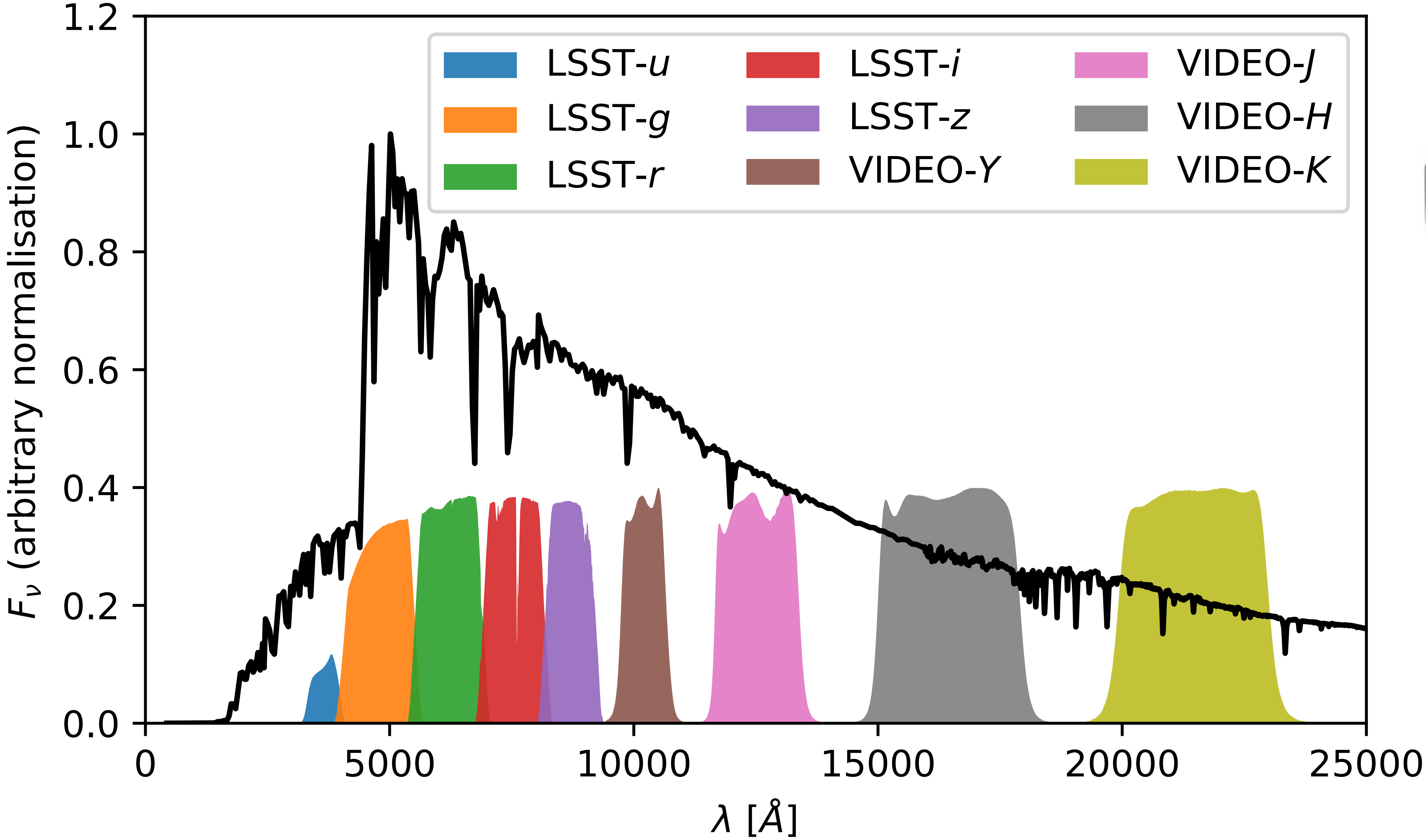
LSST & DES:

$$p(z) = \frac{1}{2\,z_0}\left(\frac{z}{z_0}\right)^2 \exp\left[-\frac{z}{z_0}\right]$$

