Plan

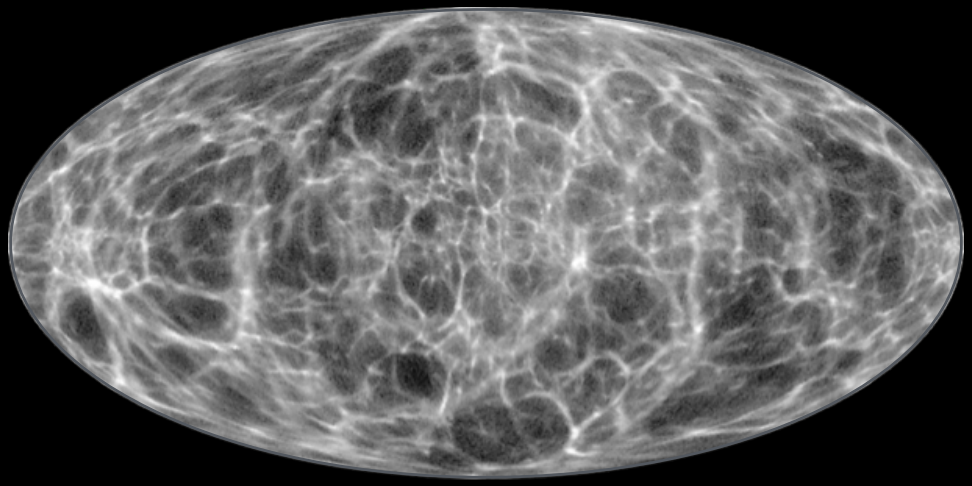
From dark matter to observables

- Tracer bias & stochasticity
- Redshift space distortions
- Projected densities

Large-scale structure probes

- Spectroscopic clustering
- Photometric clustering
- Weak lensing

Cosmic Laboratory

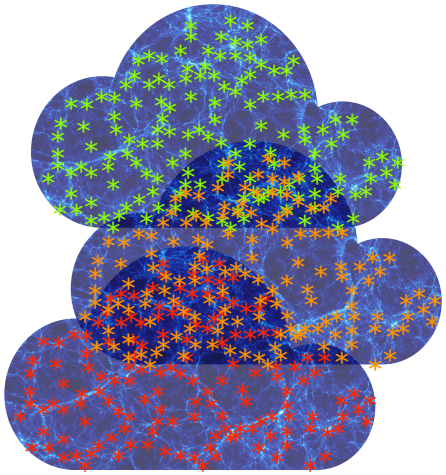


SKELETON
Dark Matter
(simulated)

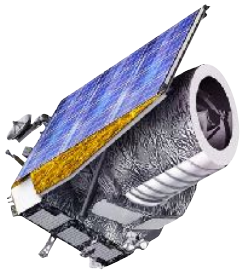
COSMIC WEB
galaxies
(observed)

