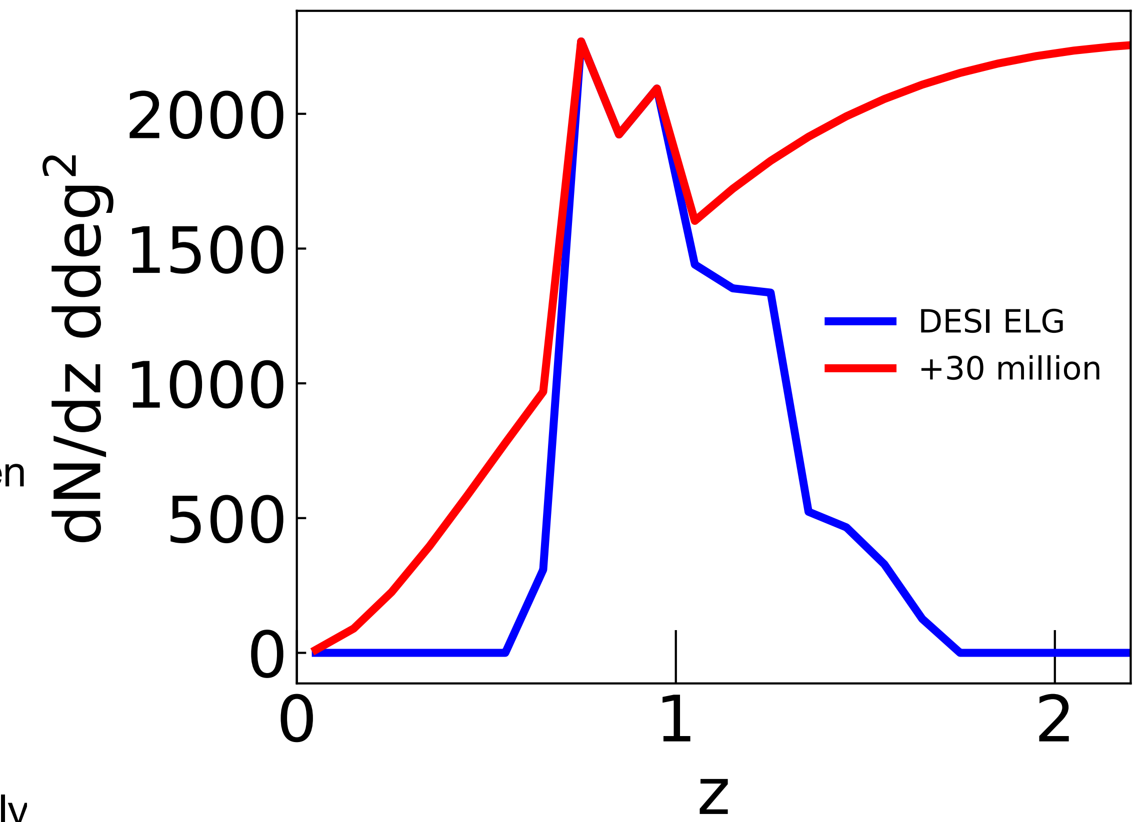
Explore parameter constraints for ~arbitrary additions to DESI

- Fisher matrix calculations including multi-tracers (ELG, LRG, QSO).
- Always assume 14k sq. deg.
- Add some number of galaxies with fixed comoving density, typically over all z<z_max, although in some cases also with z>z_min.
- "ELG" means b(z)D(z)=0.84D(0)
- "LRG" means b(z)D(z)=1.7D(0)
- b(z) capped at bias corresponding to most massive halos for given number density.
- Always include DESI as planned, Planck, CMB-S4, half of Euclid redshift survey (to avoid worrying about overlap).
- Intended more to compare different scenarios than predict absolute results, because based on power spectrum with relatively simple maximum k to account for non-linearity, while real analysis would use some hideously complicated non-linear model and hopefully higher order statistics, or a complex reconstruction process.
- 21 cm can't magically do better in the same volume



Isolated RSD

- Cosmological parameter constraints will always come from full broadband power spectrum (including BAO, RSD, AP, etc.)
- Quoting cosmological parameter constraints doesn't entirely illuminate what is going on.
- This shows f sigma_8 constraints vs. z for different scenarios, indicative of basic statistical power at that z.

