I believe I can Fl(at Sk)y!

Approximations for Euclid

[paper imminent]

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with

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Outline

- **Introduction**
- **Approximations**
- **Specifications**
- **Spectra**
- **Noisy Realisations**
- **Conclusions**

Number Counts

- **Galaxy number counts fluctuation:** $\Delta(\hat{\mathbf{n}}, z) = \frac{N(\hat{\mathbf{n}},z) - \bar{N}(z)}{\bar{N}(z)}$
- **1st order effects** [Bonvin, Durrer 2011, Challinor, Lewis 2011]:

$$\Delta(r(z), \hat{\mathbf{n}}) = \underbrace{b(z)\delta_M}_{\text{Density}} - \underbrace{\frac{1}{\mathcal{H}}\partial_r(\mathbf{v}\cdot\hat{\mathbf{n}})}_{\text{Redshift space distortion}} + \underbrace{\frac{(5s-2)}{2}\int_0^{r(z)} \mathrm{d}r\, \frac{r(z)-r}{r(z)r}\nabla^2_\Omega(\Phi+\Psi)}_{\text{Lensing}} + \ldots \quad (1)$$

Angular Power Spectrum

$$C_\ell(i,j) = \frac{2}{\pi} \int \mathrm{d}z\,\mathrm{d}z'\,w_i(z)\,w_j(z') \times \int_0^\infty \mathrm{d}\ln k\,k^3\,P(k,z,z')\,j_\ell(k\,r)\,j_\ell(k\,r') \quad (2)$$

- survey windows
- k integrals
- spherical bessel functions (and derivatives)

Approximations

- Limber Approximation $\left(|k| = \sqrt{k_\parallel^2 + k_\perp^2} \sim k_\perp = \frac{\ell+1/2}{r(z)}\right)$:

Approximations

- Limber Approximation $\left(|k_{\mathrm{L}}| = \frac{\ell+1/2}{r(z)}\right)$:

$$
{}^{\mathrm{L}}C_\ell(i,j) \simeq \int \mathrm{d}z \quad \ldots \quad P\left(\frac{\ell+1/2}{\bar{r}}, z, z\right) \tag{3}
$$

[Limber (1954), Durrer (2020)]

Good on **small scales**, and for **wide bins**

[Di Dio et al. (2014, 2019), Fang et al. (2020)]

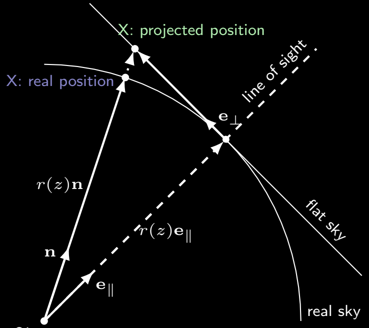
Approximations

- Limber Approximation $\left(|k_{\rm L}| = \frac{\ell+1/2}{r(z)}\right)$:

$$ {}^{\rm L}C_\ell(i,j) \simeq \int {\rm d}z \quad \dots \quad P\left(\frac{\ell+1/2}{\bar{r}}, z, z\right) \tag{3} $$

[Limber (1954), Durrer (2020)]

- Flat Sky Approximation $(\mathbf{k} = k_\parallel \, \mathbf{e} + r^{-1}\, \boldsymbol{\ell})$:



Approximations

- Limber Approximation $\left(|k_{\mathrm{L}}| = \frac{\ell+1/2}{r(z)}\right)$:

$$\boxed{\mathrm{L}}C_\ell(i,j) \simeq \int \mathrm{d}z \quad \ldots \quad P\left(\frac{\ell+1/2}{\bar{r}}, z, z\right) \tag{3}$$

[Limber (1954), Durrer (2020)]

- Flat Sky Approximation $(\mathbf{k} = k_{\parallel}\,\mathbf{e} + r^{-1}\,\boldsymbol{\ell})$:

