BAO IN LYα-QUASAR CROSS-CORRELATIONS

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Based on work in progress with Shirley Ho, Xiaoying Xu, KG Lee,
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SDSS III

WHY CROSS-CORRELATIONS?

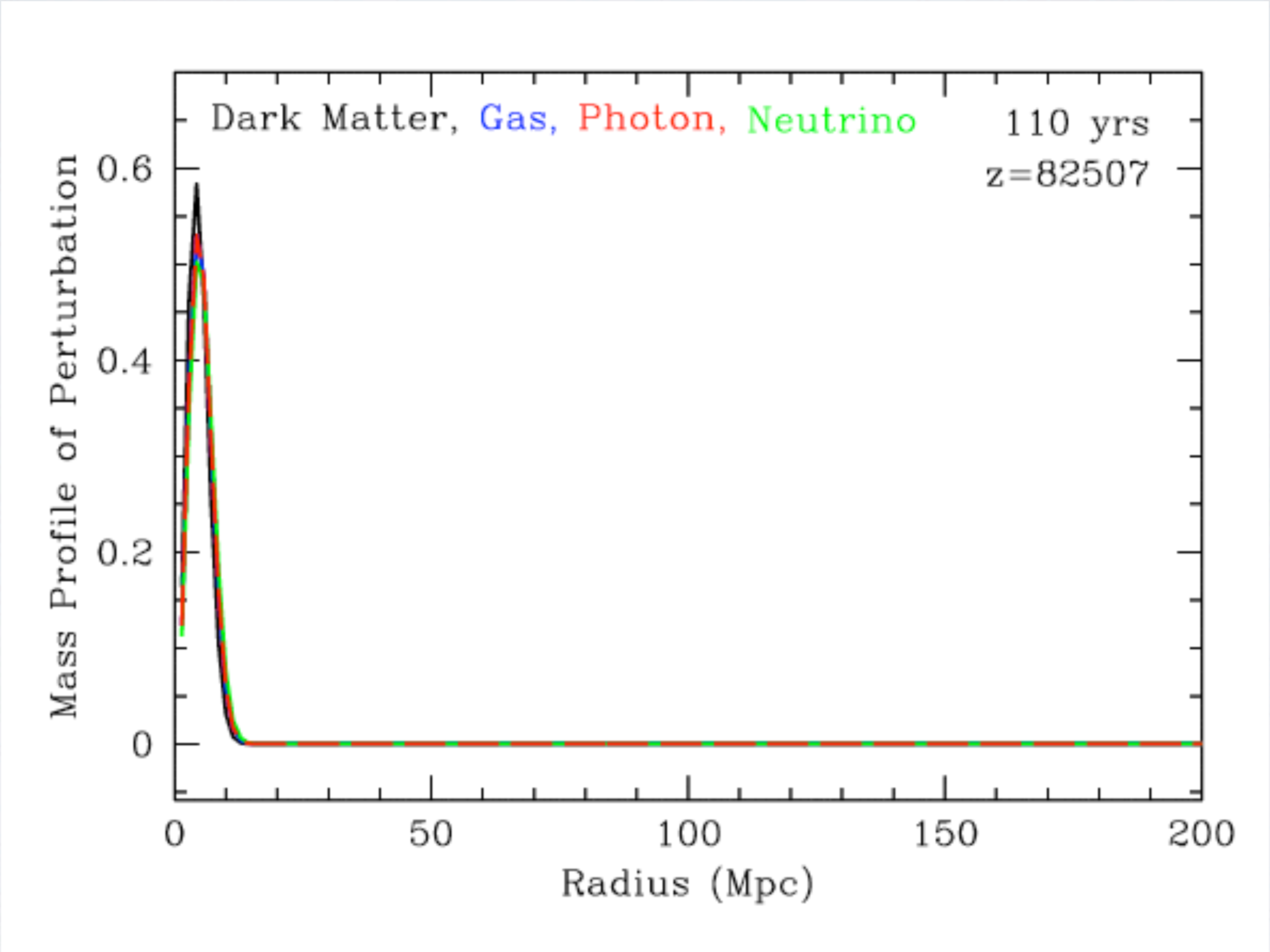
- Each tracer has its own systematics, but they're probably not correlated with one another.
- Density of the forest allows us to make a BAO measurement with quasars, easier than doing quasar autocorrelation.
- Techniques should be easily applicable to (your favorite density field) × (your favorite point source)!

OVERVIEW

- Introduction to BAO
- Data sources
- A new estimator
- Covariance matrix
- Anisotropic fitting
- Systematic uncertainty

WHAT IS BAO?

Taken from D. Eisenstein, https://www.cfa.harvard.edu/~deisenst/acousticpeak/acoustic_physics.html