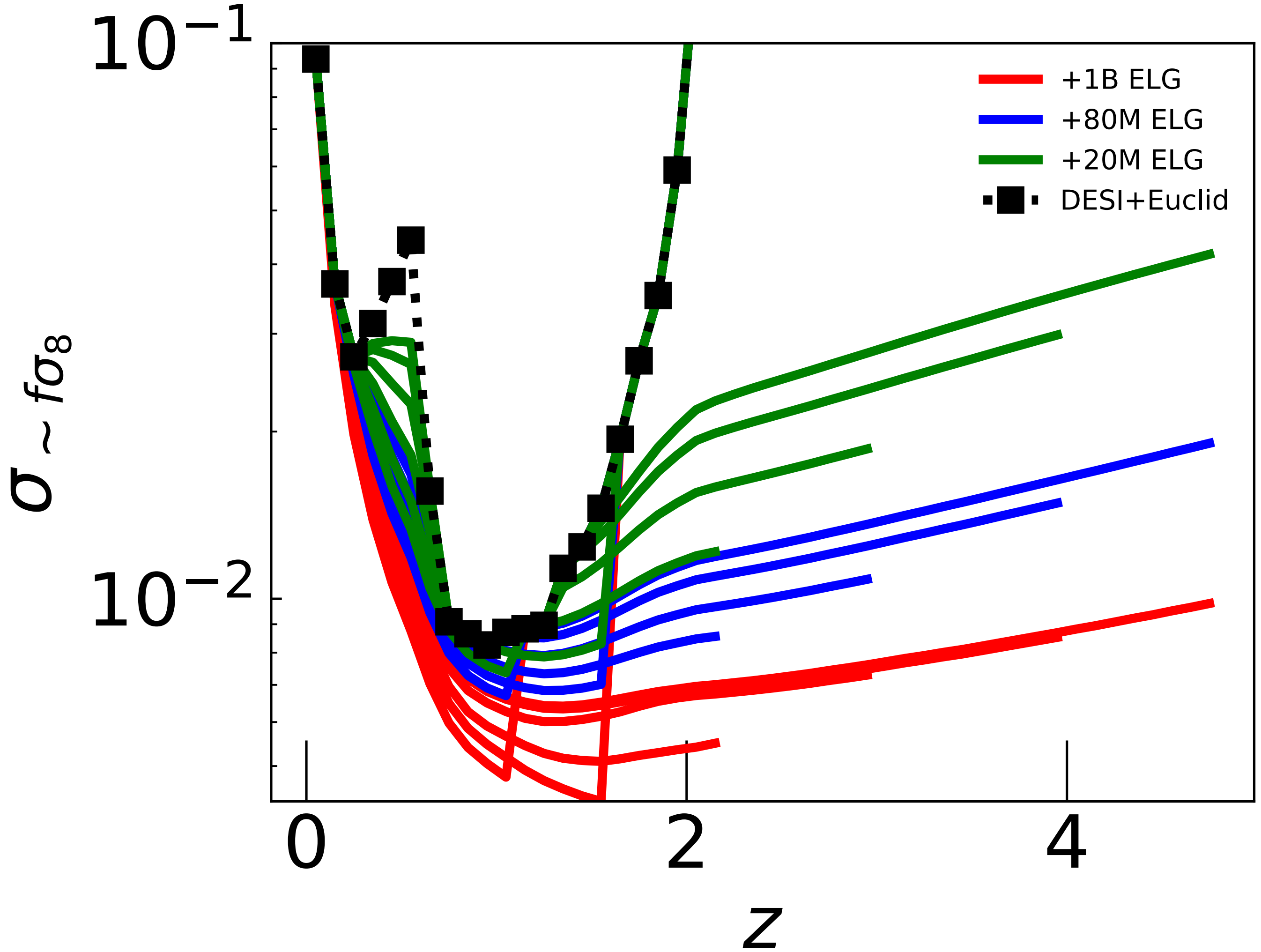


FIG. 2. Isolated RSD errors, assuming geometry and linear power spectrum effectively known. All errors assume $dz = 0.1$ bins, shown by squares for baseline DESI+Euclid case. The colored lines show adding different numbers of galaxies to the baseline, spread to different maximum z identifiable by the end of the line (for low $z_{\max}$ the line goes back to the baseline at higher z where no galaxies are added). The odd-looking behavior going from $z_{\max} \leq 2.2$ to $z_{\max} \geq 3$ in the +1 billion case appears to result from the higher $z_{\max}$ densities still being low enough to use the baseline bias, while at $z_{\max} \lesssim 3$ the densities are becoming high enough that the bias is reduced by the halo density constraint (which leads to better RSD constraints, beyond the simple reduction in noise).

Neutrino mass

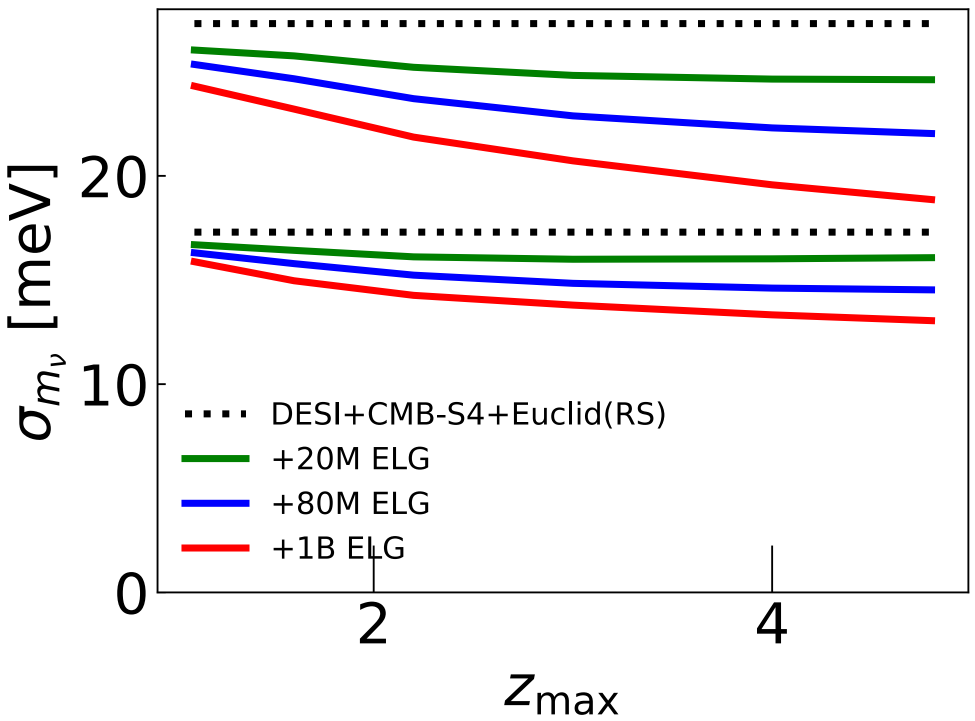


FIG. 3. Neutrino mass constraints, for 14000 sq. deg. with uniform comoving density out to $z_{\max}$. Upper lines of each type use current τ constraint, while lower lines add prior with $\sigma_\tau = 0.005$. Baseline is DESI plus CMB-S4 plus Euclid redshift survey only. Maximum inverse variance improvement factors 1.2, 1.5, 2.1 for the +20, +80, 1000 million cases with poor τ, or 1.2, 1.4, 1.8 for better τ.

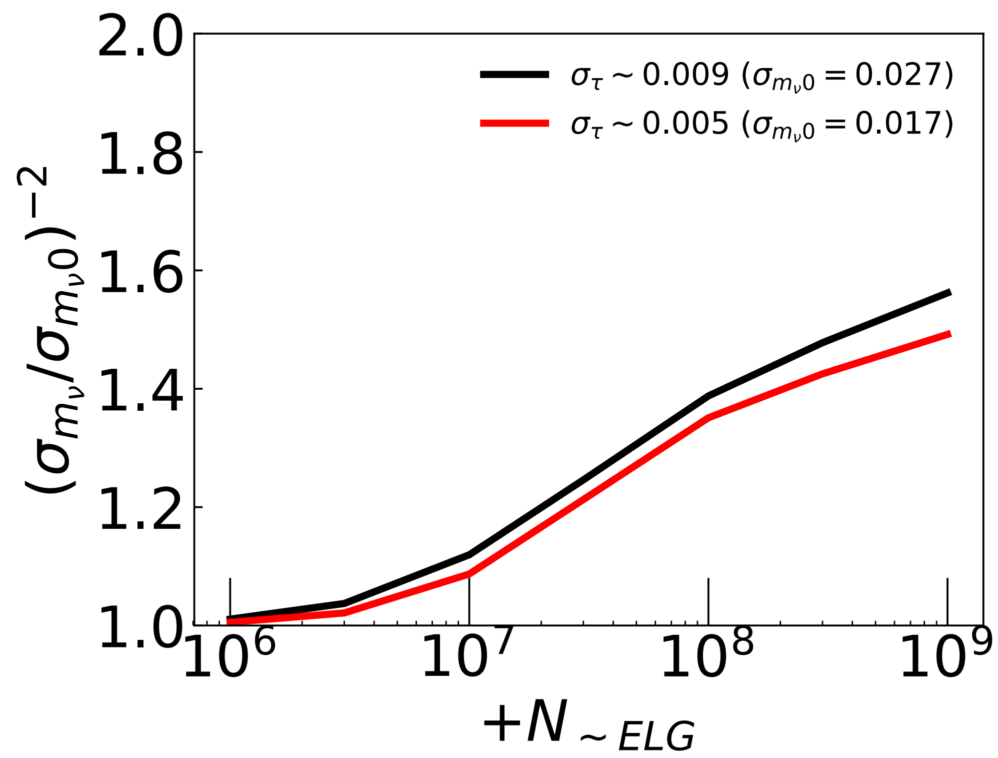


FIG. 5. Neutrino mass constraint improvements (inverse variance relative to baseline), for 14000 sq. deg. with uniform comoving density added over the range $2 < z < 3.5$. Black lines use current τ constraint, while red lines add prior with $\sigma_\tau = 0.005$. Baseline is DESI plus CMB-S4 plus Euclid redshift survey only.