Matter -> Observables

(dark)
matter



galaxies



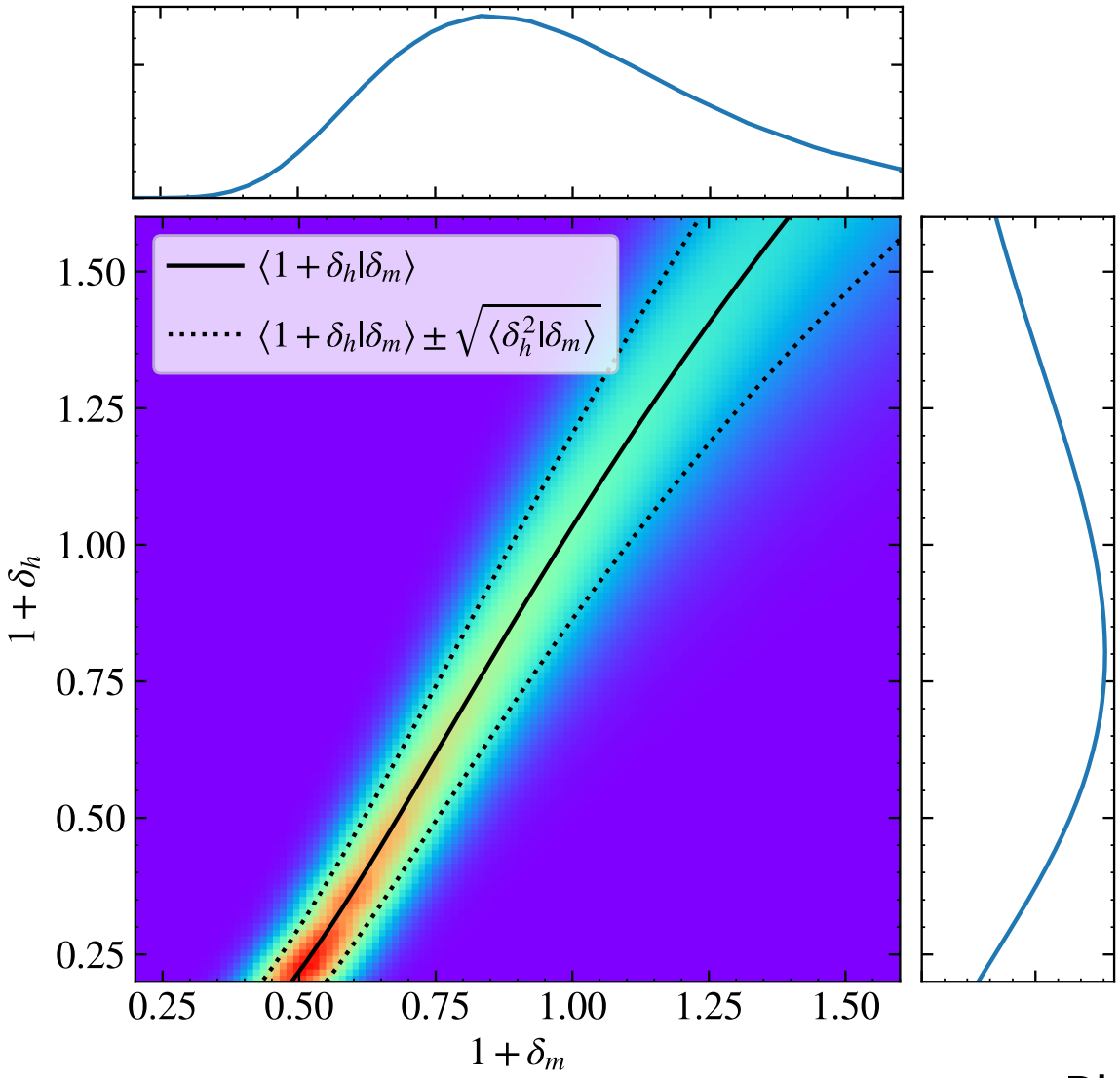
Euclid

galaxy counts

density δ_g

spec-z

Tracer Bias & Stochasticity



matter PDF

local bias:
conditional mean
$<\delta_h|\delta_m>$

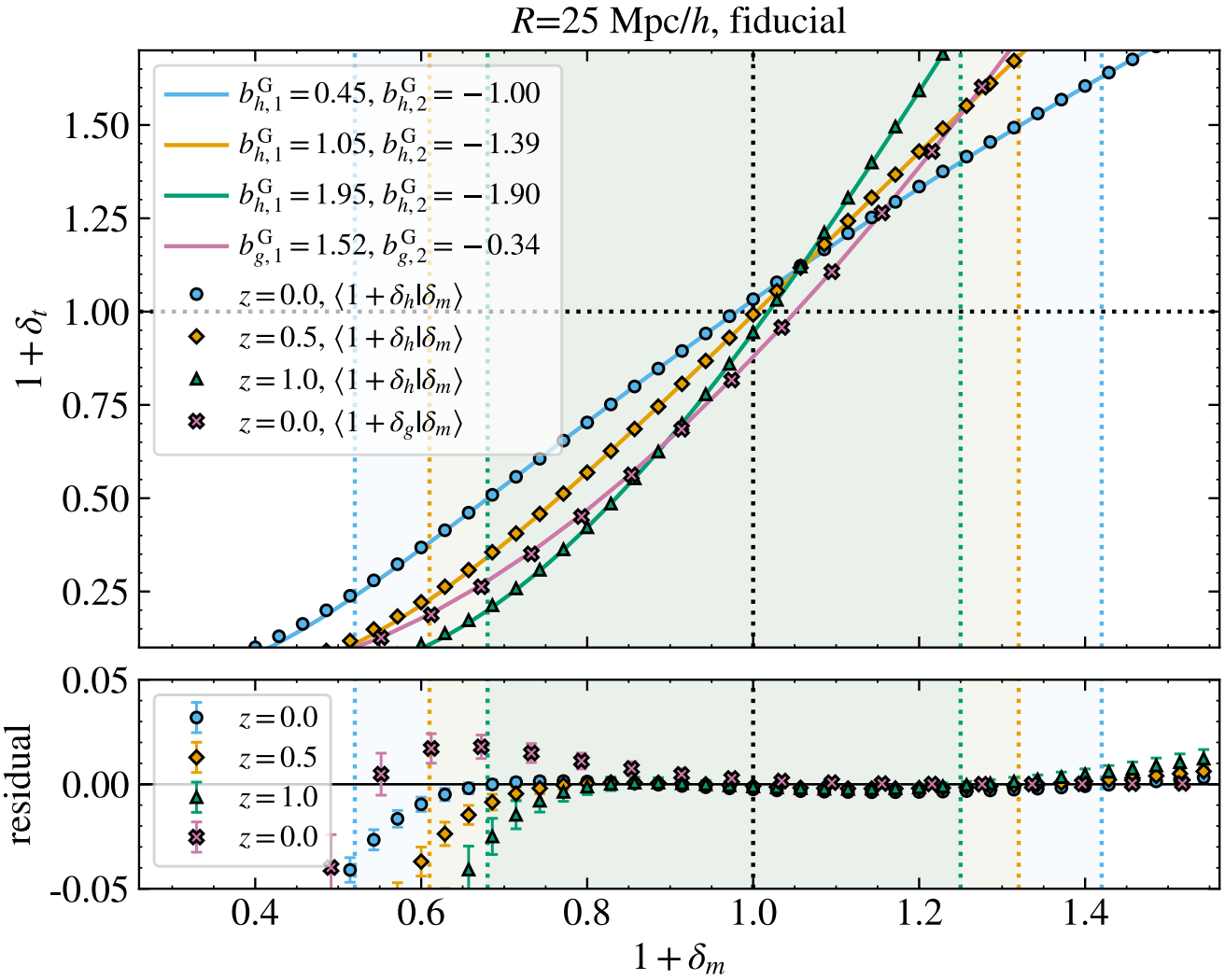
shot noise:
conditional varianc
$<\delta_h^2|\delta_m>$