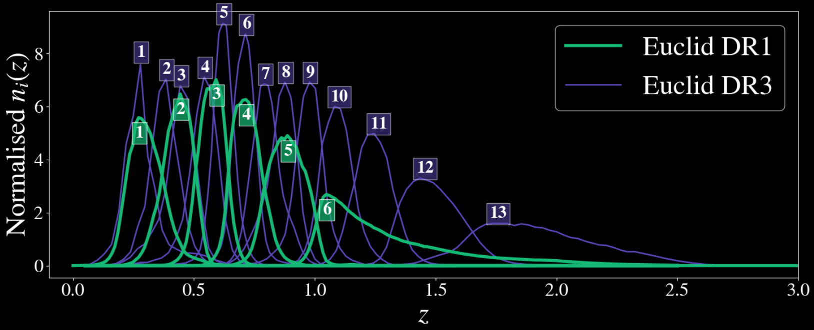
$$\boxed{\mathrm{F}}C_\ell(i,j) \simeq \int \mathrm{d}z\,\mathrm{d}z' \quad \ldots \quad \int_{\ell^2/r(\bar{z})}^{\infty} \mathrm{d}k \quad \ldots \quad P\left(k, \bar{z}, \bar{z}\right) \tag{4}$$

$$\left(k = \sqrt{k_{\parallel}^2 + k_{\mathrm{L}}^2(\ell)}\right)$$

- reduces to Limber for **Density-Lensing** and **Lensing-Lensing**

Euclid Photometry

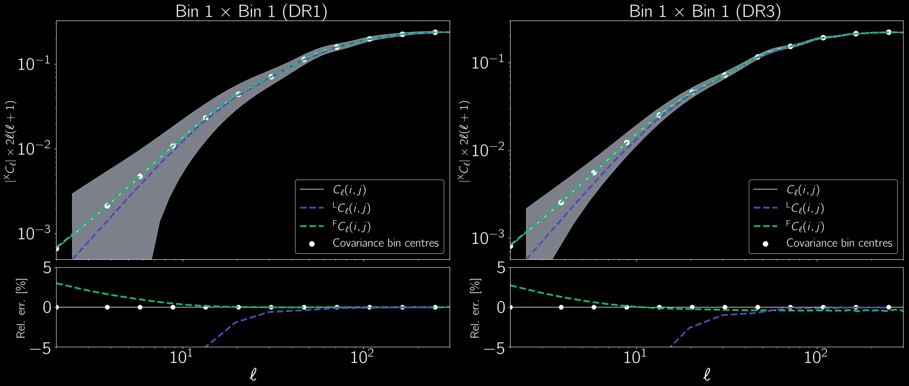
- DR1: 6 equi-populated bins, ...
- DR3: 13 equi-populated bins, ...
- Spaceborne → Gaussian covariance: Σ



[Euclid Collaboration: Mellier et al. 2024]