- Best neutrino mass constraint comes by comparing low-z power amplitude measured by RSD to high-z power amplitude measured by CMB.
- Limited by CMB optical depth measurement, even for modestly optimistic improvements over Planck. Really still limited by CMB, at a lower level, even with better tau.
- Scale dependence not *quite* powerful enough to allow a competitive internal-to-z-survey measurement.

Dark Energy TF FoM

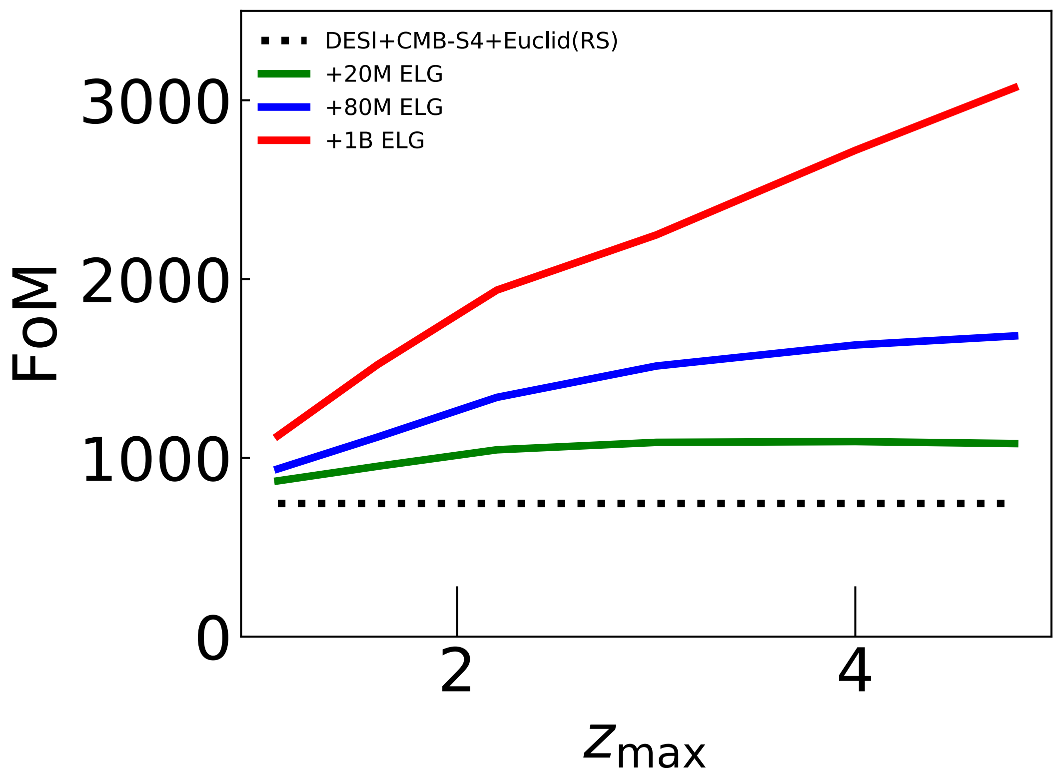


FIG. 7. DETF FoM (marginalized over neutrino mass) for 14000 sq. deg. with uniform comoving density out to z_{max}. Baseline is DESI plus CMB-S4 plus Euclid redshift survey only. Improvement factors 1.5, 2.3, 4.1.

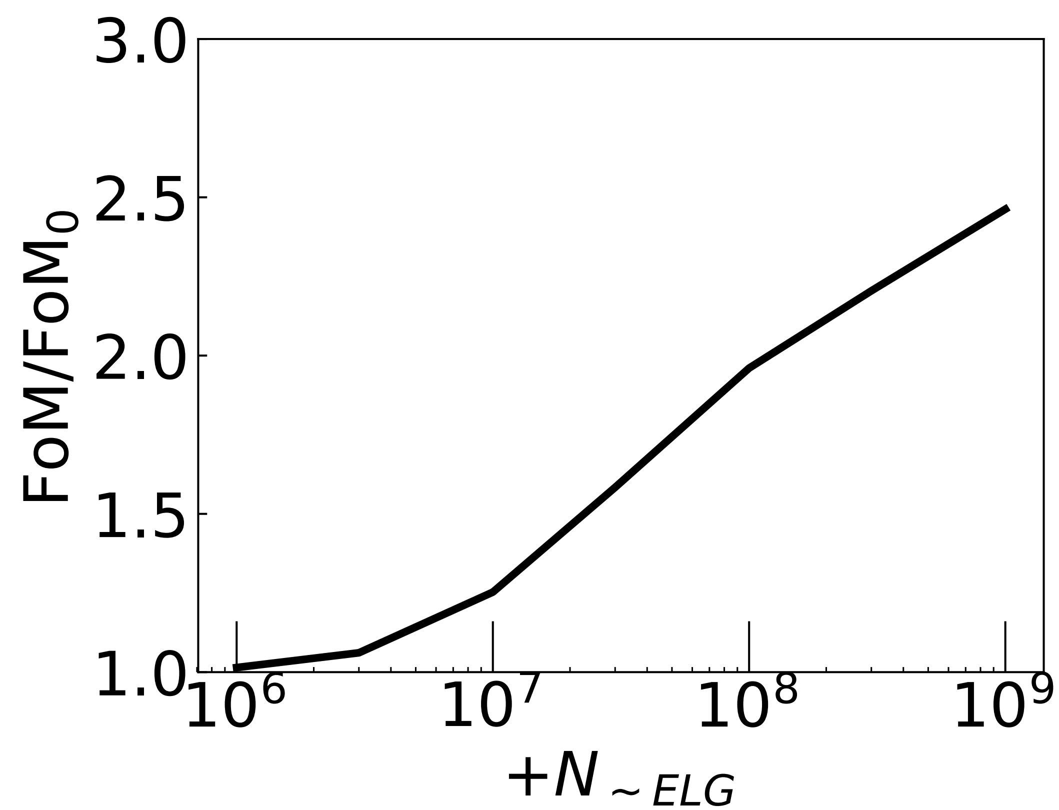


FIG. 9. Dark Energy FoM improvements for 14000 sq. deg. with uniform comoving density added over the range $2 < z < 3.5$. Baseline is DESI plus CMB-S4 plus Euclid redshift survey only.

- Proportional to area inside w_0-w_a contours.
- Marginalize over neutrino mass.
- Can get factor of 2 improvement with, e.g., ~100 million galaxies in the range 2<z<3.5 (imagining LAE survey).