$$z_0 = 0.0417\, i_{\rm lim} - 0.744$$

with (∼ 353 GHz) Cosmic infrared background, Ly-a emitters etc, and

integral constraint provided by Ckk itself



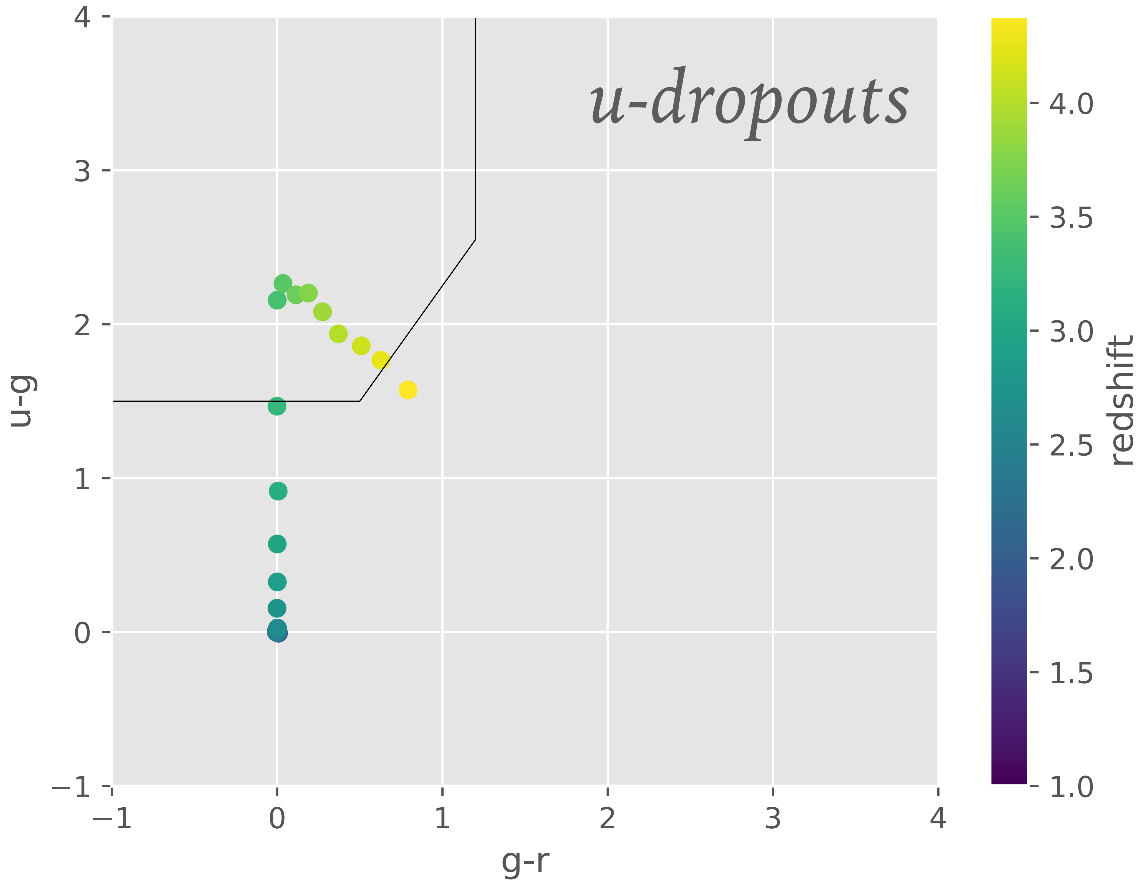
Euclid

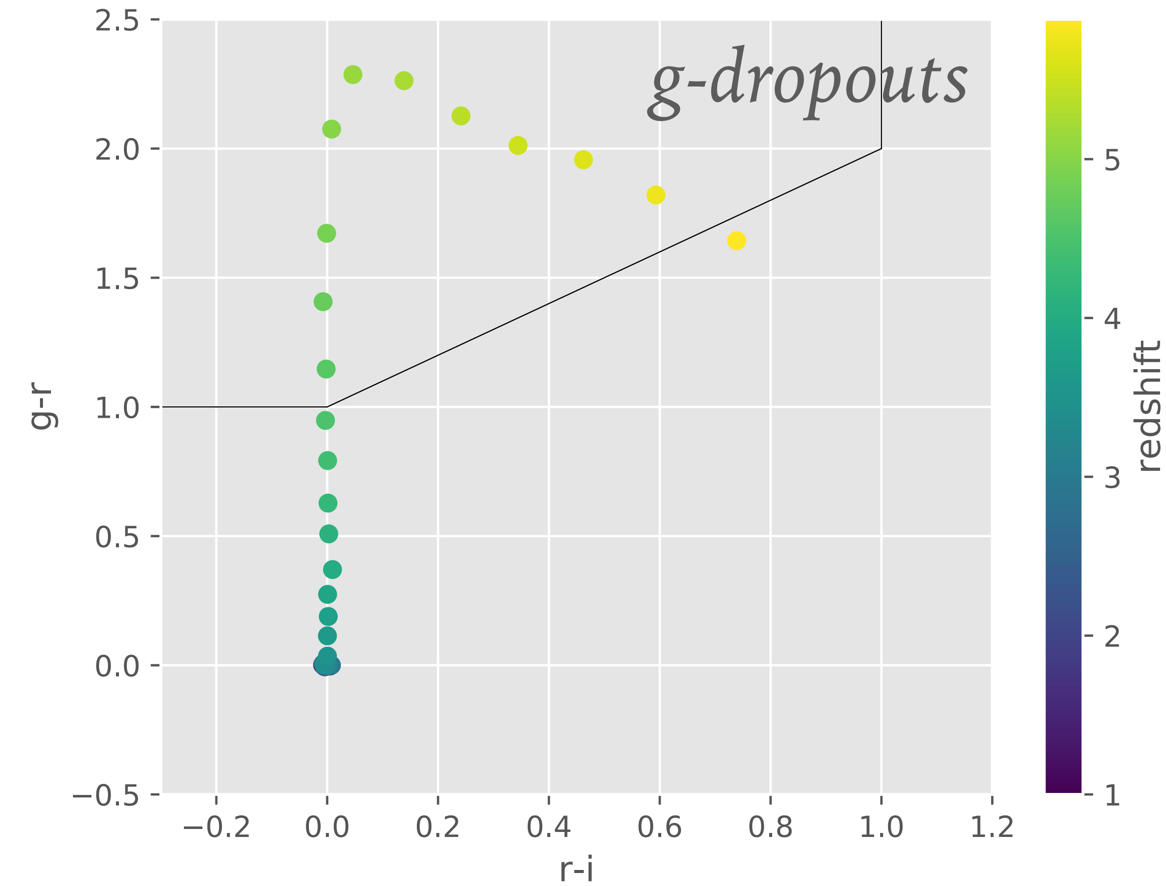
"forerunner"

— *Young (O and B) star-forming galaxies (Bruzual and Charlot) with modest, Calzetti-like attenuation, 0.0 < E(B-V) < 0.5*

— *Lyman-break at ~912A due to intrinsic neutral hydrogen absorption and the mean Lyman-alpha forest (Madau extinction)*

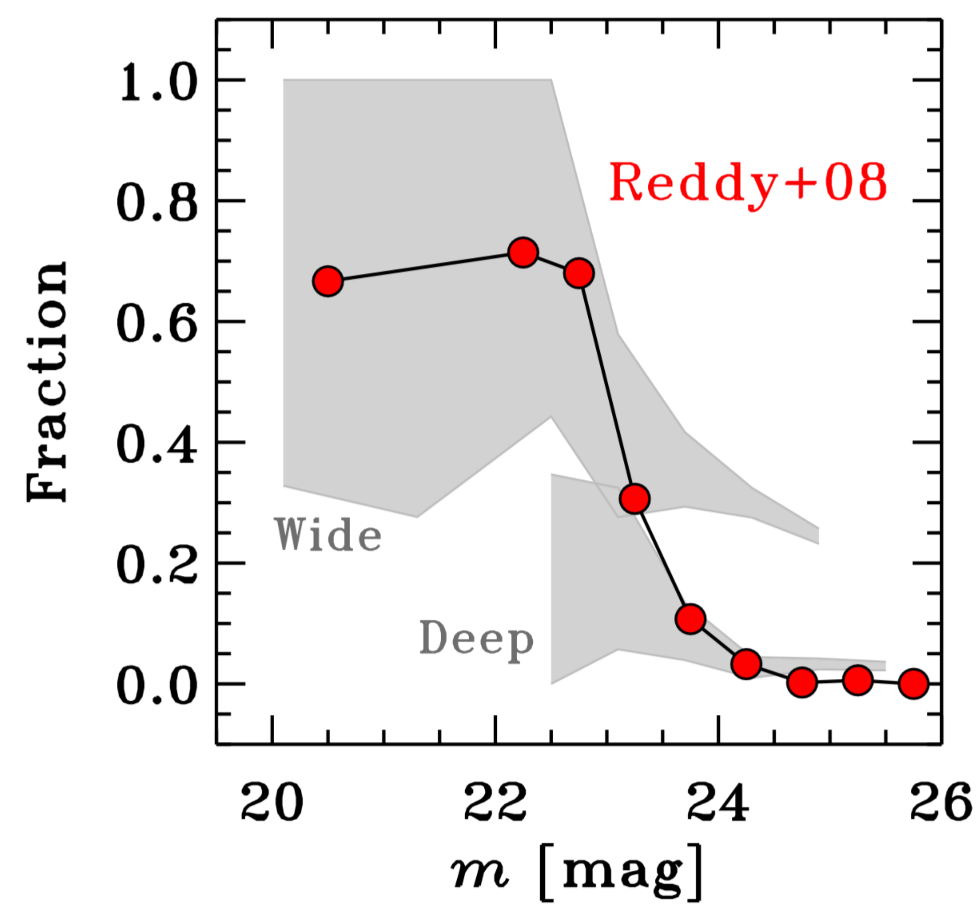
— *Zero colours for filters above the break with ~ one mag. across it*