Imagine a spherically symmetric overdensity

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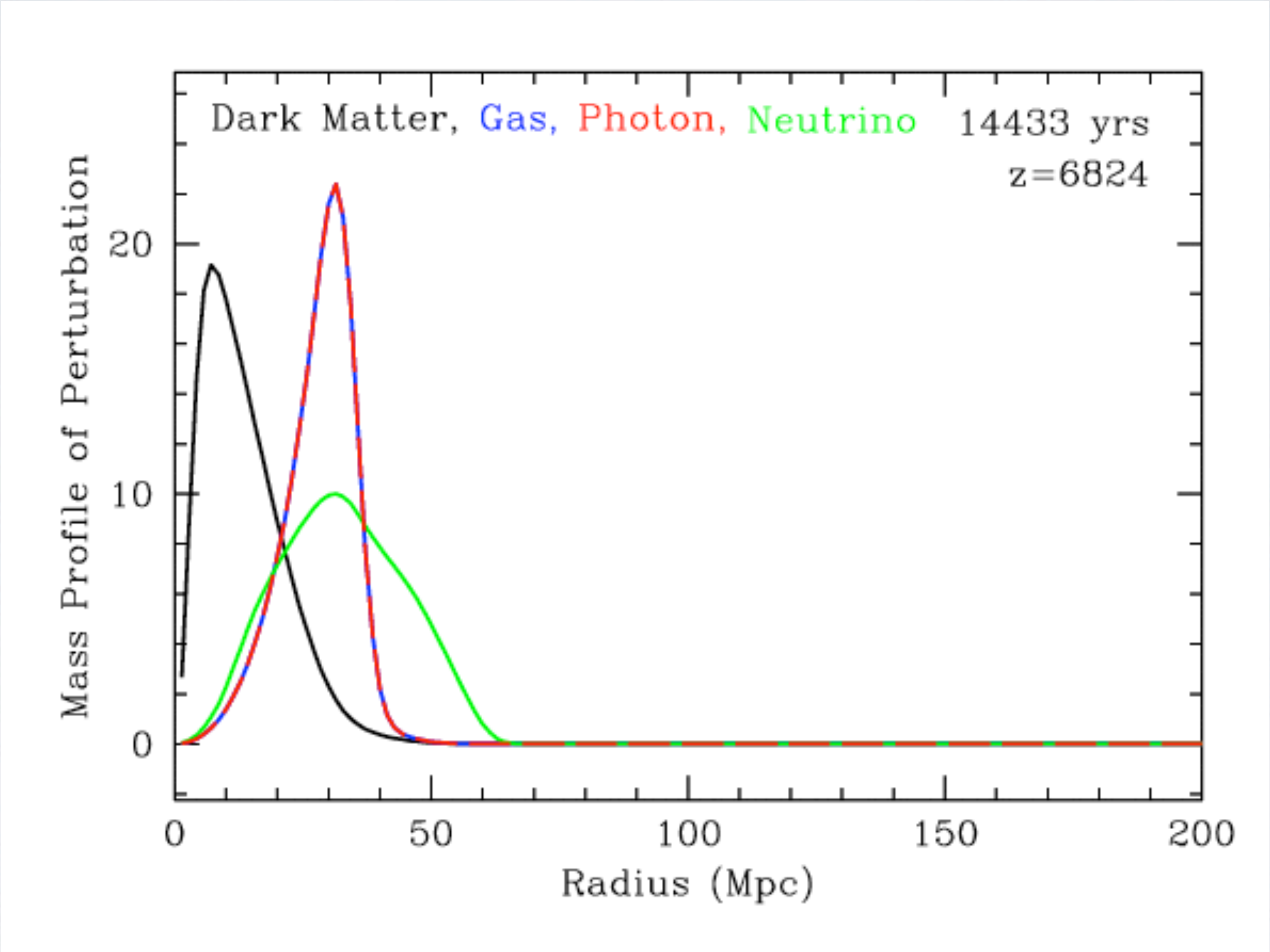

Plasma and photons are strongly coupled

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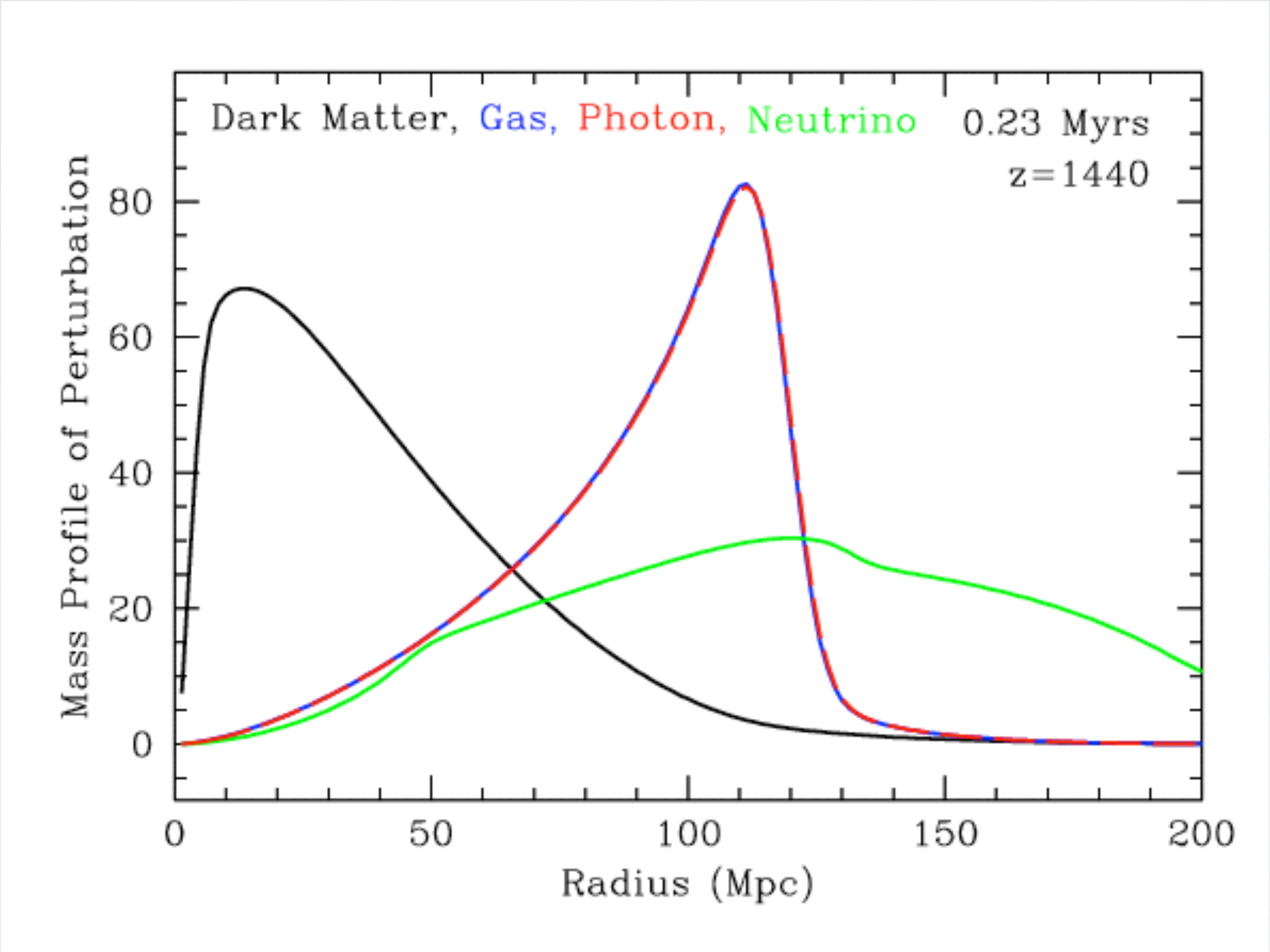