Curvature

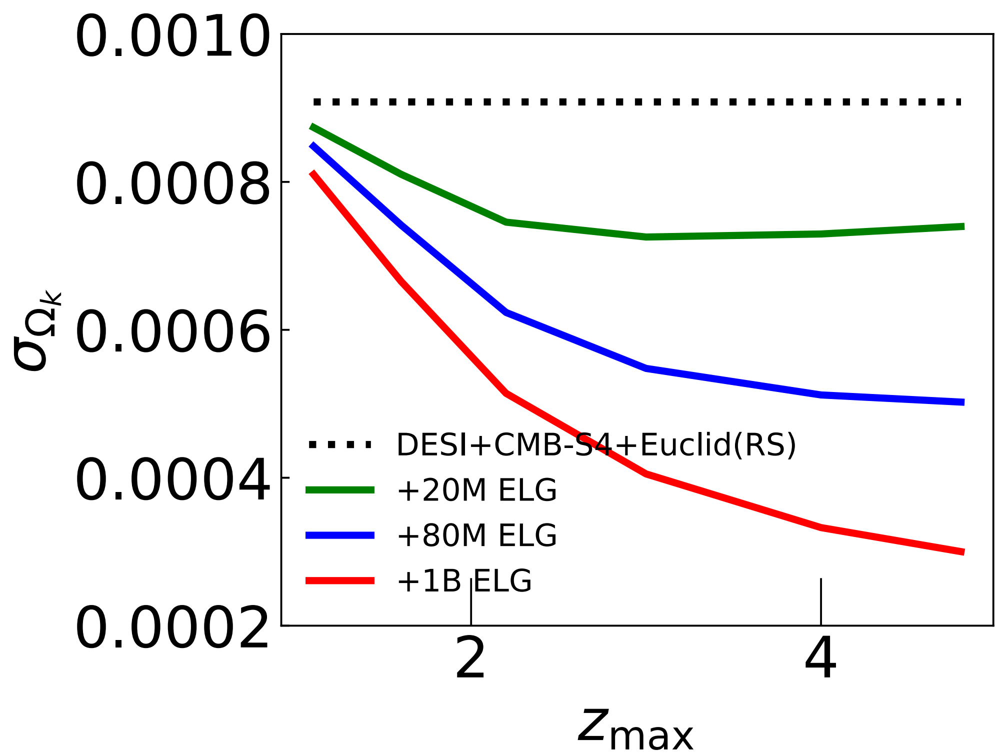


FIG. 20. Curvature, i.e., Ω_K, constraints for 14000 sq. deg. with uniform comoving density out to $z_{\rm max}$. Baseline is DESI plus CMB-S4 plus Euclid redshift survey only. Improvement factors 1.6, 3.3, 9.2.

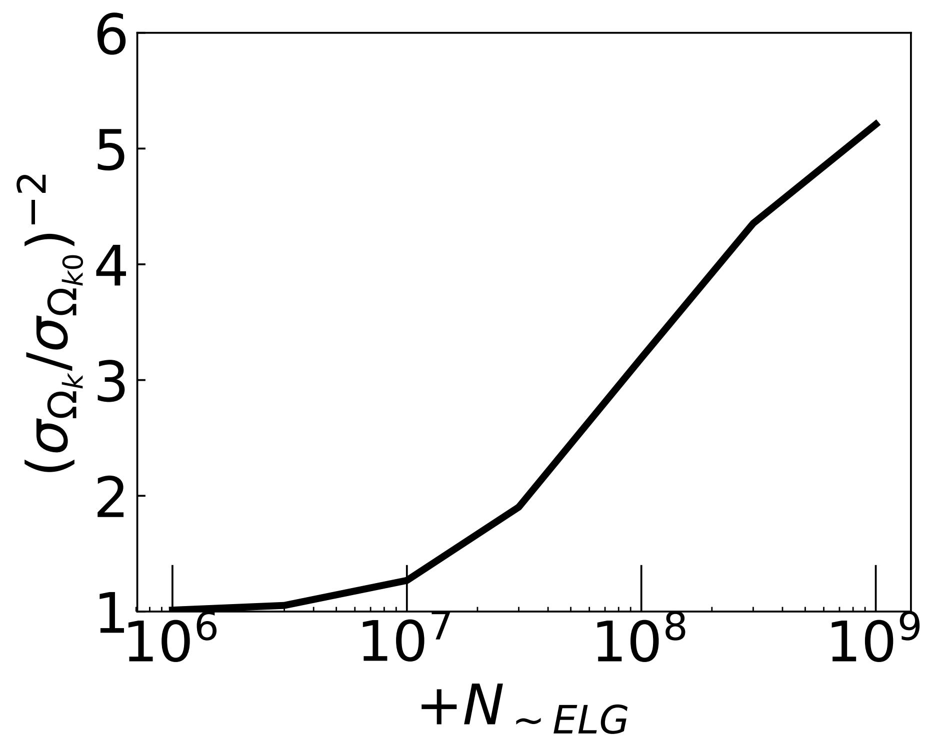


FIG. 22. Ω_k constraint improvements (inverse variance relative to baseline), for 14000 sq. deg. with uniform comoving density added over the range $2 < z < 3.5$. Baseline is DESI plus CMB-S4 plus Euclid redshift survey only.

- Measuring curvature (as a single-parameter extension) is easier, with a factor of 2 improvement in inverse variance at ~30 million 2<z<3.5 galaxies.
- A factor of 2 improvement in inverse variance means improvement equivalent to duplicating all previous data - it’s pretty unreasonable to ask for more than that from a modest cost extension.