adapted from Gould et al. 24

PhD student
Beth Gould

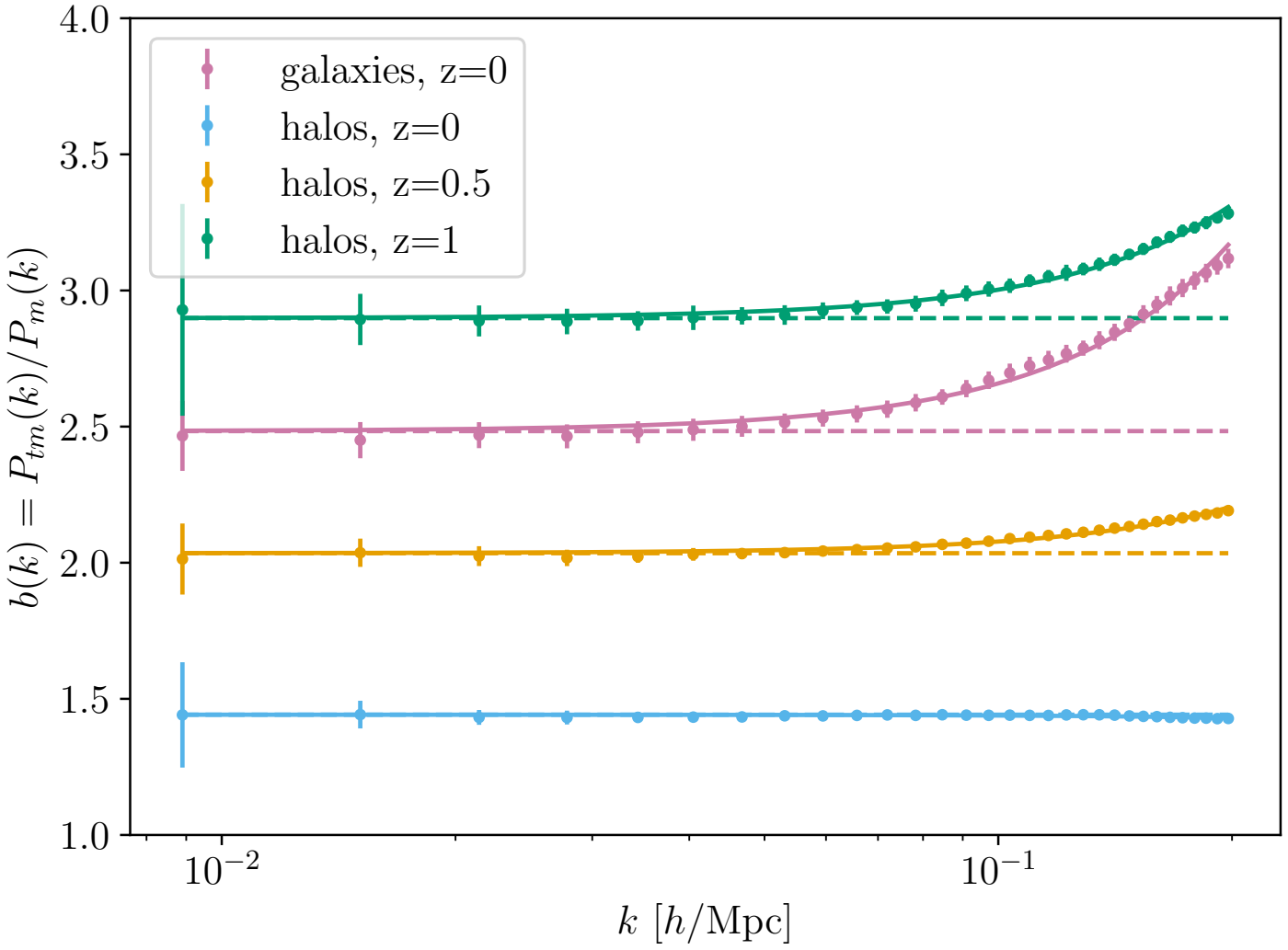
Tracer Bias

one-point local bias: conditional mean $\langle \delta_h | \delta_m \rangle$



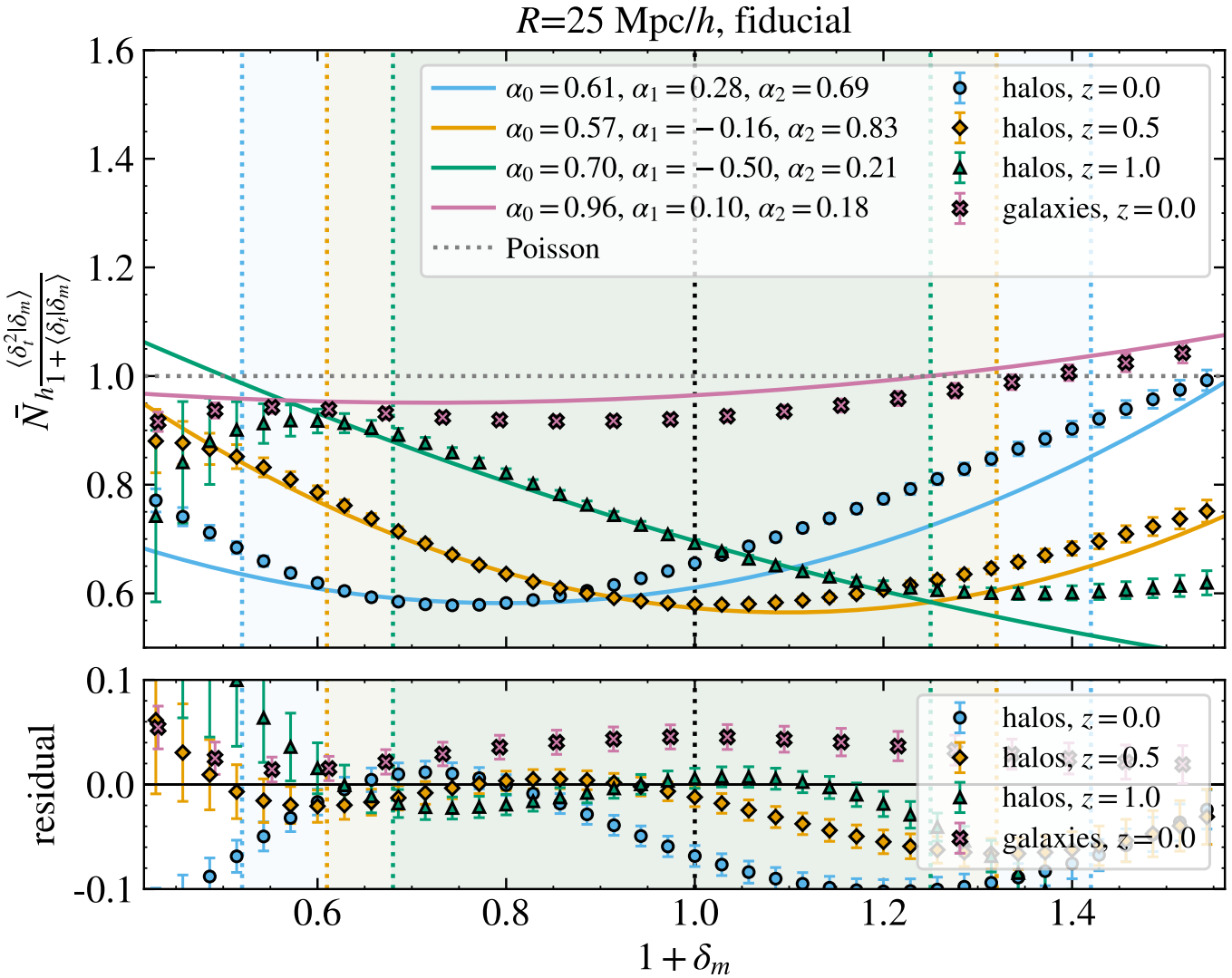