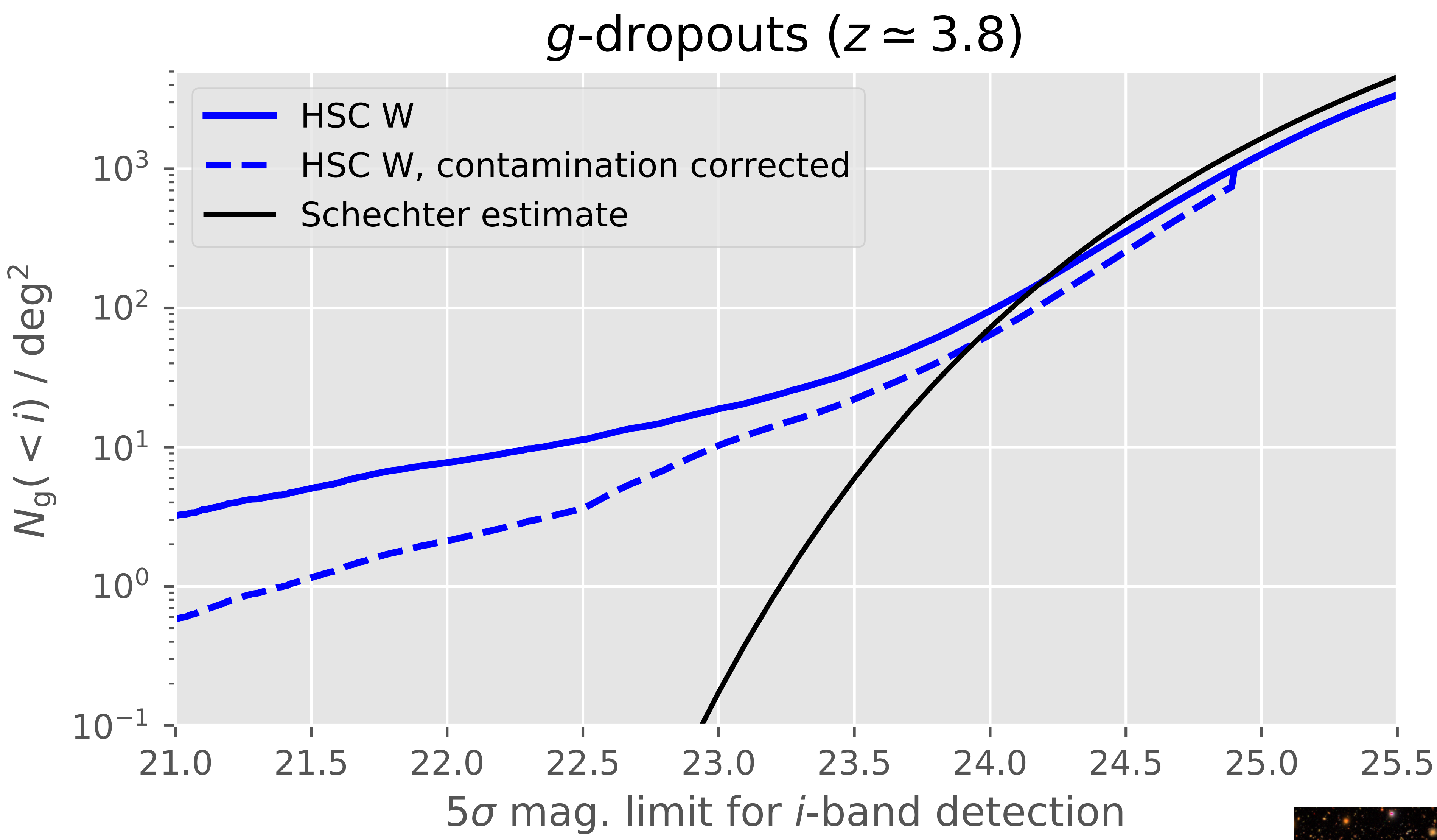


— Stellar locus and low-z red galaxies encroach on the selection box, especially with "shallow" photometry.

— Infrared VIDEO / Euclid bands essential to understand contamination rates and tailor selection to cross-correlation (cross-correlation only catalogues? e.g. 3 sigma detections)