Modified Gravity

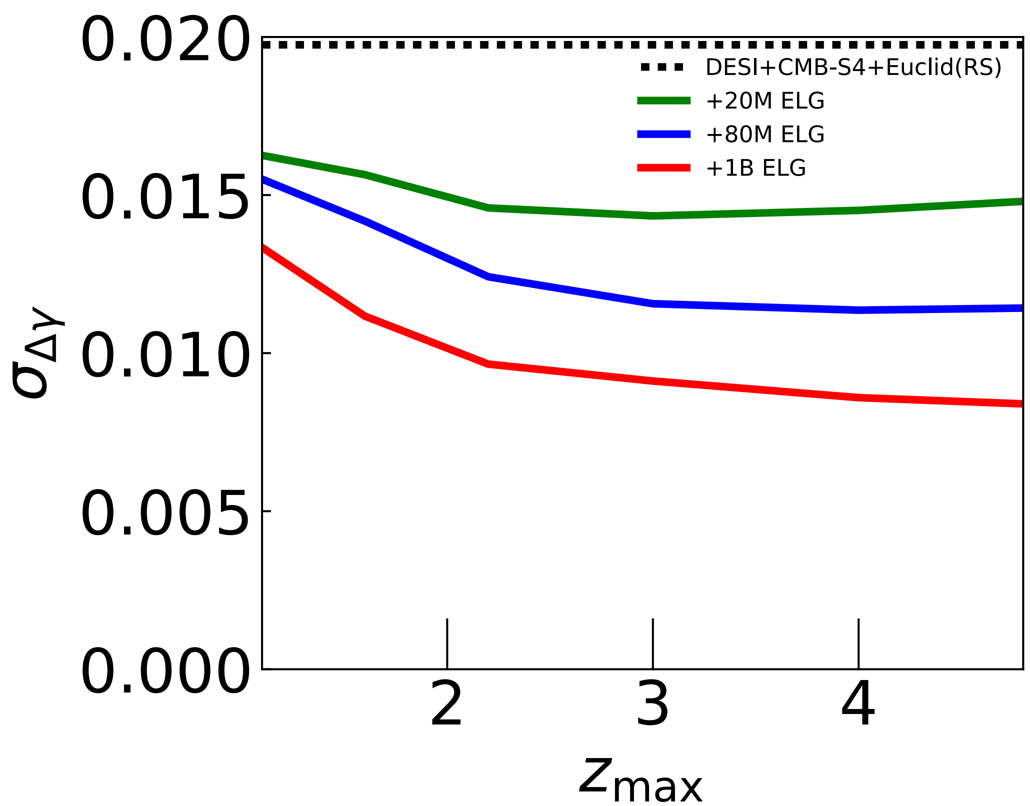


FIG. 23. Constraints on modified gravity parameter $\Delta\gamma$ Baseline is DESI plus CMB-S4 plus Euclid redshift survey only. Improvement factors: 1.9, 3.0, 5.5. [PM: *For now, this parameter does not affect CMB lensing*]

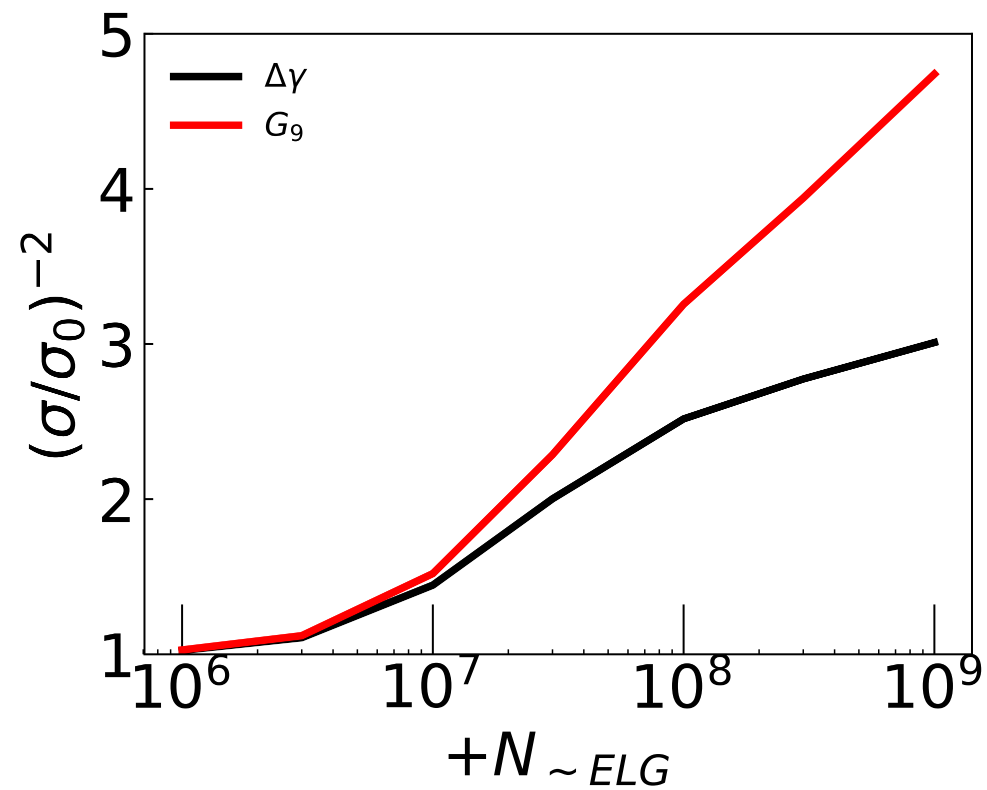


FIG. 25. Modified gravity constraint improvements (inverse variance relative to baseline), for 14000 sq. deg. with uniform comoving density added over the range $2 < z < 3.5$. Baseline is DESI plus CMB-S4 plus Euclid redshift survey only. Note that gravity modification is not applied to CMB lensing.

- Factors of 2 improvement in modified growth of structure parameters from 20-30 million galaxies. (see Font-Ribera et al. 2014 for definitions)

non-Gaussianity

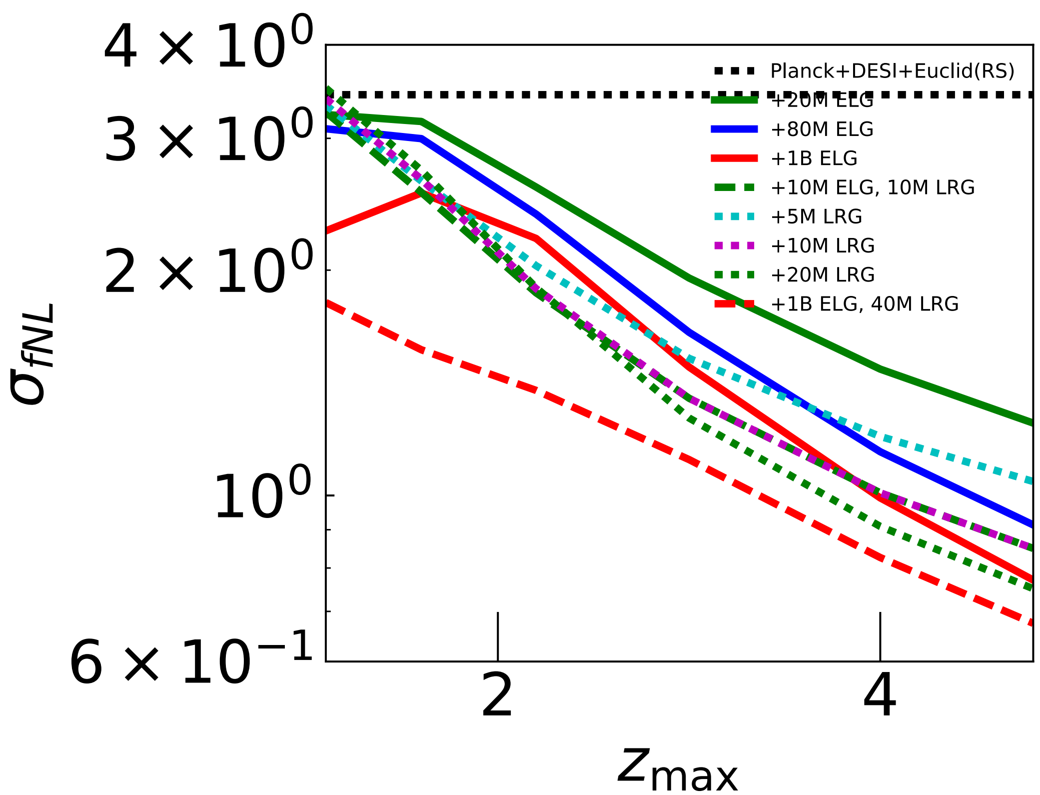


FIG. 26. Local non-Gaussianity constraints, for 14000 sq. deg. with numbers added to approach uniform comoving density out to $z_{\max}$, for different numbers of "ELGs" (objects with bias $0.84D(0)/D(z)$) and "LRGs" (objects with bias $1.7D(0)/D(z)$). Bias is always capped to be no greater than the bias expected if the objects lived in the most massive halos with this number density (this is why increasing the density of LRGs can actually give worse results).