Tracer Bias Power Spectrum

power spectrum: linear (scale-dep) bias



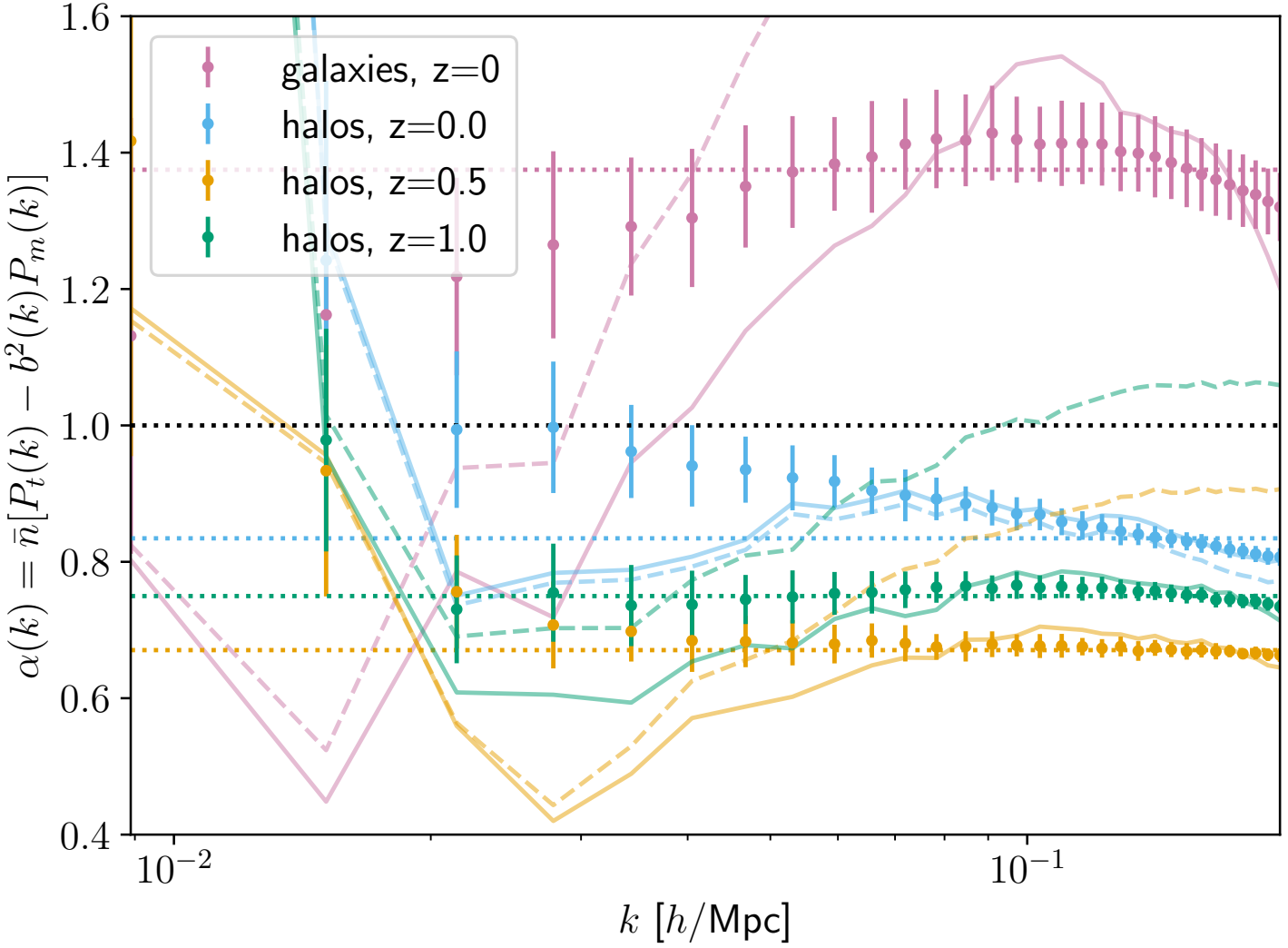
Tracer Stochasticity

one-point shot noise: conditional variance $\langle \delta_h^2 | \delta_m \rangle$