Plasma and photons expand at $c_s \approx 0.57c$.

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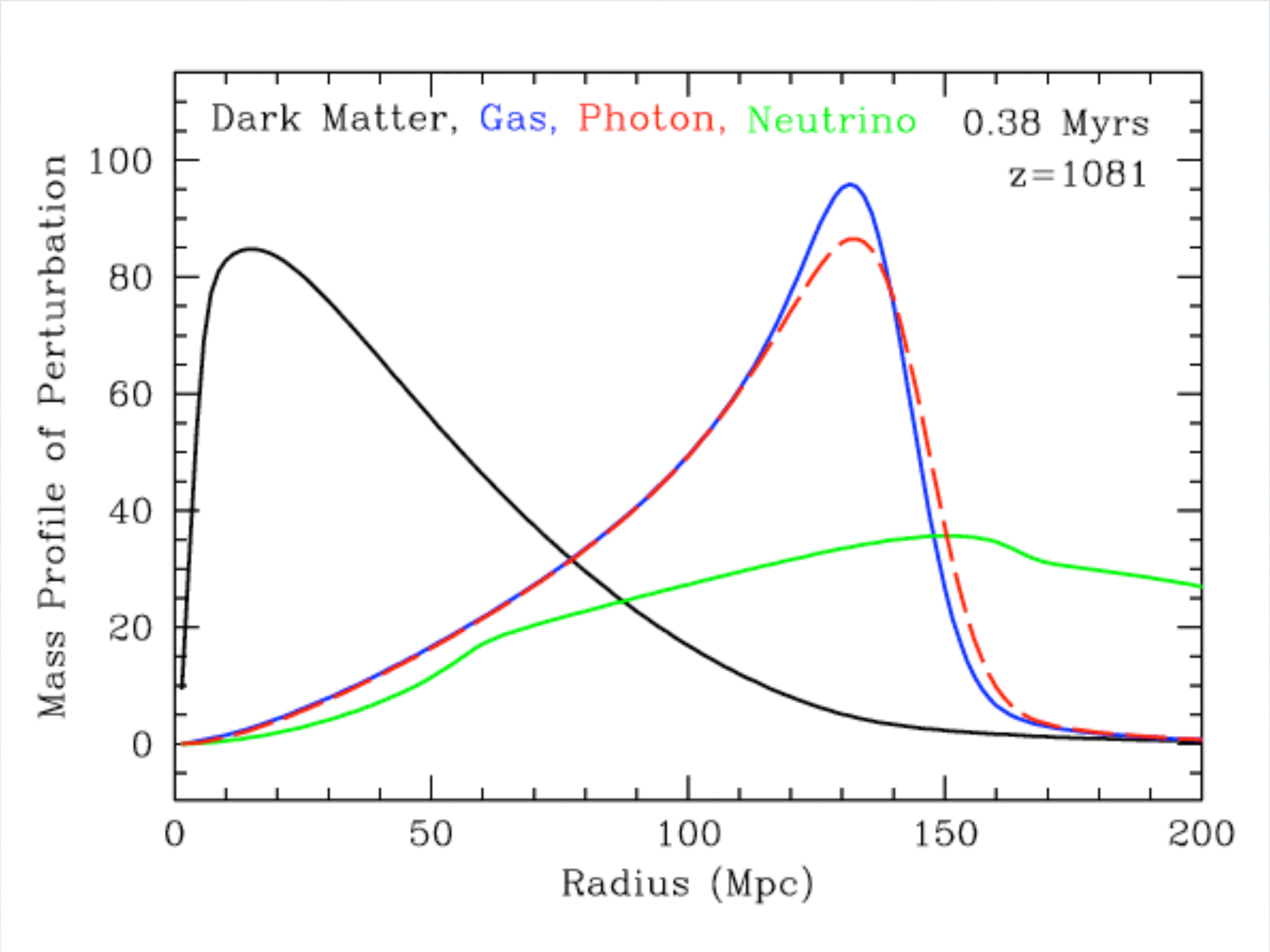