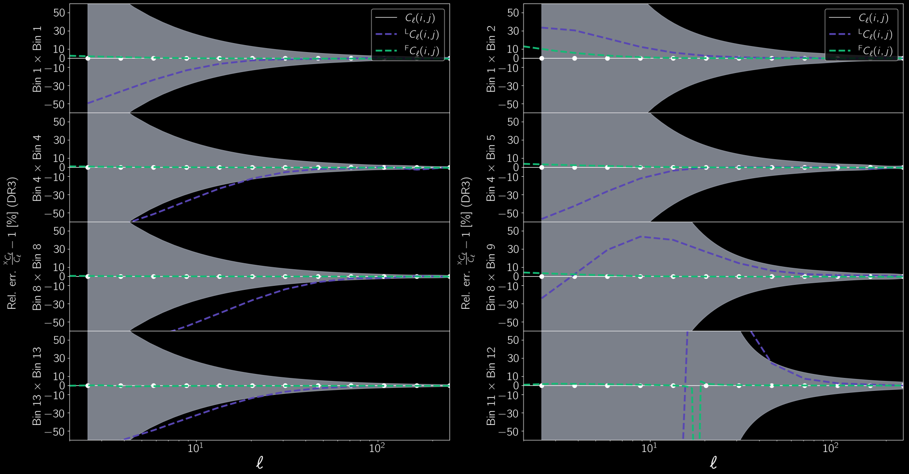
Results

- Full Calculation: CLASS (linear, all terms) [Lesgourgues 2011]
- Limber: CosmoSIS (CAMB) [Zuntz et al. 2015]
- Flat sky: CLASS adaptation of GZC [Gao et al. (2024)]



Results

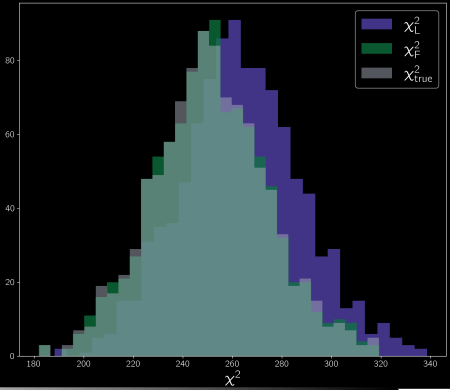
- Euclid DR3



Make Some Noise

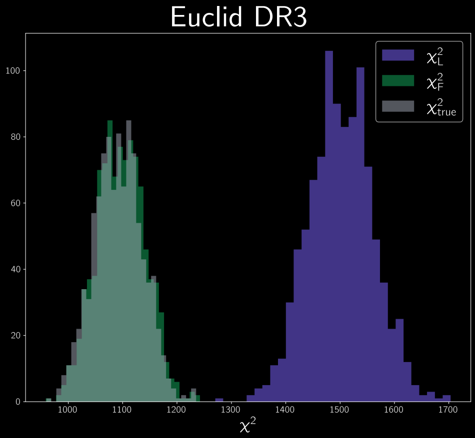
- 1000 noisy simulations: $\tilde{C}_\ell \sim \mathcal{N}(C_\ell, \Sigma^{-1})$
- residuals: $\mathbf{r}_\ell^X \sim \left[\tilde{C}_\ell(i,j) - {}^X C_\ell(i,j)\right]$, $X =$ [L,F,true]
- χ^2_X $\sim \sum_\ell \left(\mathbf{r}_\ell^X\right)^T \Sigma_\ell^{-1} \mathbf{r}_\ell^X$

Euclid DR1

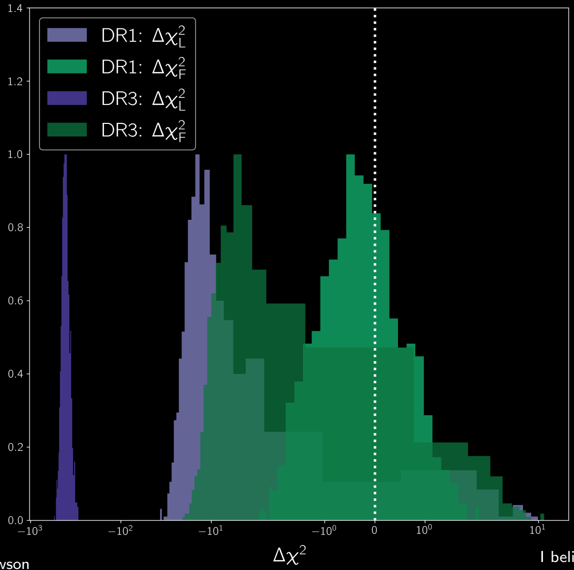


Make Some Noise

- $\Delta\chi^2 \sim 400$



Make Some Noise



Conclusions

- Improvements over Limber will be necessary in DR3
- Flat sky - accuracy and speed
- Other options, beyond Limber
- Future: code optimisation