Tracer Stochasticity

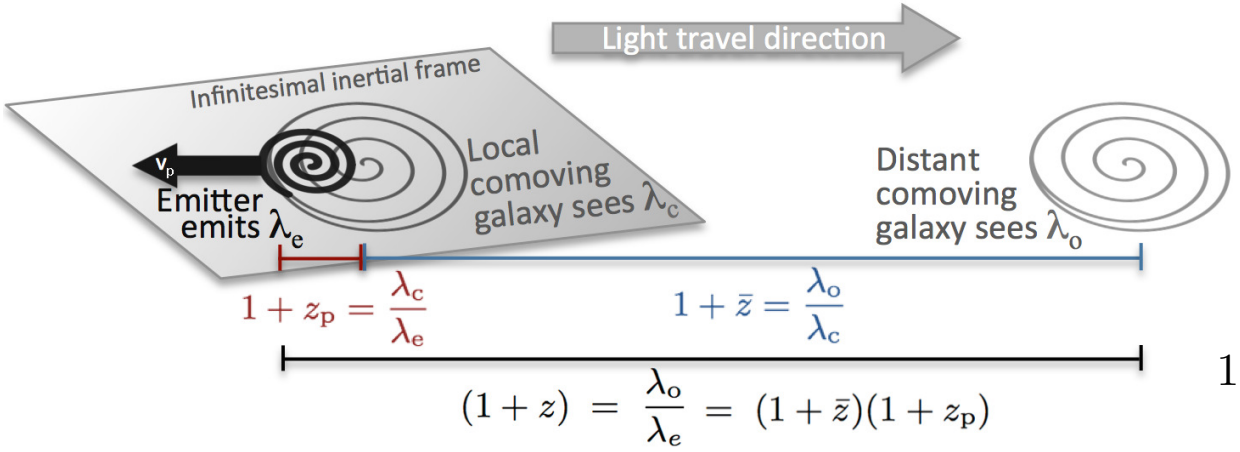
power spectrum shot noise: white noise



Redshift Space Distortions

Newtonian picture: Effect of peculiar velocities on redshift

- object with intrinsic redshift z & radial peculiar (w.r.t. overall Hubble flow) velocity || line of sight



extra Doppler type redshift
w.r.t (imaginary) object at rest

$$1+z_p = \frac{1+v_{||}/c}{\sqrt{1-(v/c)^2}}$$

- redshift - distance relation via Hubble: expand around intrinsic redshift

$$s(z) = \int_0^{z_{\rm obs}} \frac{dz'}{H(z')} = \int_0^{z} \frac{dz'}{H(z')} + \int_z^{z+(1+z)v_r} \frac{dz'}{H(z')} \simeq r(z) + \frac{v_r}{aH(z)}\,,$$

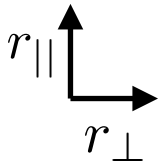
$$\boldsymbol{s}(\boldsymbol{r}) = \boldsymbol{r} + \frac{v_r(\boldsymbol{r})}{\mathcal{H}}\hat{\boldsymbol{r}}$$

general formula:
wide angle
different line of sights

$$\hat{\boldsymbol{r}} \equiv \hat{\boldsymbol{z}}$$

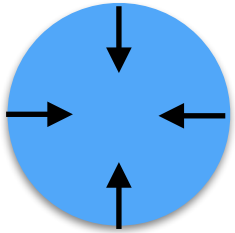
distant observer
fixed line of sight
w.l.o.g z-direction

Redshift Space Distortions

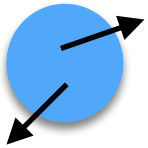


real space

coherent infall $\frac{\boldsymbol{v}}{\mathcal{H}}$



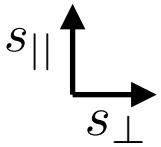
nonlinear structure

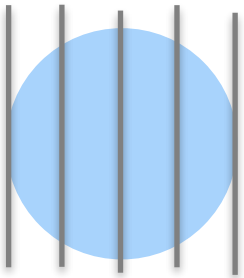


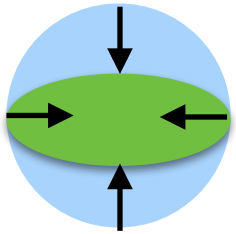
overdensity

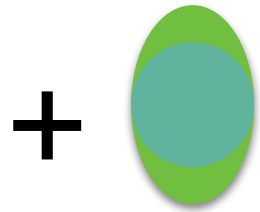
redshift space $s(\boldsymbol{r}) = \boldsymbol{r} + \frac{v_r(\boldsymbol{r})}{\mathcal{H}}\hat{\boldsymbol{r}}$