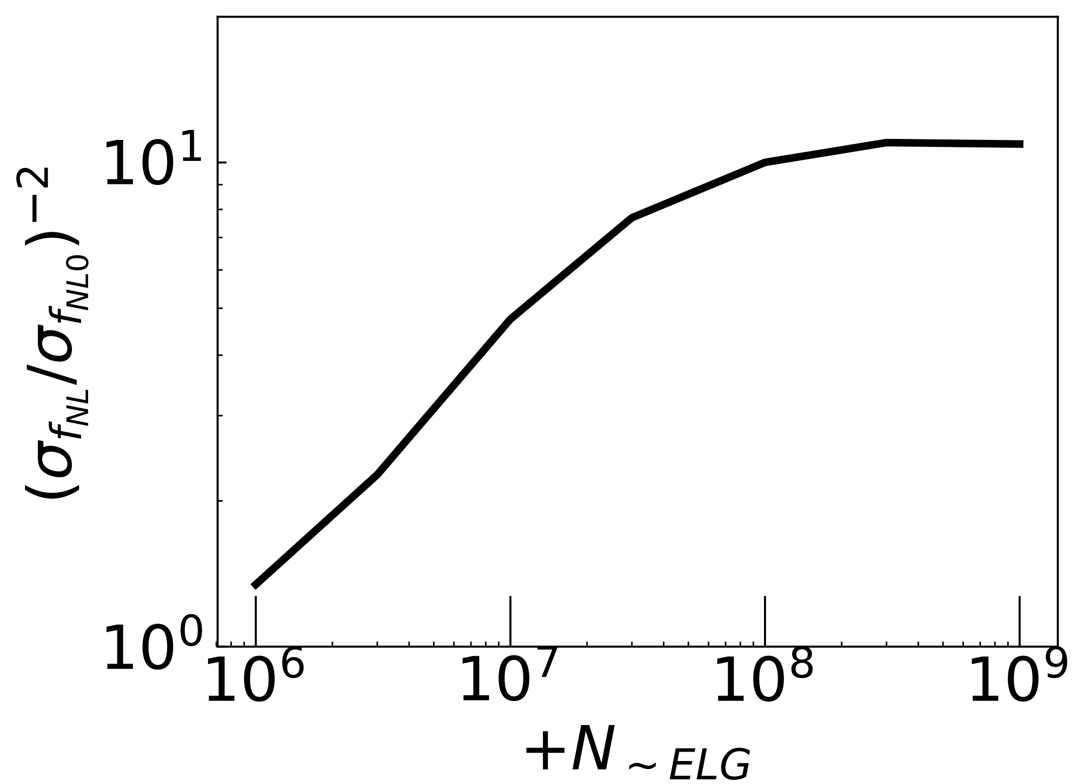


FIG. 27. Local non-Gaussianity constraint improvements (inverse variance relative to baseline), for 14000 sq. deg. with uniform comoving density added over the range $2 < z < 3.5$. Baseline is DESI plus CMB-S4 plus Euclid redshift survey only. Note vertical log scale.

Conclusions

- A 20-30 million galaxy survey (at least if they are in $2<z<3.5$) can produce powerful measurements of Modified Gravity and curvature, and a very powerful measurement of local non-Gaussianity.

- 100 million-level surveys could produce powerful measurements of Dark Energy and running of the spectral index.

- Neutrino mass, n_s, N_nu,eff are harder within calculations I can do.

Discussion

- DESI volume (z<1.4) ~110 cubic Gpc. z<2.2 (4.0) over the same area is ~250 (560) Gpc^3

- If you aren't excited about these gains, we are probably seeing here the exhaustion of usefulness of these kinds of projections. They are useful in the near-linear regime when densities are not too high, but very big gains in the future probably rely on going beyond that, i.e., once the (easily accessible at least) volume in the Universe starts to run out, improvements will only come through sophisticated non-linear and multi-tracer analyses that can take advantage of high number densities. If these ideas are to be used to motivate future surveys, ~theorists need to work toward concrete Fisher-matrix-like projections for how well they can do for specific surveys.

- LSST/Euclid lensing does not change the basic picture, improving the baseline results but not changing the relative value of z-survey.

Annoyingly non-simple maximum k

- Wanted to somewhat realistically account for fact that non-linearity is less of a problem at high z, and for lower bias objects.
- Cut on observable fluctuation amplitude, including z dependence and angle dependence (radial modes have higher amplitude so lower max k).
- Additionally have tracer-independent, Lagrangian displacement-inspired z and angle-dependent cut.
- Also, Seo & Eisenstein signal damping factors (e.g., makes BAO within broadband consistent with isolated BAO).