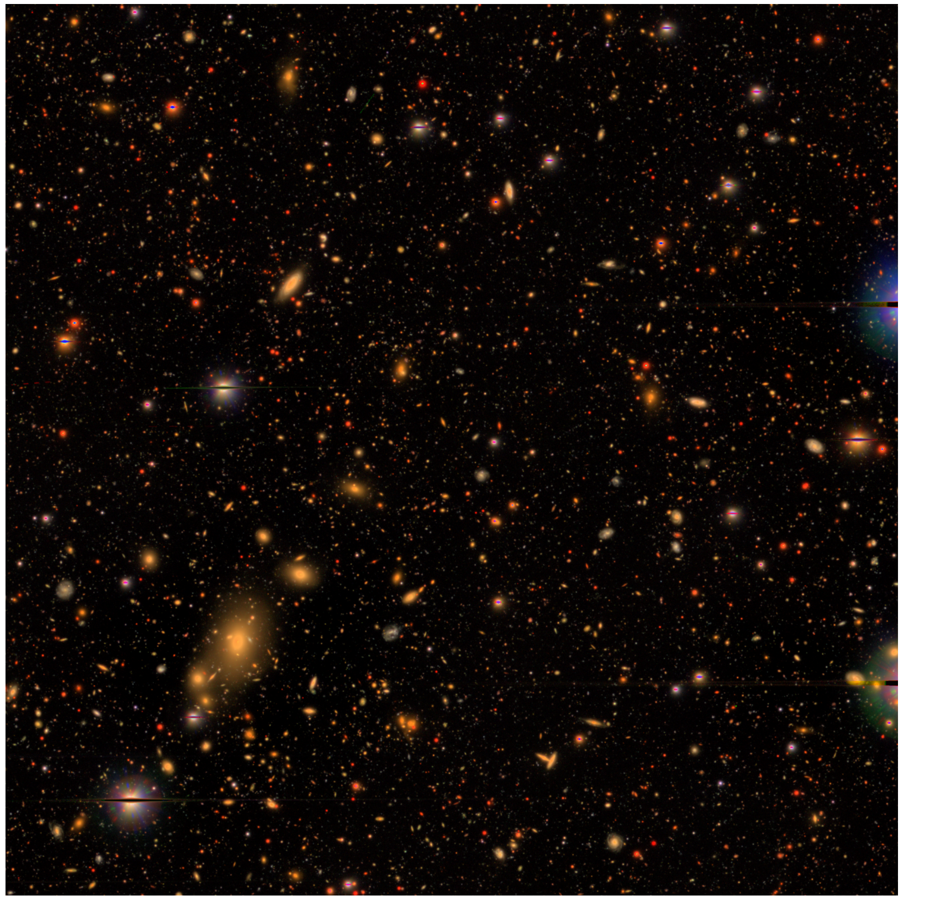


Ono ++



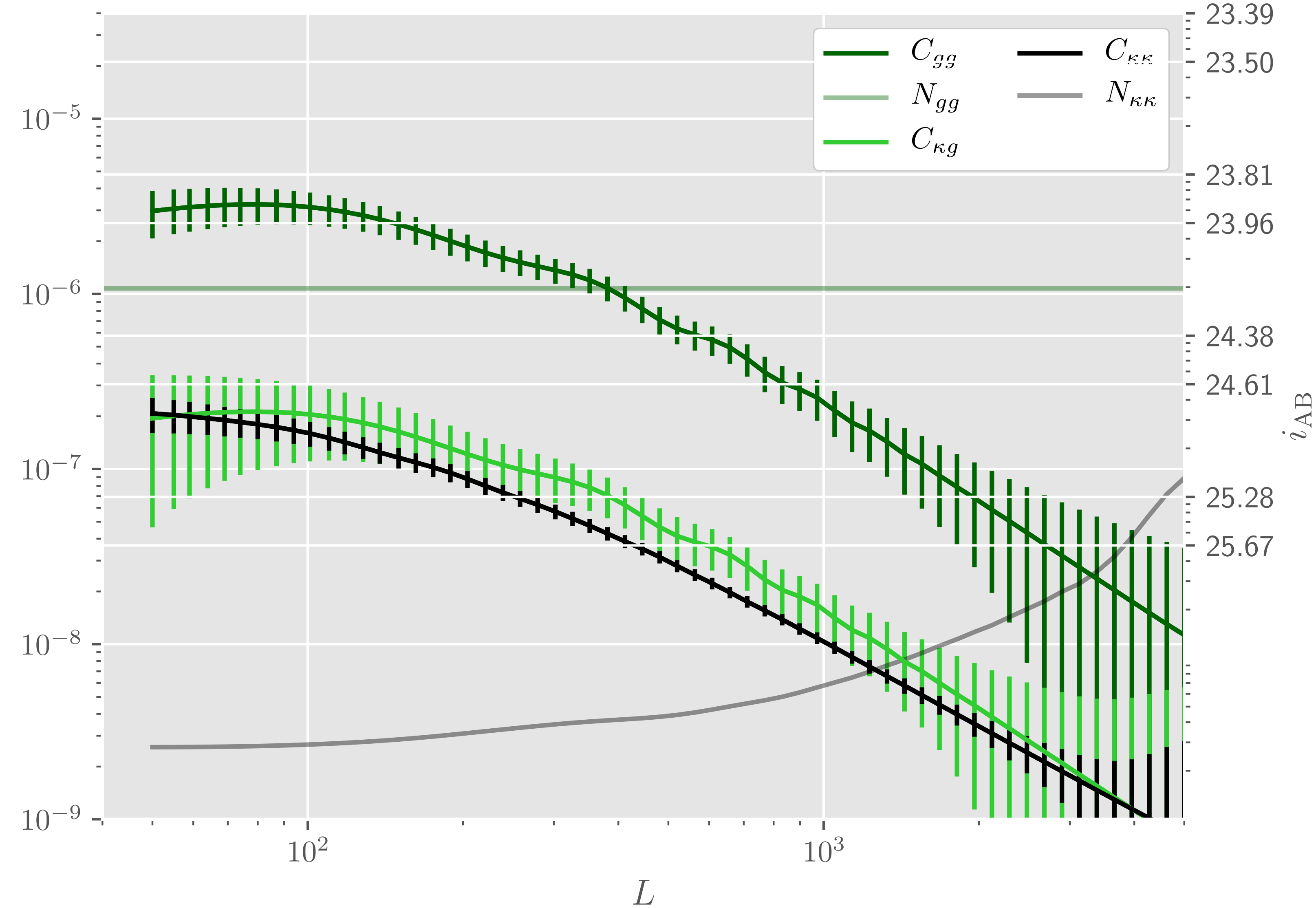
— ***500 g/deg² at i ∼ 24.5,***

over 100 deg² for Goldrush, but DES and LSST

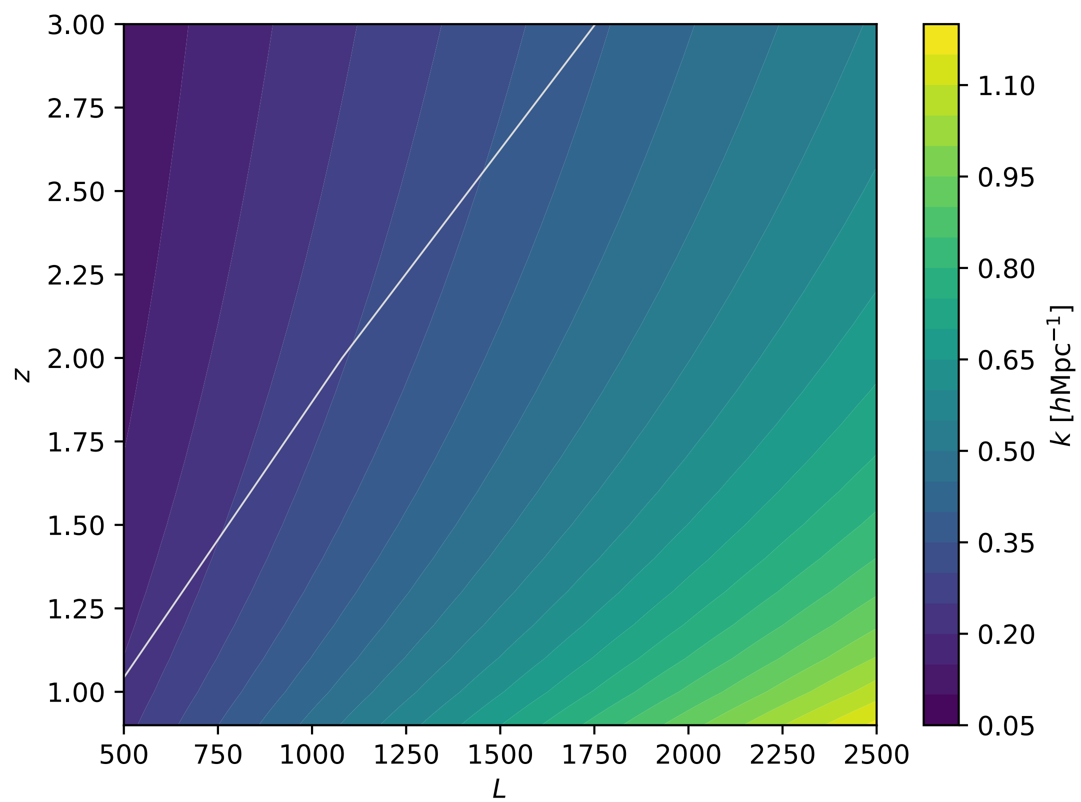


z~4 Goldrush dropouts

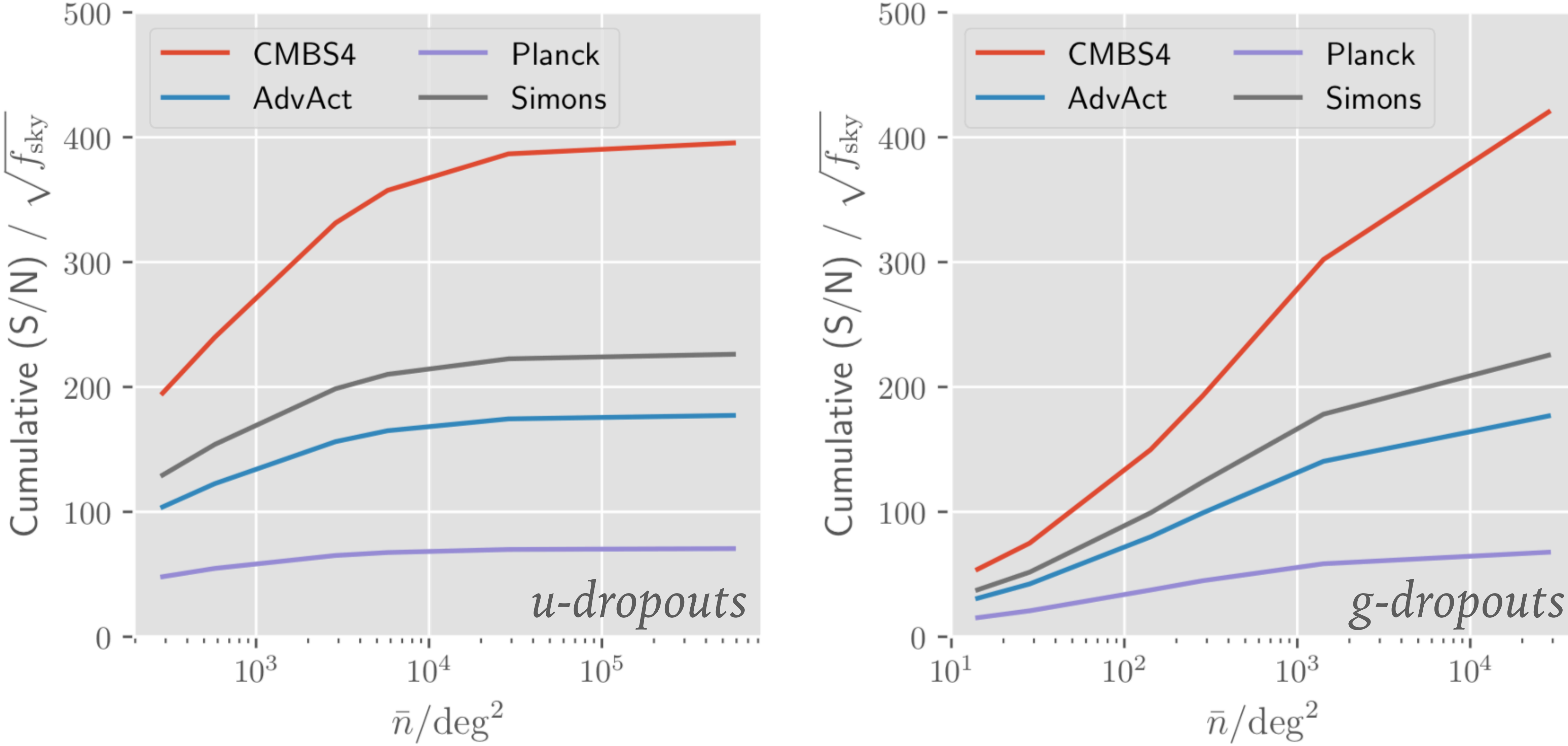
Ono++, Harikane++



— Larger bias is a bonus



— But mode-sampling variance limit may not be reached with infinite depth if the modelling is not sufficient, i.e. external L_{max}



Survey	$f_{\rm sky}[\%]$	Map rms $[\mu K - \mathrm{arcmin}]$	Resolution [′]	Ref.
Planck	50	30.0	7.0	[44]
Advanced ACT	20	12.0	1.5	[86]
SPT-3G	6	4.5 - 7.5	1.0 - 1.6	[87]