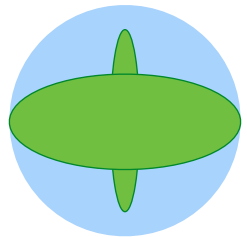
distant observer
fixed line of sight







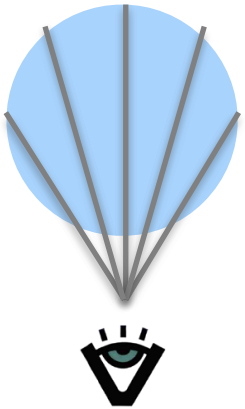


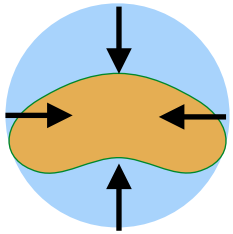


Pancake of God Fingers of God

wide angle

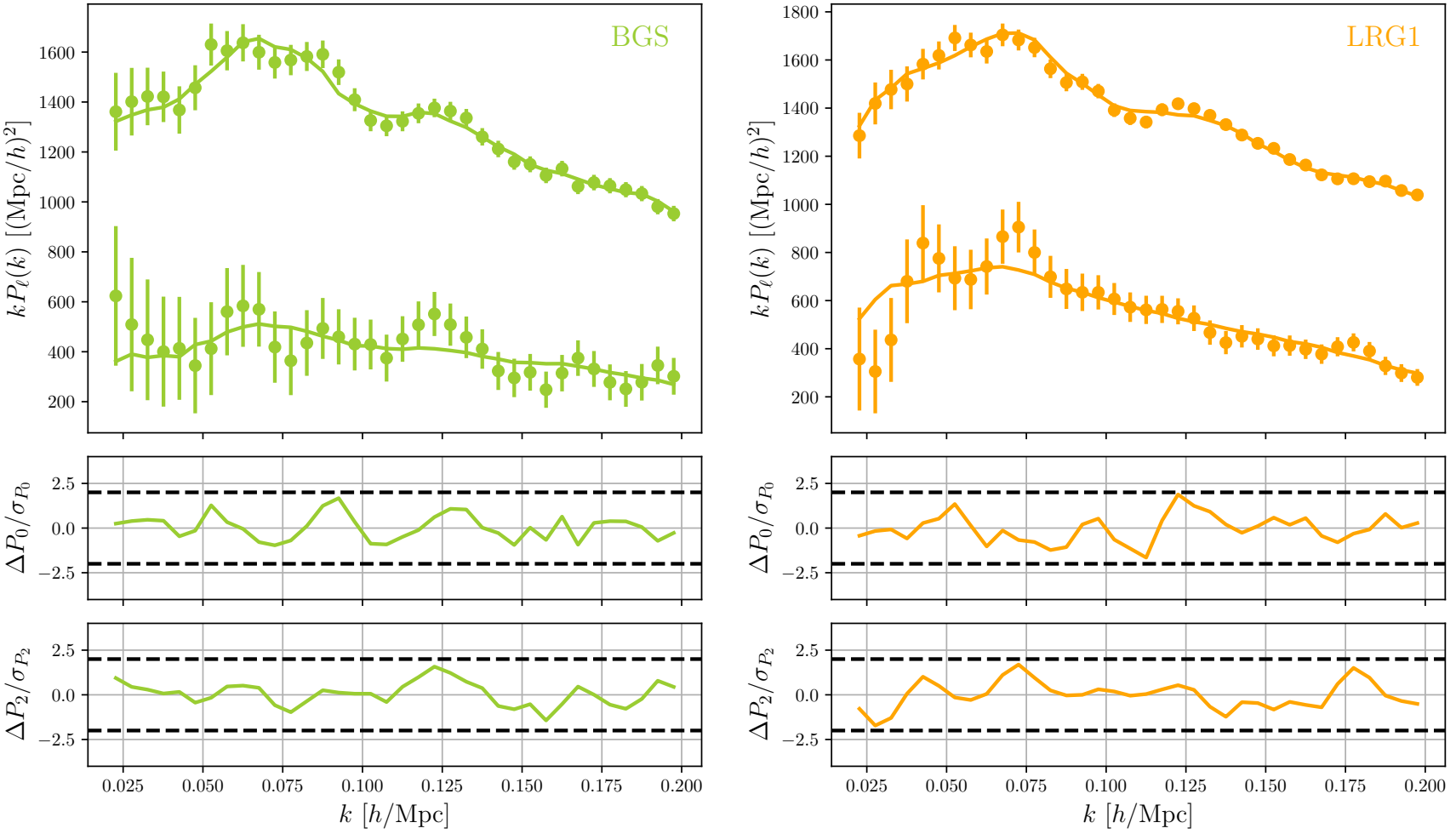
different
line of sights





Croissant of God

Spectroscopic Surveys

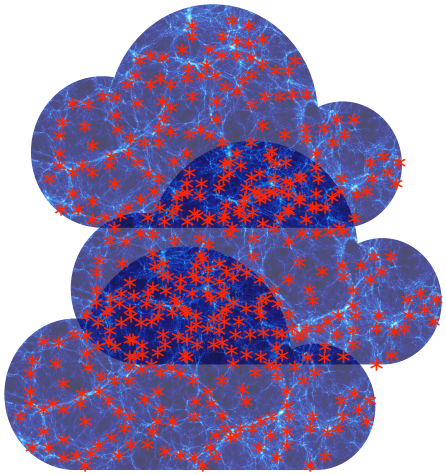


DESI 2024 V: Full-Shape Galaxy Clustering from Galaxies and Quasars
DESI Collaboration, arXiv: 2411.12021