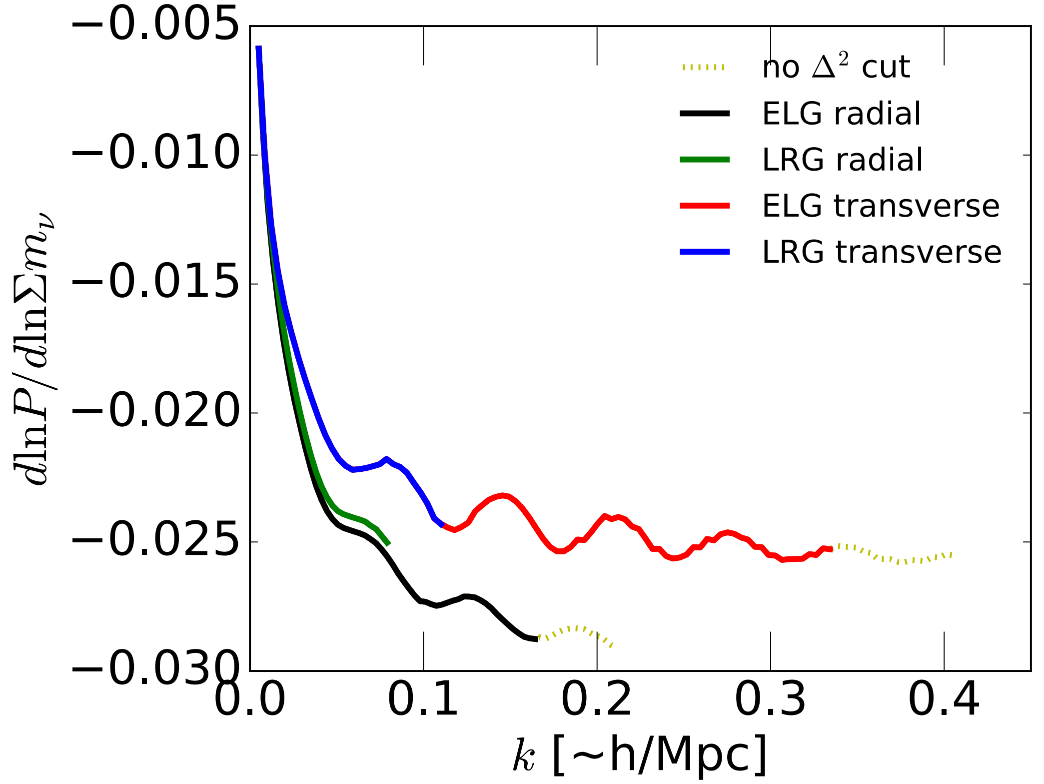


FIG. 28. Derivative of tracer power with respect to sum of neutrino masses, at $z = 1.55$ (for a case where there are some LRG-bias objects at all z). The solid lines stop at the $\Delta^2(\mathbf{k}) < 1$ cutoff that we use for Fisher calculations (which is much more stringent for high bias). The dotted lines show the object-independent maximum k, which has no impact in this case.

Inflation perturbation spectrum

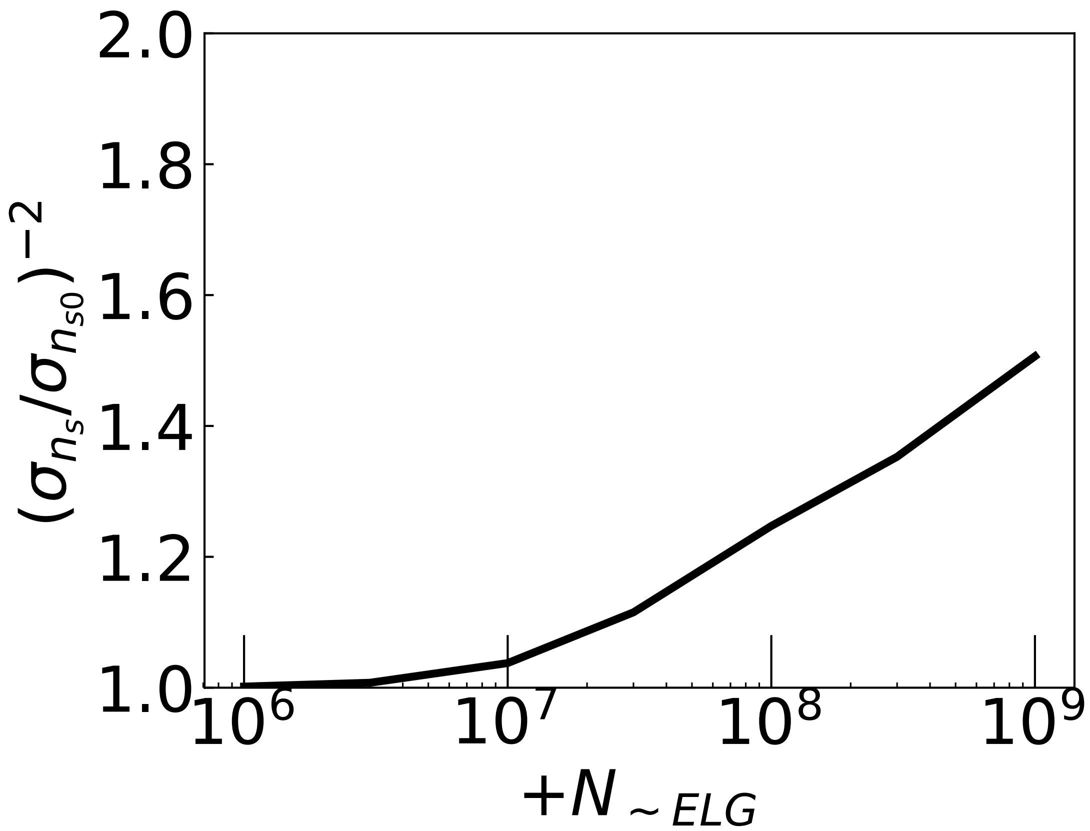


FIG. 16. n_s constraint improvements (inverse variance relative to baseline), for 14000 sq. deg. with uniform como added over the range $2 < z < 3.5$. Baseline is DESI plus CMB-S4 plus Euclid redshift survey only.

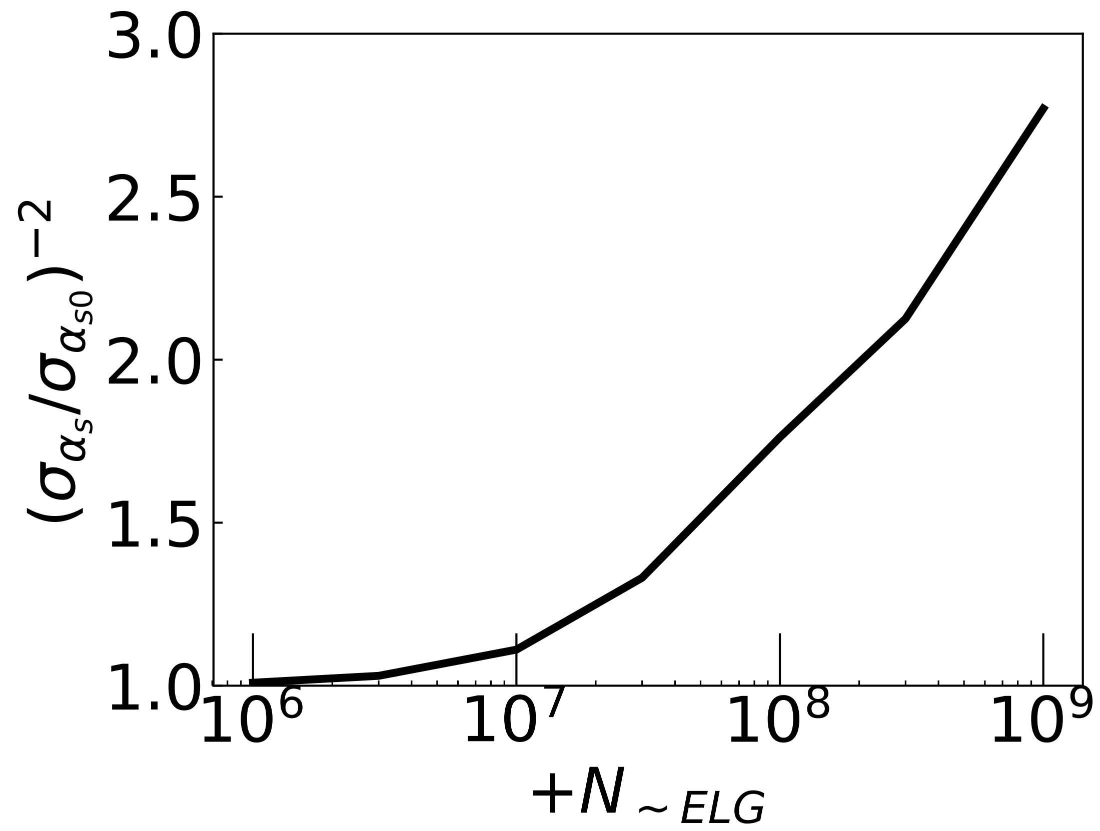


FIG. 19. α_s constraint improvements (inverse variance relative to baseline), for 14000 sq. deg. with uniform comoving density added over the range $2 < z < 3.5$. Baseline is DESI plus CMB-S4 plus Euclid redshift survey only.