Simons Observatory	65	11.8 - 40.0	2.7 - 5.2	[88]
CMB-S4	40	1.0	1.4	[45]
COrE	80	2.0	2.0	[89]
LiteBIRD	70	3.8 - 10.0	16.0 - 75.0	[90]

Detection is likely possible today, but much more interesting in the future.

Choose your survey or stipulate $$; particularly interesting avenues?

Determine N(z) from Cls of pp, ss, ps; E.g. McQuinn and White;

$$C_{XY}(\ell) = \int \frac{d\chi}{\chi^2}\, W_X(\chi) W_Y(\chi)\, P_{XY}\left(k_\perp = \frac{\ell+1/2}{\chi},\ k_\parallel \simeq 0\right)$$

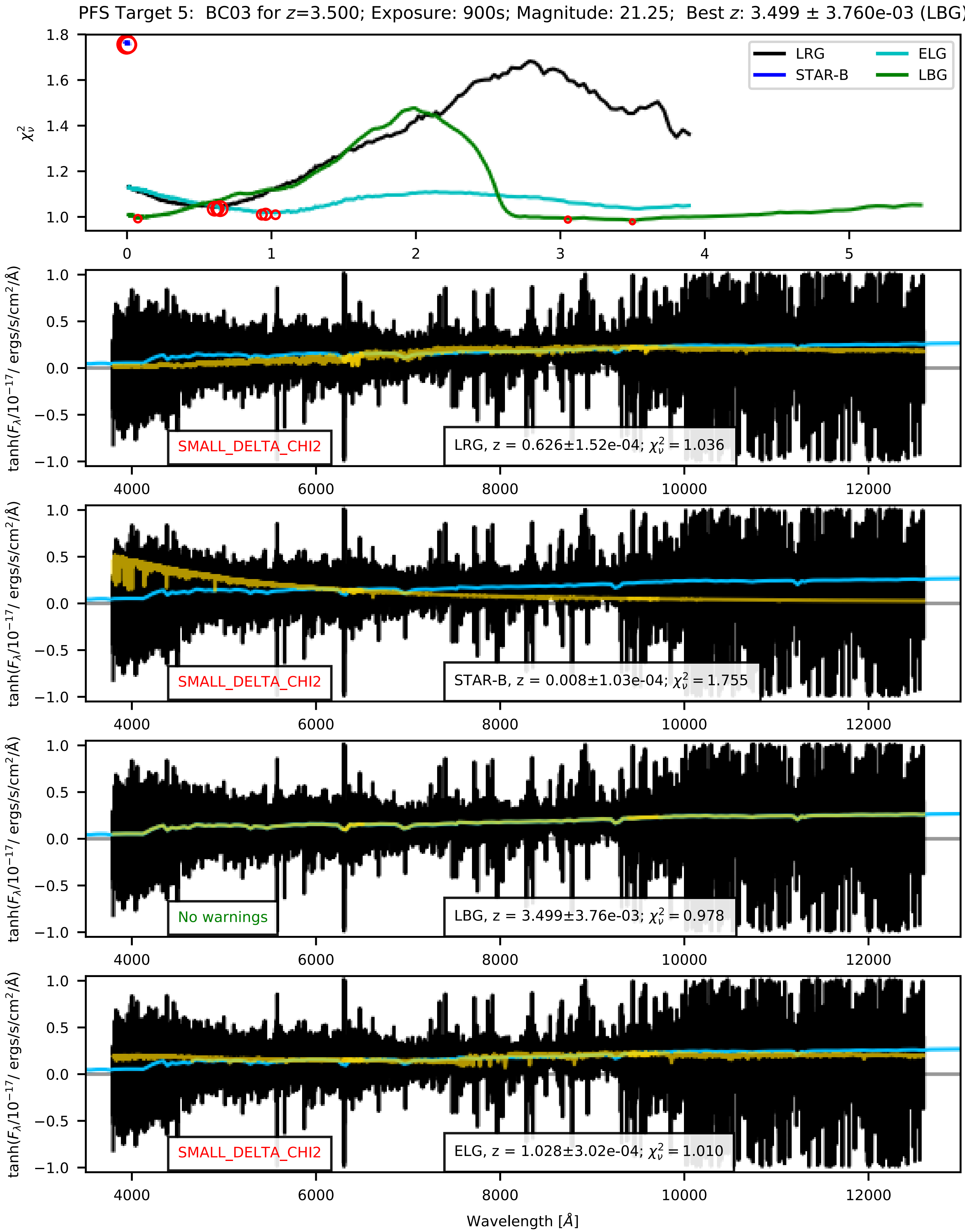
$$W^\kappa(\chi) = \frac{3}{2}\Omega_m(1+z)\left(\frac{H_0}{c}\right)^2\, \frac{\chi(\chi_\star - \chi)}{\chi_\star}$$