After recombination, the photons are free to go

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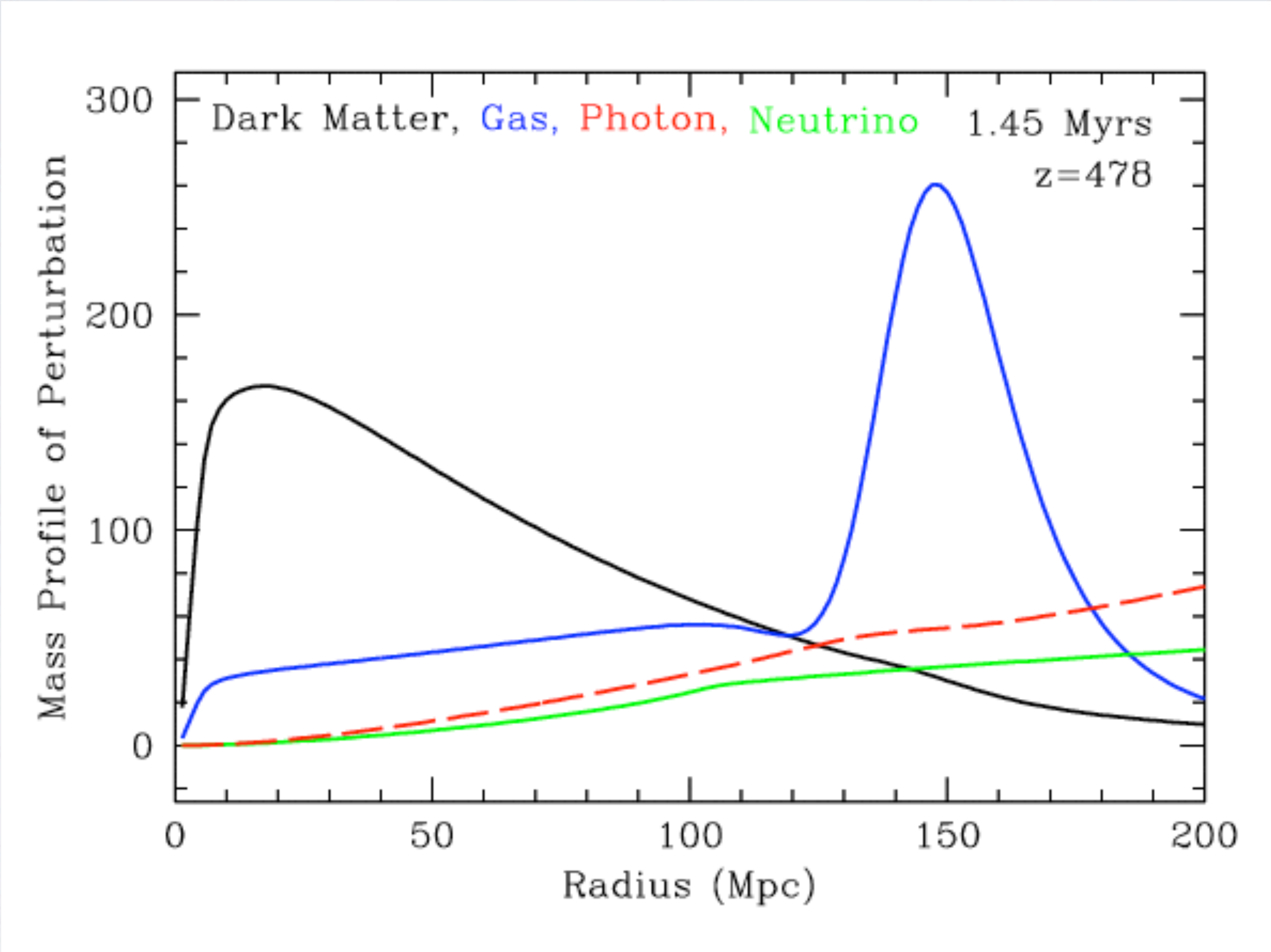

And the baryons stop

WHAT IS BAO?