Dark Radiation

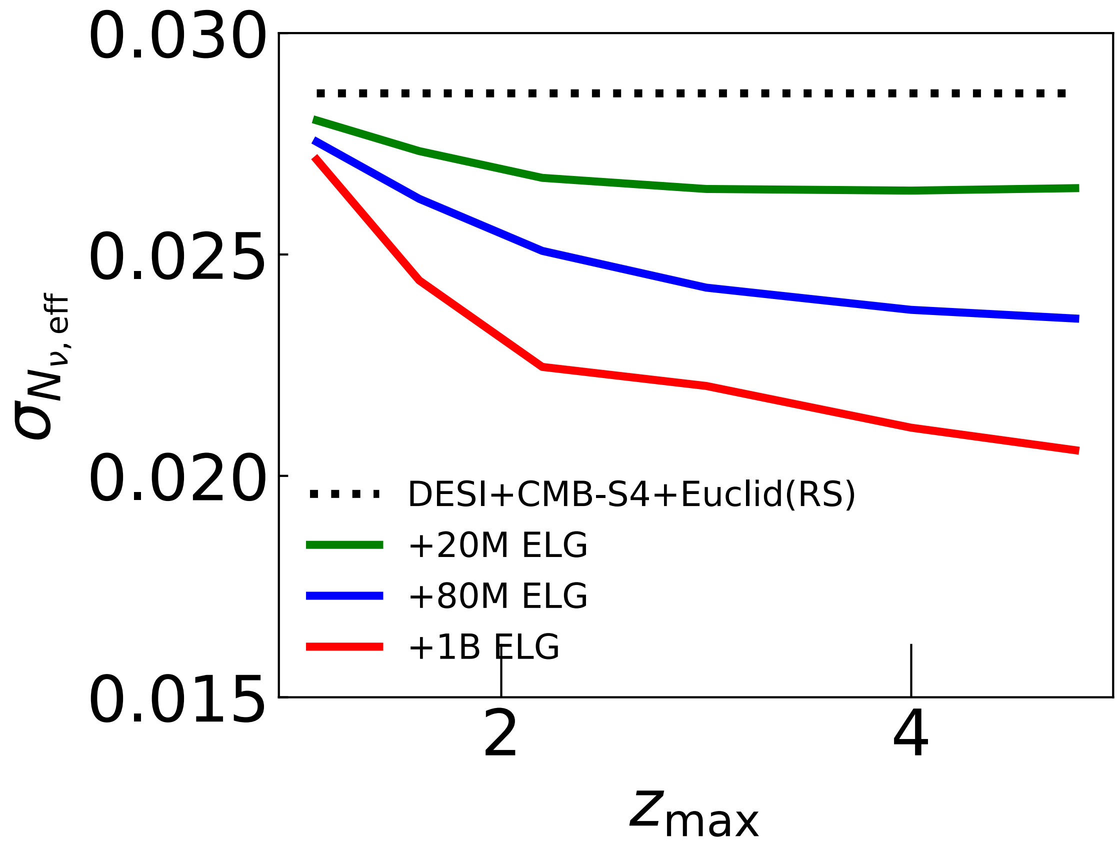


FIG. 10. Dark radiation, i.e., $N_{\nu,\mathrm{eff}}$, constraints for 14000 sq. deg. with uniform comoving density out to $z_{\max}$, for different total numbers of galaxies. Baseline is DESI plus CMB-S4 plus Euclid redshift survey only. Improvement factors 1.2, 1.5, 1.9.

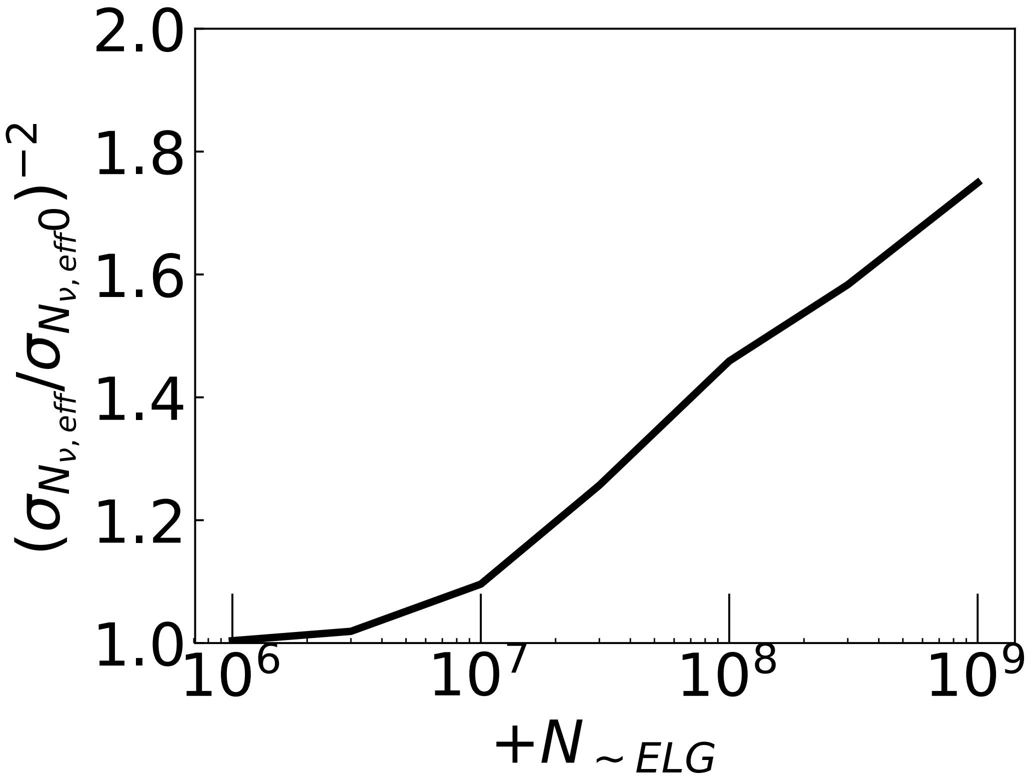


FIG. 12. Dark Radiation constraint improvements (inverse variance relative to baseline), for 14000 sq. deg. with uniform comoving density added over the range $2 < z < 3.5$. Baseline is DESI plus CMB-S4 plus Euclid redshift survey only. This does not try to include BAO phase information beyond standard maximum k for broadband power.