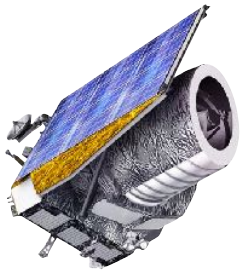
Matter -> Observables

source galaxies

(dark) matter



lens galaxies



Euclid

galaxy shapes

convergence κ

& shear ɣ

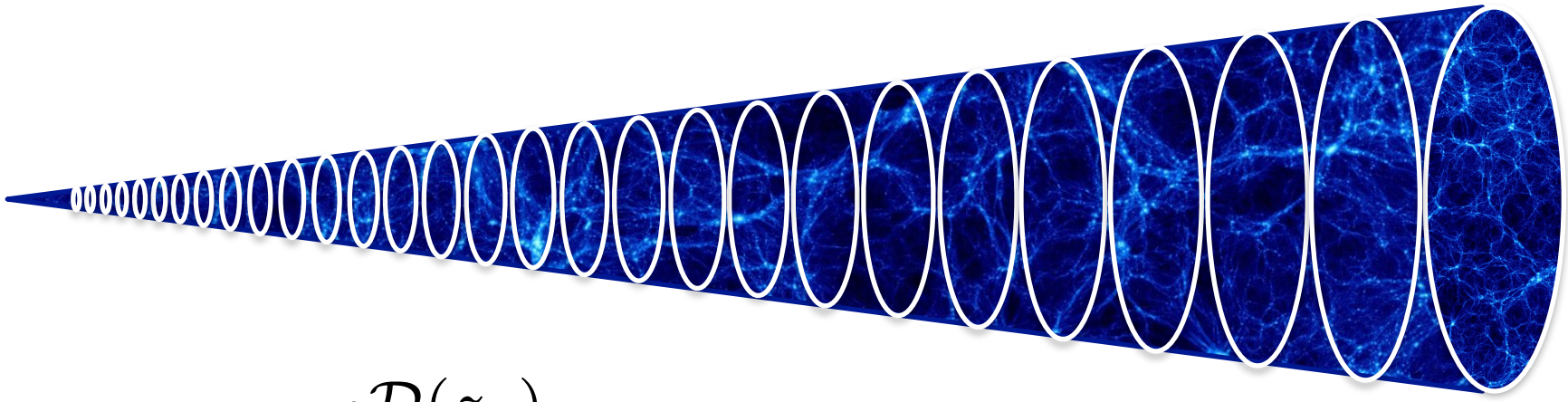
galaxy counts

density δ_g

photo-z

Projected Statistics

weight 2D density slices



$$\left.\begin{matrix}\kappa_{<\theta} \\ \delta_{g,<\theta}\end{matrix}\right\} = \int_0^{\mathcal{D}(z_s)} d\mathcal{D}(z)\, \delta^{\rm disk}_{<\theta\mathcal{D}(z)}\, w(z, z_s)$$

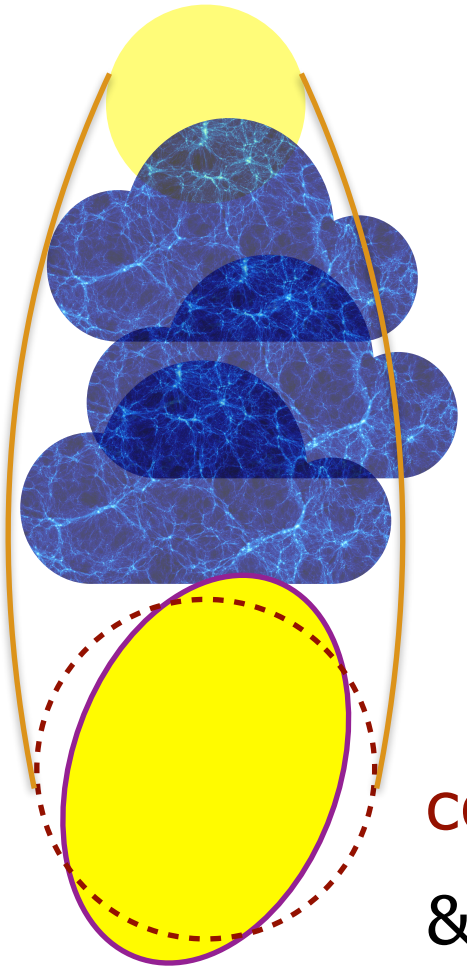
weights

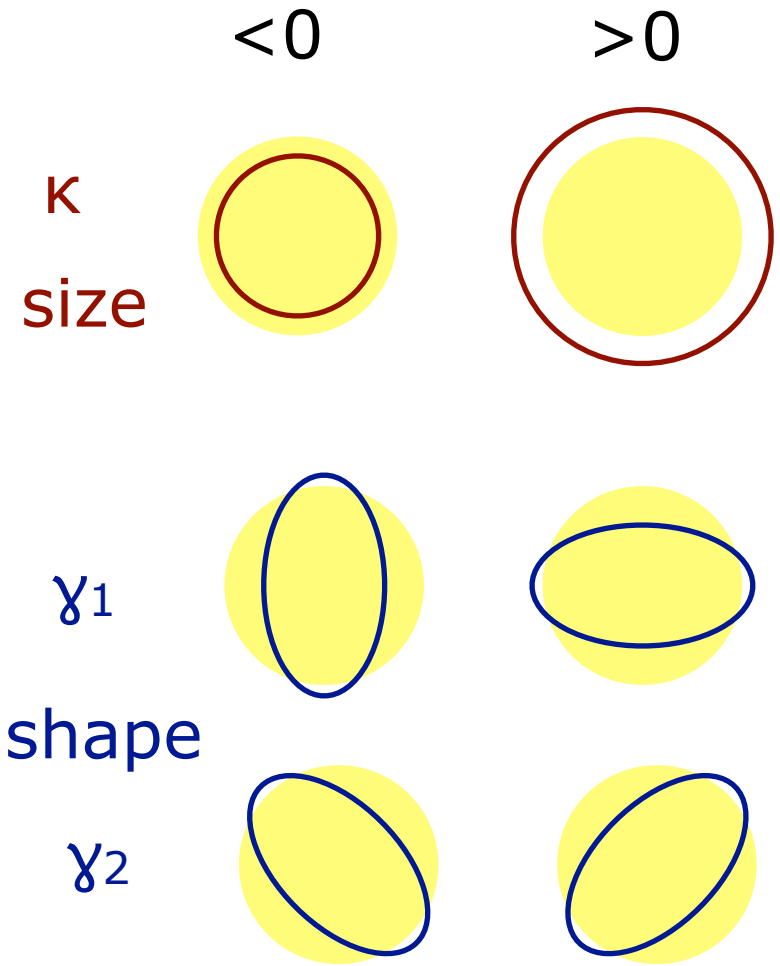
do angular clustering, e.g. like CMB C_l