$$W^g(\chi) \propto H(z)\, \frac{dN}{dz}$$

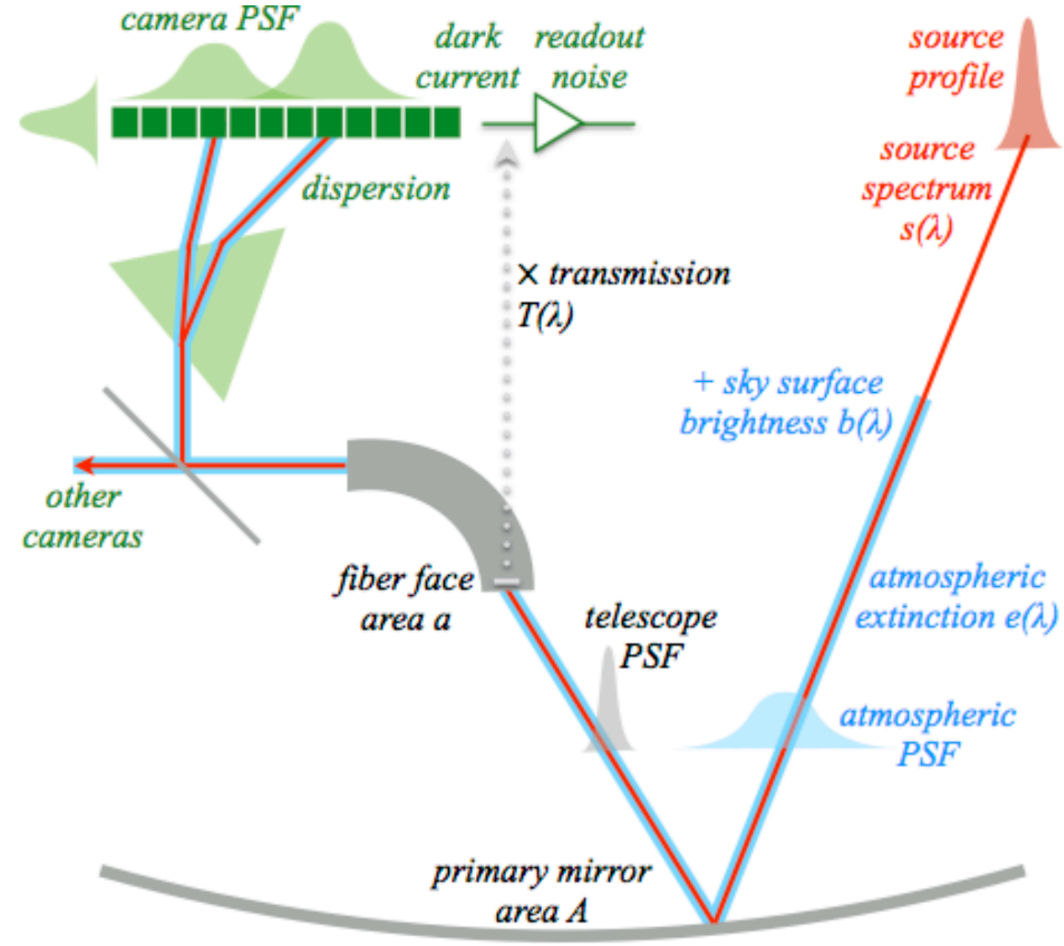
Fractional error on the N(z) for the photometric population; assuming you have spectroscopy at the relevant redshifts, but not necessarily of a complete population

$$\frac{\delta N_i^{(p)}}{N^{(p)}} \approx \frac{0.6}{b_i^{(s)} D_i}\left(\frac{N_i^{(s)}}{10^3}\, \frac{\langle \beta_i \rangle_C}{0.1}\right)^{-1/2}\left(\frac{1+z}{2}\right)^{-0.5} \qquad \textit{where} \qquad \beta_i \equiv \frac{[N_i^{(p)} b_i^{(p)}]^2\, C_{ii}(\ell, m)}{\sum_{j=1}^{N_{\rm bin}} [N_j^{(p)} b_j^{(p)}]^2\, C_{jj}(\ell, m)}.$$

Can we get the relevant spectra (&, as a bonus, in sufficient numbers for RSD)?



DESI /PFS (1D) spectra simulation (Specsim, Kirkby ++)



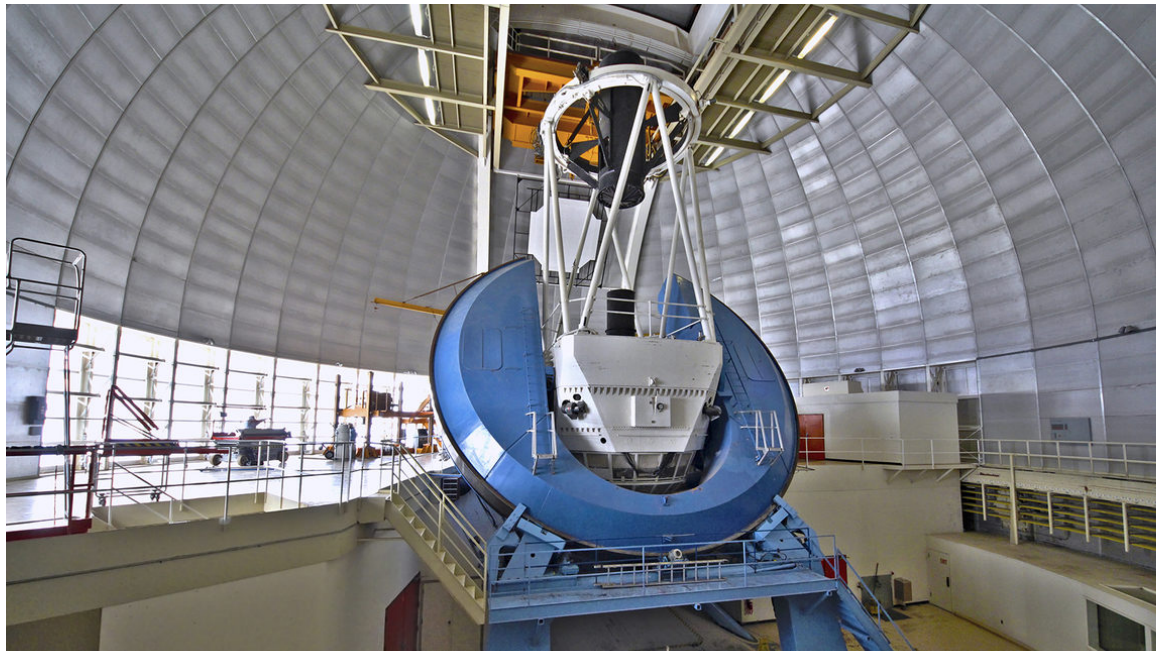
and DESI template-based redshifting (Redrock, Bailey++) of the break.

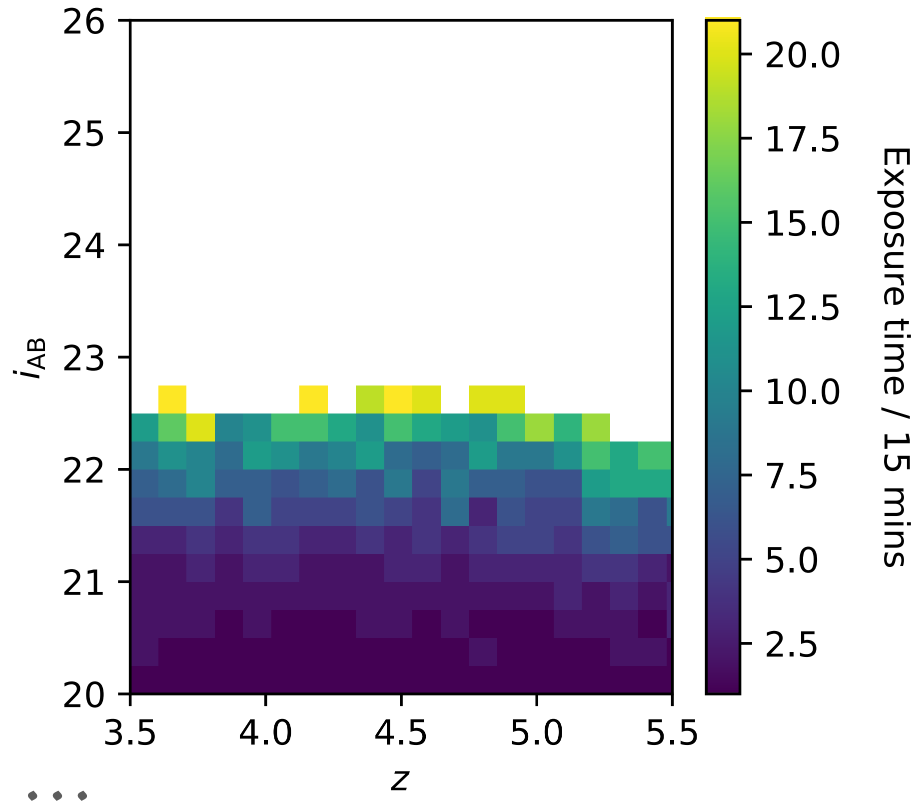
— Forecasting isn't trivial:

EM /Abs lines 🙂 :

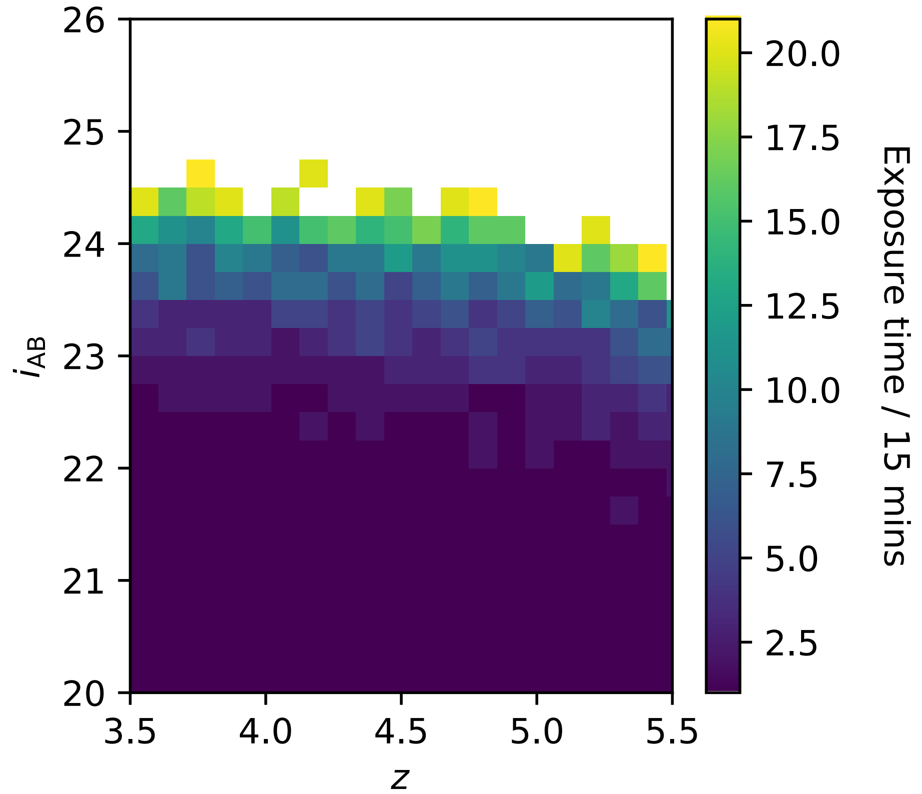
50% Ly-a but resonance …,

population degeneracies 🤨 , etc





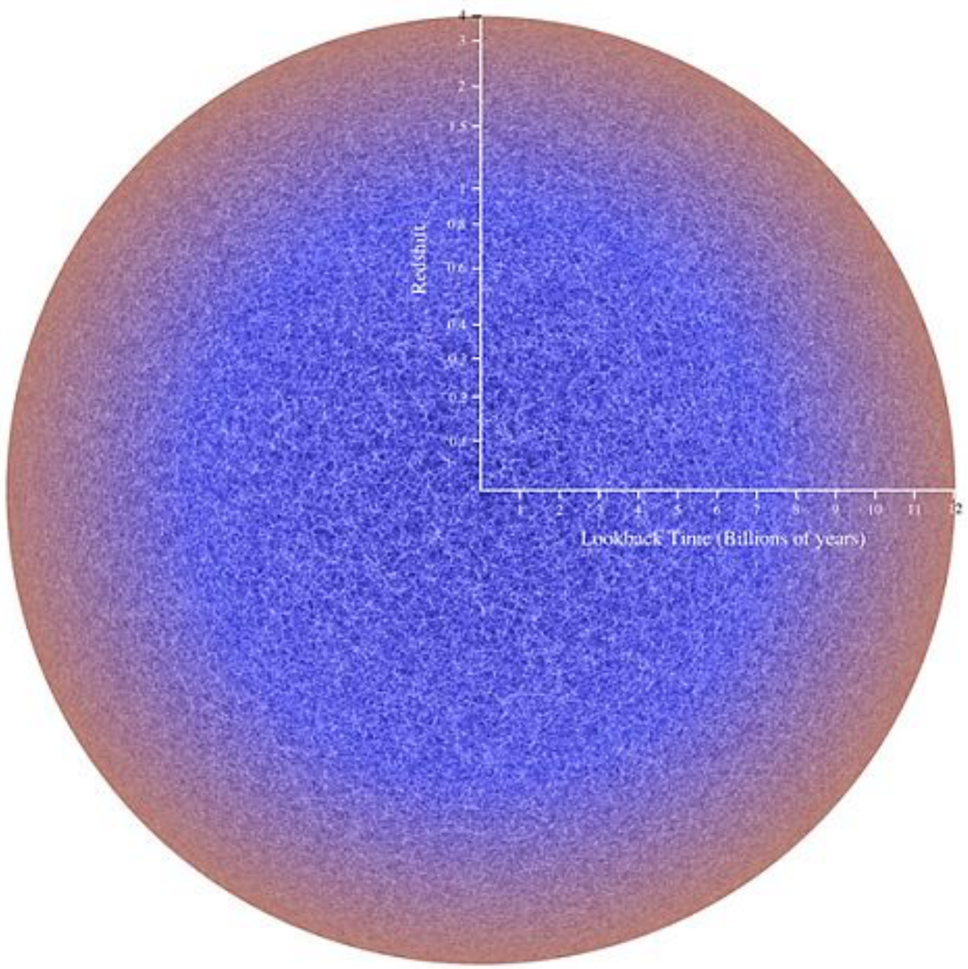
4m; 5000 multiplex; 14k deg²; near-infrared to 1um, …