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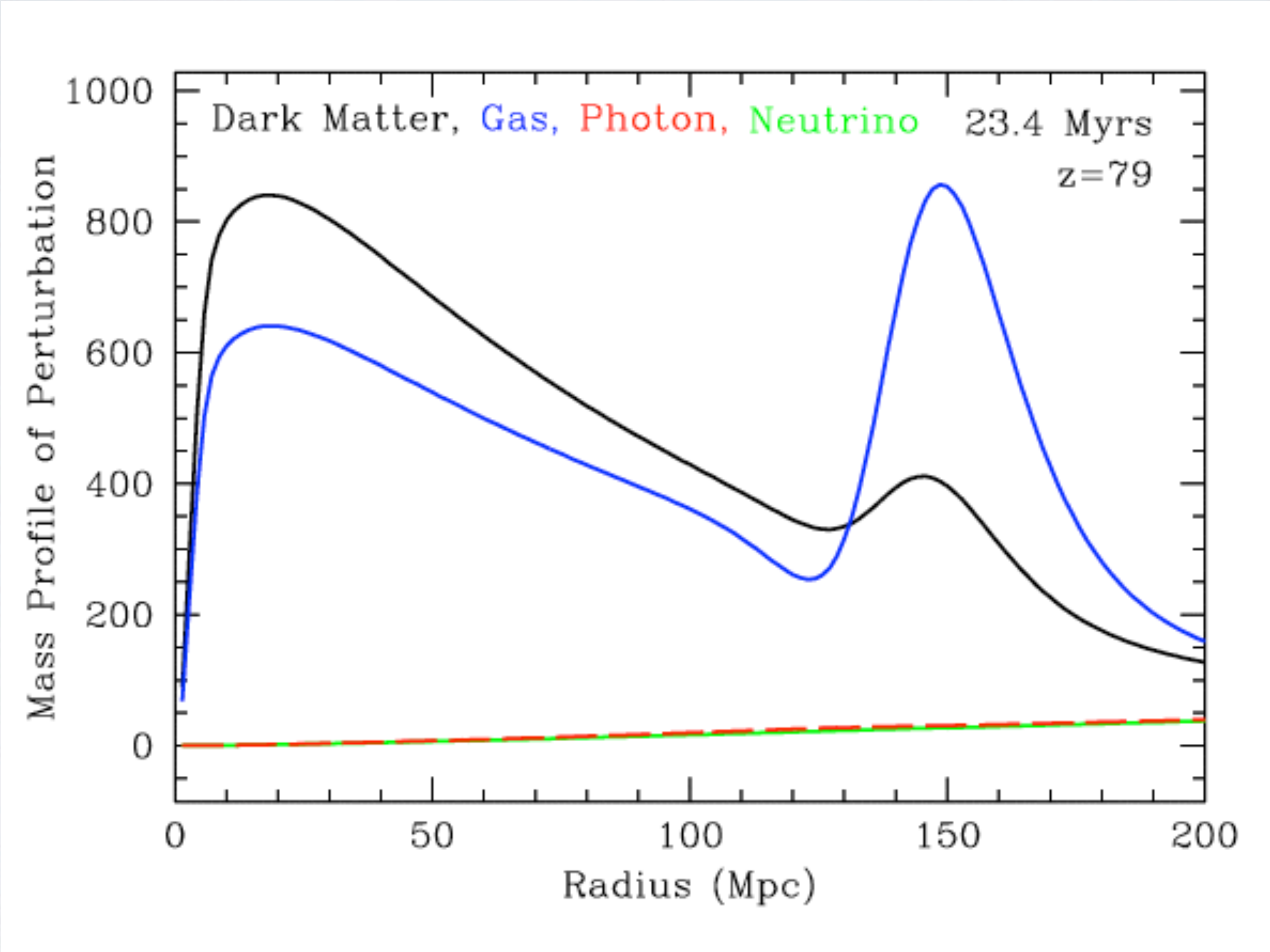

Gravity causes DM and gas to trace each other

WHAT IS BAO?