mixing of scales depending on redshift

Weak Lensing

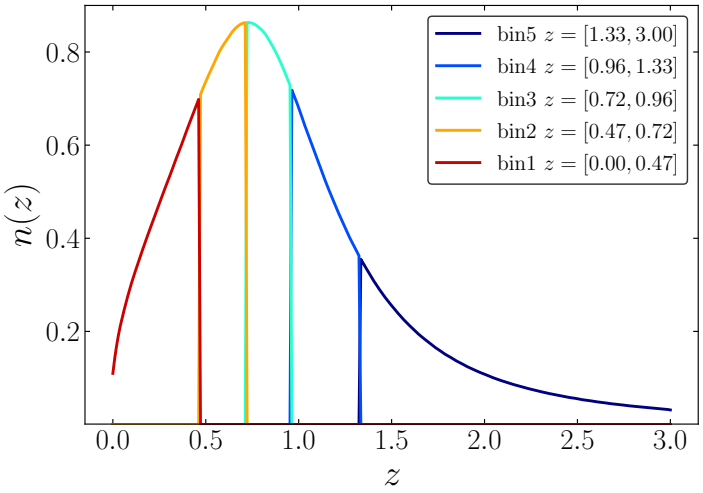
$|\kappa|, |\gamma| \ll 1$

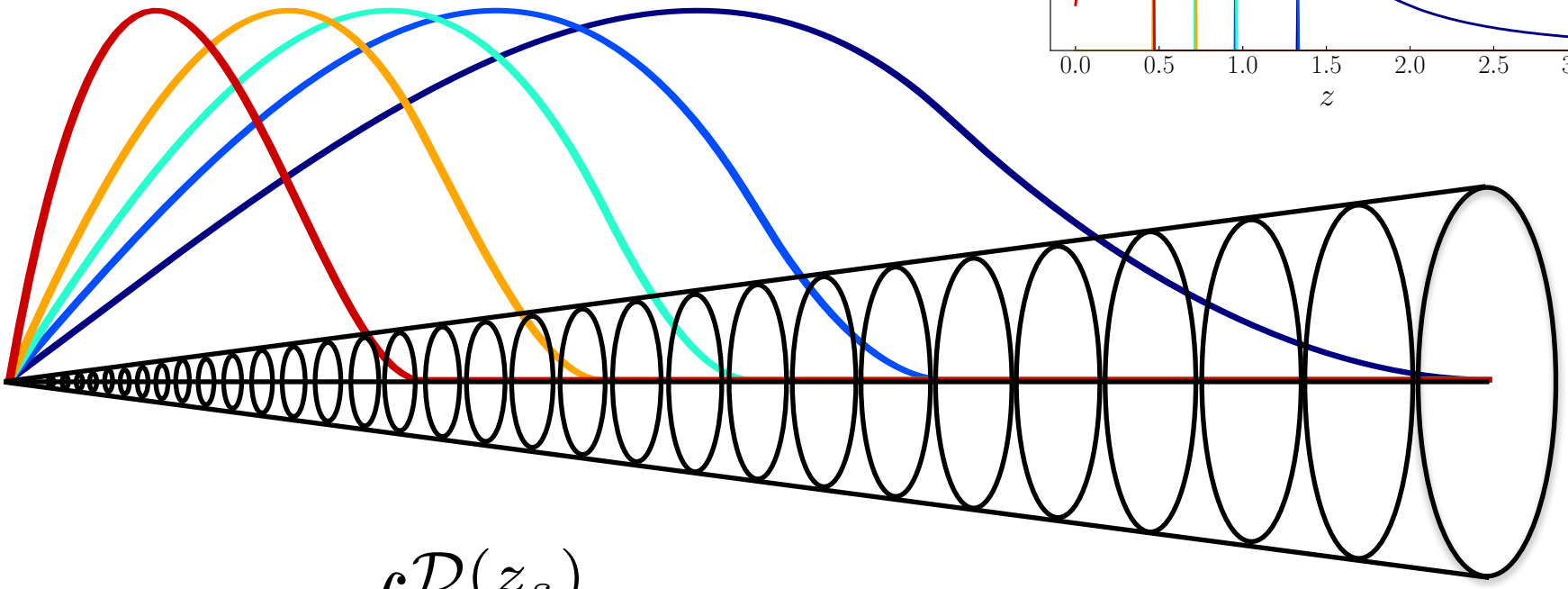




Weak Lensing

weak lensing weight





$$\kappa_{<\theta} = \int_0^{\mathcal{D}(z_s)} d\mathcal{D}(z)\, \delta^{\rm disk}_{<\theta\mathcal{D}(z)} w(z, z_s)$$

3x2pt Statistics

$$\left.\begin{matrix}\kappa_{<\theta} \\ \delta_{g,<\theta}\end{matrix}\right\} = \int_0^{\mathcal{D}(z_s)} d\mathcal{D}(z)\, \delta^{\rm disk}_{<\theta\mathcal{D}(z)}\, w(z, z_s)$$

$$C_{\kappa^i,\kappa^j} = \int_0^{\chi_\infty} \frac{W_i(\chi) W_j(\chi)}{\chi^2} P_{m,m}\left(\frac{\ell}{\chi}, \chi\right)$$ cosmic shear

$$C^{\ell}_{\kappa^i,g^j} = b_j \int_0^{\chi_\infty} d\chi \frac{W_i(\chi)}{\chi} \frac{dN^j_l}{d\chi} P_{m,g^i}\left(\frac{\ell}{\chi}, \chi\right)$$ galaxy-galaxy lensing

$$C^{\ell}_{g^i,g^i} = b_i^2 \int_0^{\chi_\infty} d\chi \frac{dN^{i\,2}_l}{dz} P_{g^i,g^i}\left(\frac{\ell}{\chi}, \chi\right)$$ photometric clustering

matter power spectrum modelled by halofit or updates