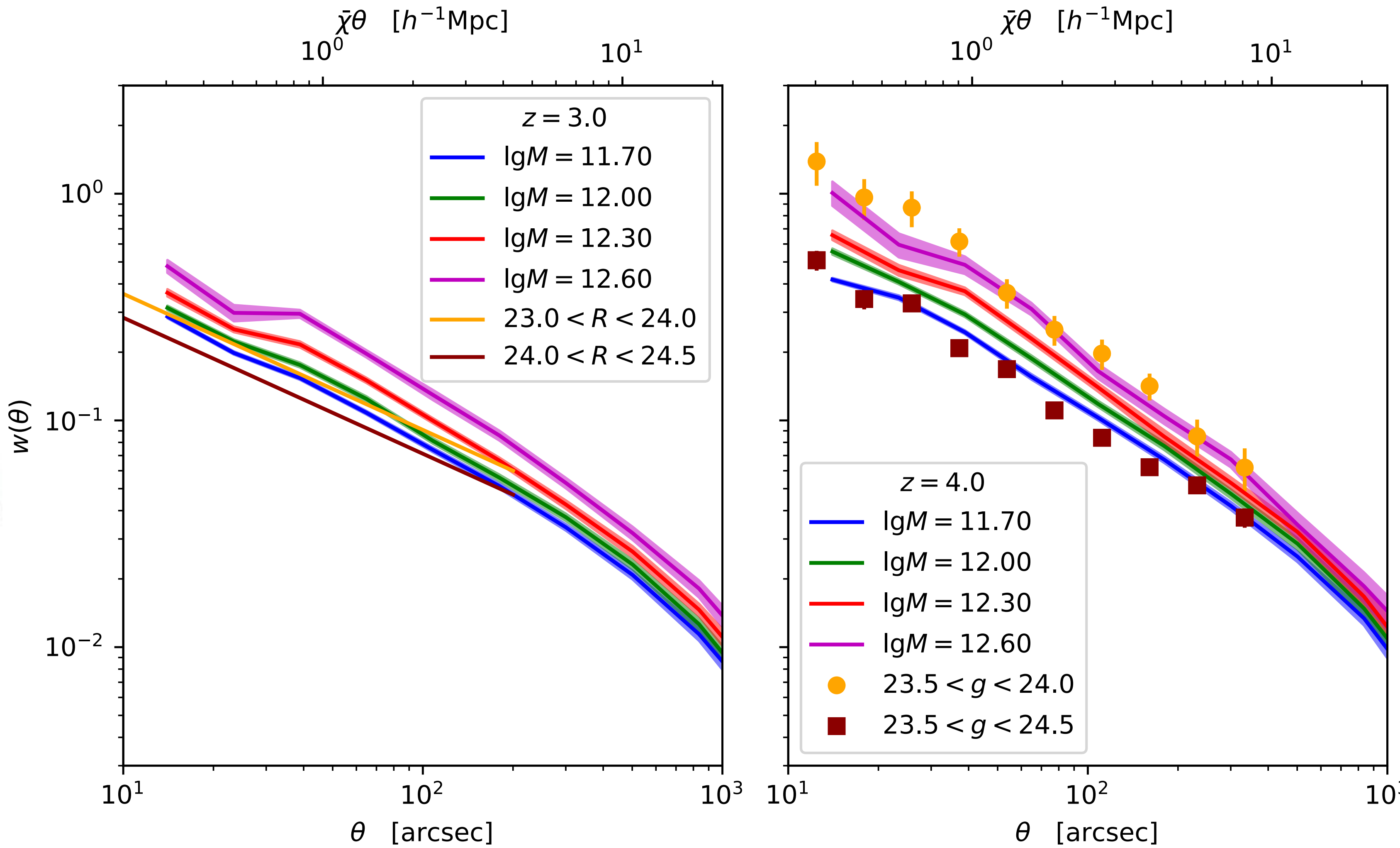


8.2m; 2400 multiplex; 1.4k deg²; near-infrared to 1.26um, …

Precursor: 16 deg² spectroscopic programme of 25th mag. LBGs as part of GF program

(Many) Future directions:





$z \sim 3, 4$ halo catalogues meeting:

mass resolution, cosmology and volume are, as usual, hard to find…

***KIAS Horizon Run 3 & 4** are ~ solutions,*

but perhaps there are others?

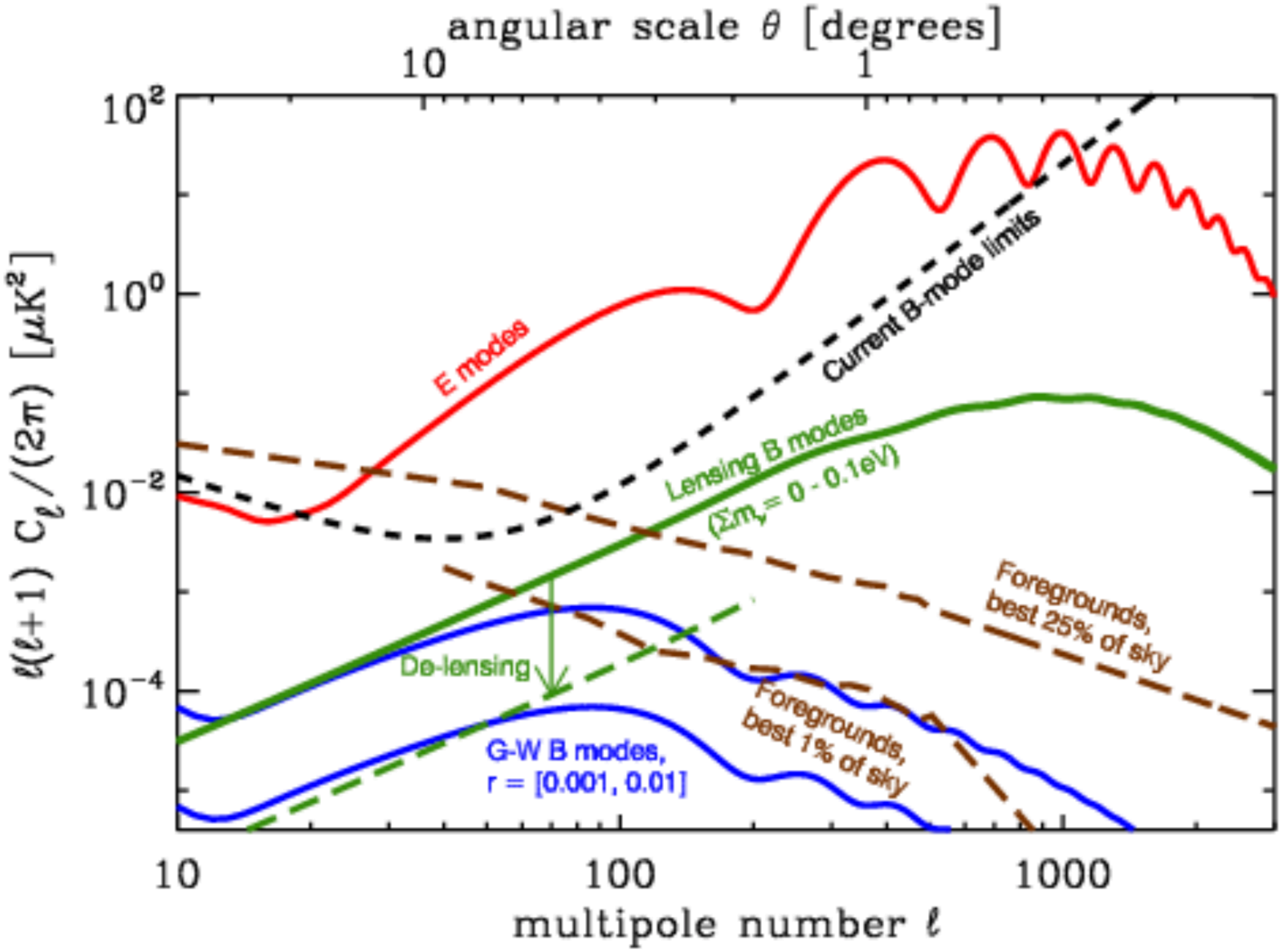
Observed clustering is consistent with simple, dated, HOD;

Accuracy is crucial for accurate forecasting

Exercise for the reader:

NBODYKIT

About time we all started working towards one public code base? Beat shot noise in code development for e.g. DESI, Taipan, etc… even Euclid? e.g. LSST CosmoLIB



$$C_l^{\kappa\kappa} \rightarrow (1-\rho_l^2)C_l^{\kappa\kappa} \qquad \rho_l = \frac{C_l^{\kappa I}}{\sqrt{C_l^{\kappa\kappa}C_l^{II}}}$$

Increased (S/N) on Ckg, or even regimes for which competitor to (small-area) internal delensing? The latter is unlikely.

— *Delensing requires complete knowledge of the gravitational potential along the line of sight, e.g. $z \sim 3, 4, 5$, etc …*

— *Future generation B-mode searches will likely internally delens (x12 in r, as opposed to x4 for complete knowledge of $z < 4$, Smith ++), but …..*

— *We have **low-z tracers**, and corresponding mass adds **statistical fluctuations to the high-z kappa** (e.g. Sherwin & Schmittfull; Yu++)*

Come find me or mjwilson@lbl.gov