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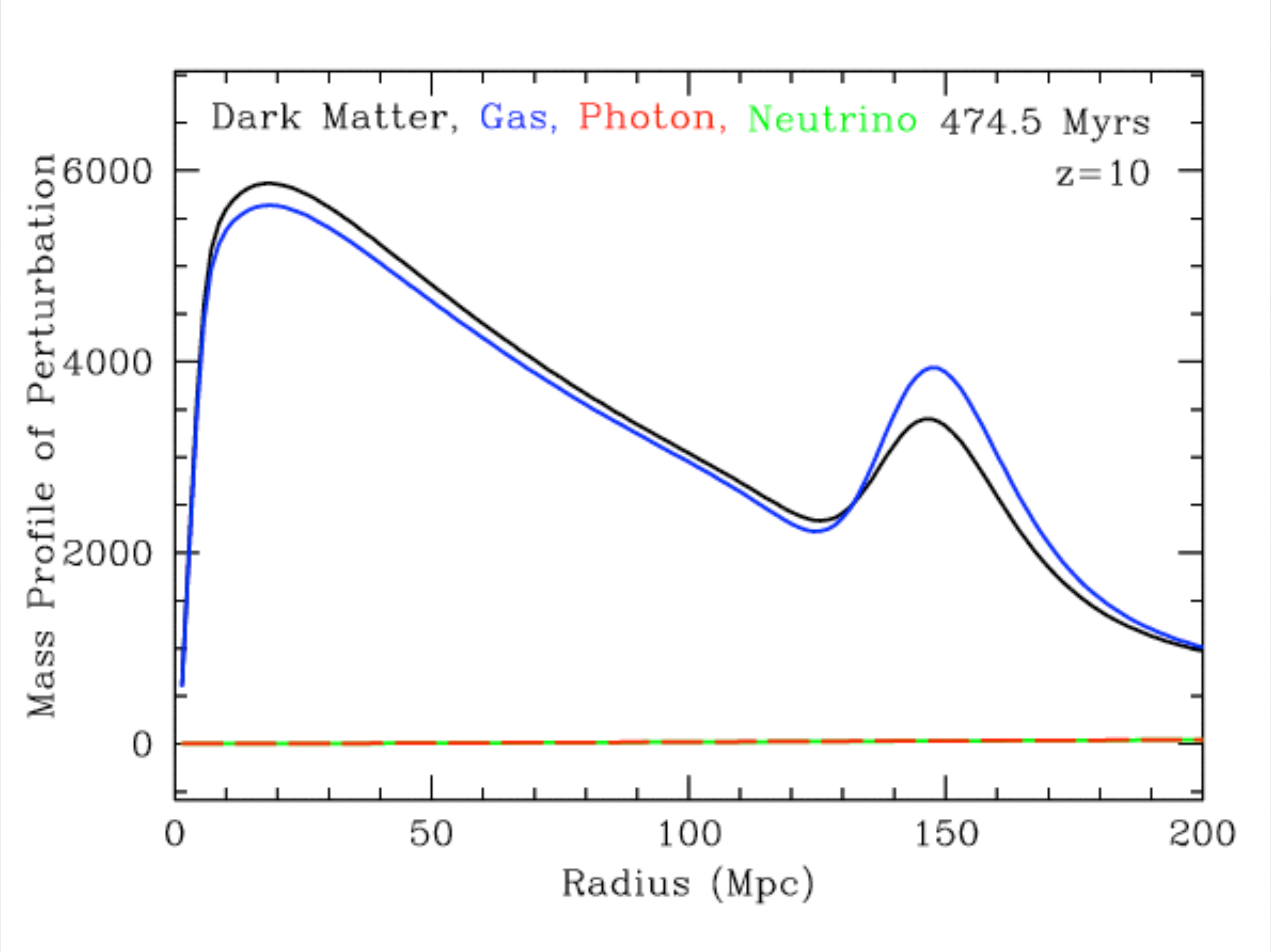
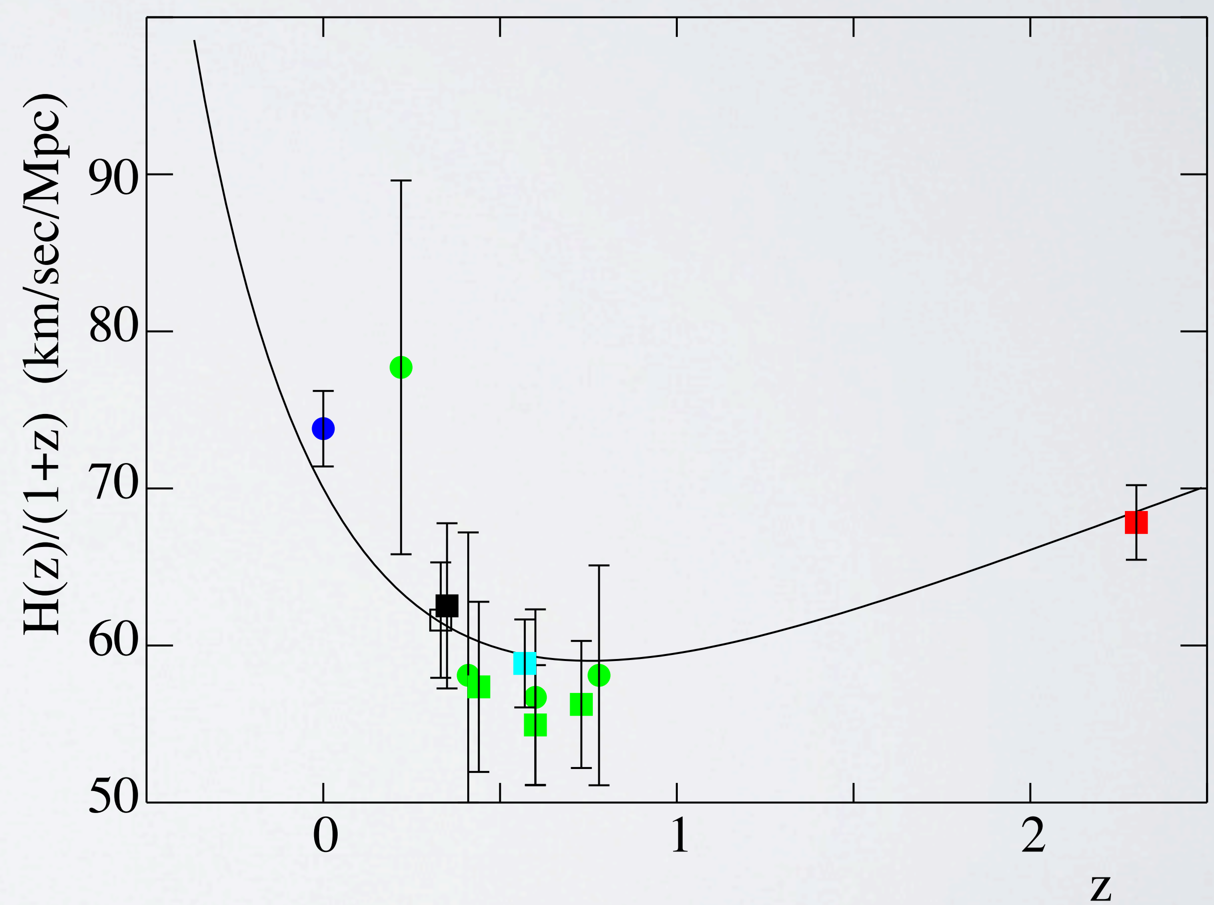


At late times, both distributions have a peak at ~150 Mpc

WHAT WE DO WITH BAO

- Position of the BAO peak is determined by simple physics – "standard ruler"
- Measurement constrains $H(z)$ and $D_A(z)$.
- Feature is sharp – a *relatively* easy measurement.

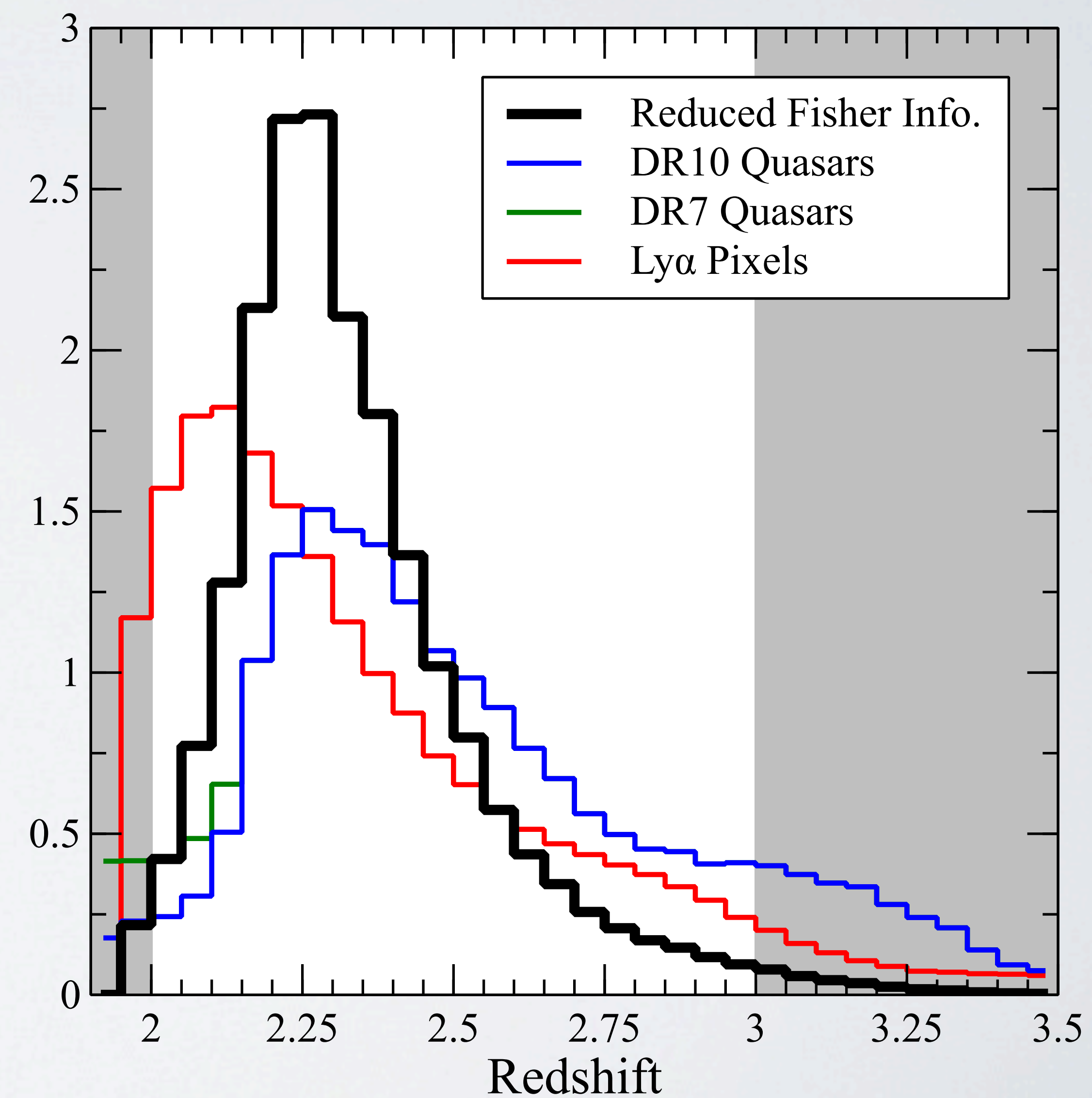


From Busca et al., 1211.2616

BOSS DR10

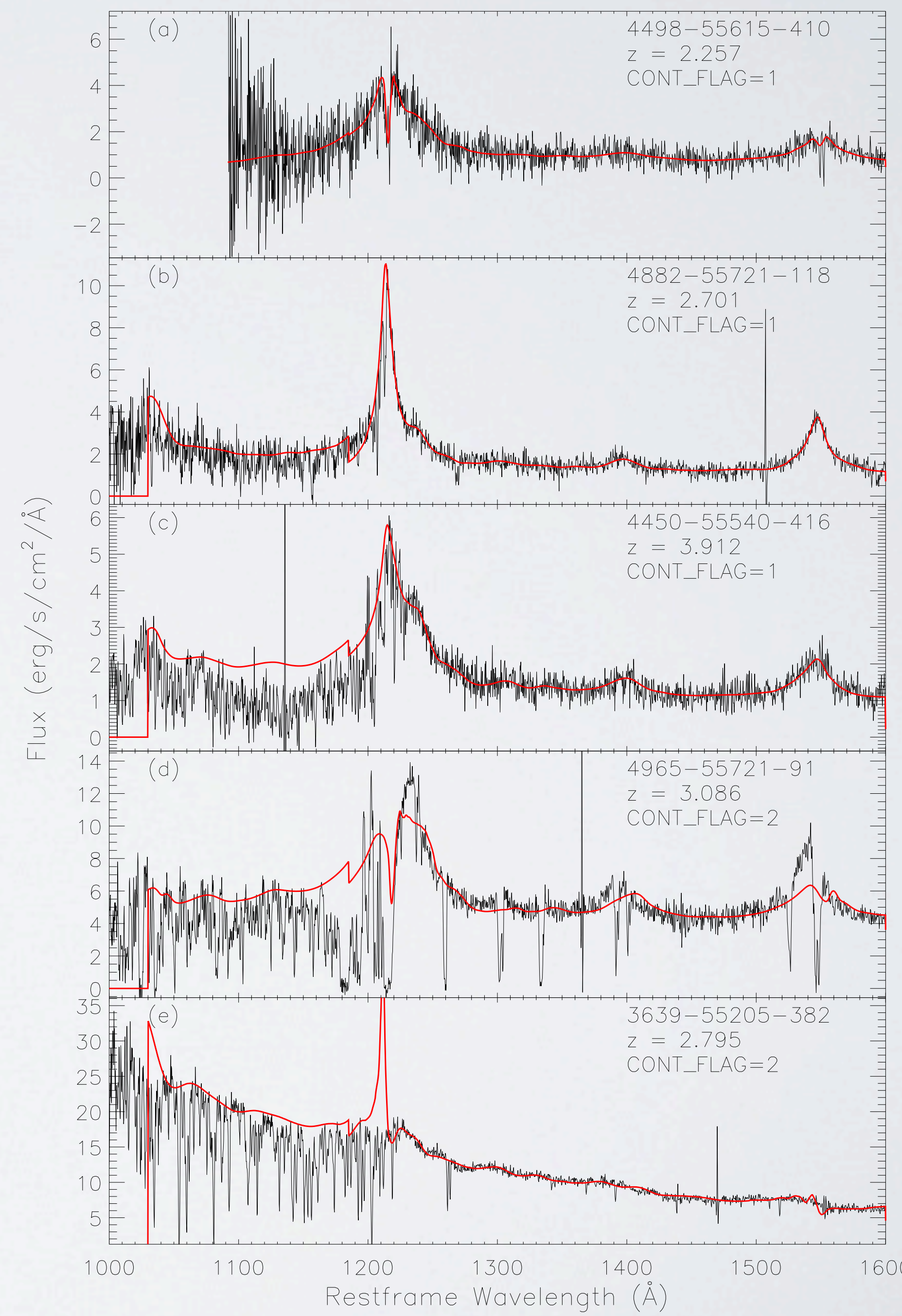
- 102,684 quasars from DR10 (Paris et al.), 3,187 z<2.15 quasars from DR7 (Schneider et al.)
- 29,039,754 Lyα pixels (1080-1185Å)
- Simple measure of information density:

$$F(z) \propto N_{QSO}(z)\frac{w_{tot}(z)}{R^2(z)}$$



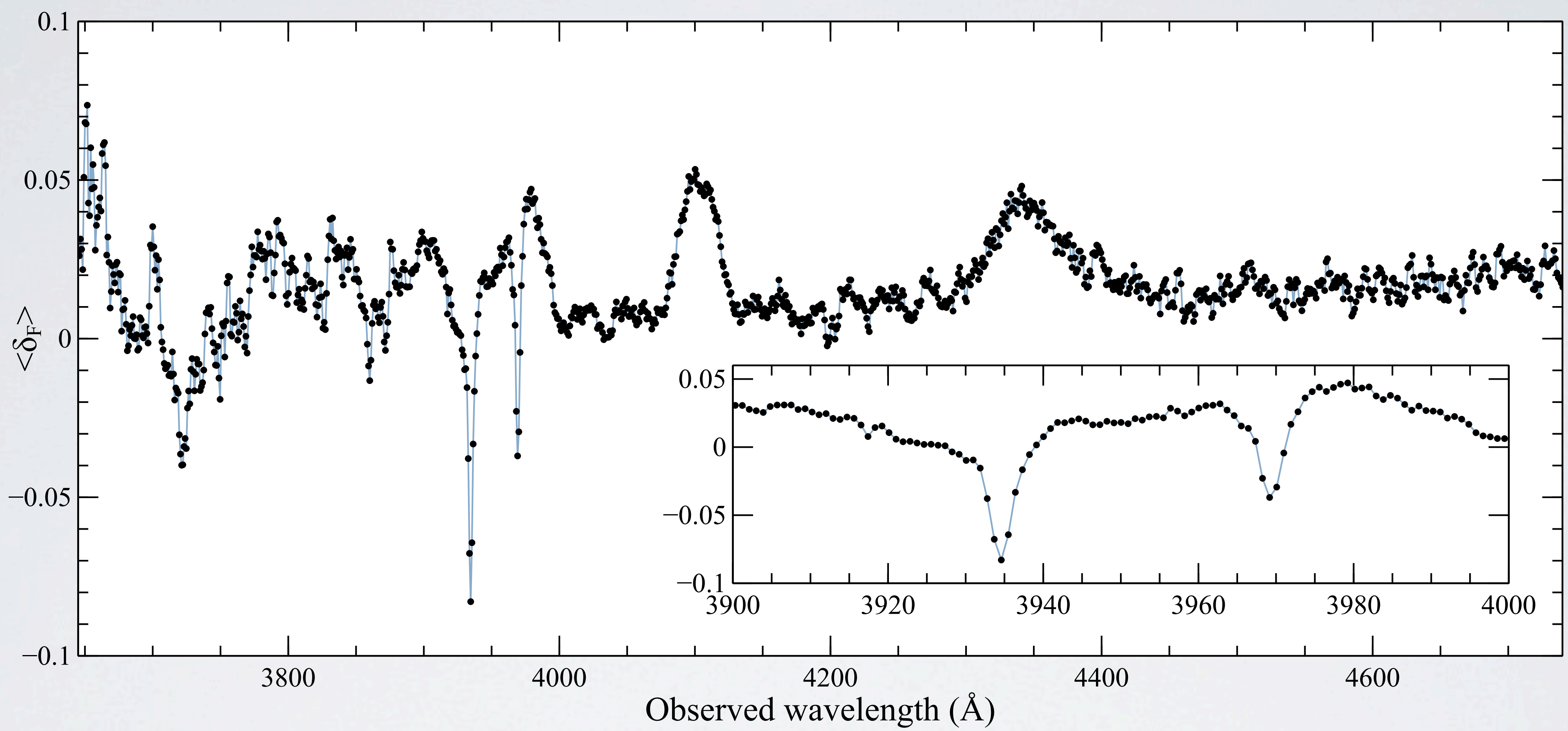
FROM SPECTRA TO FOREST

- Identify absorption features in quasar spectra.
- To map out absorption, need to predict unabsorbed spectrum.
- We use PCA fits from Lee et al.



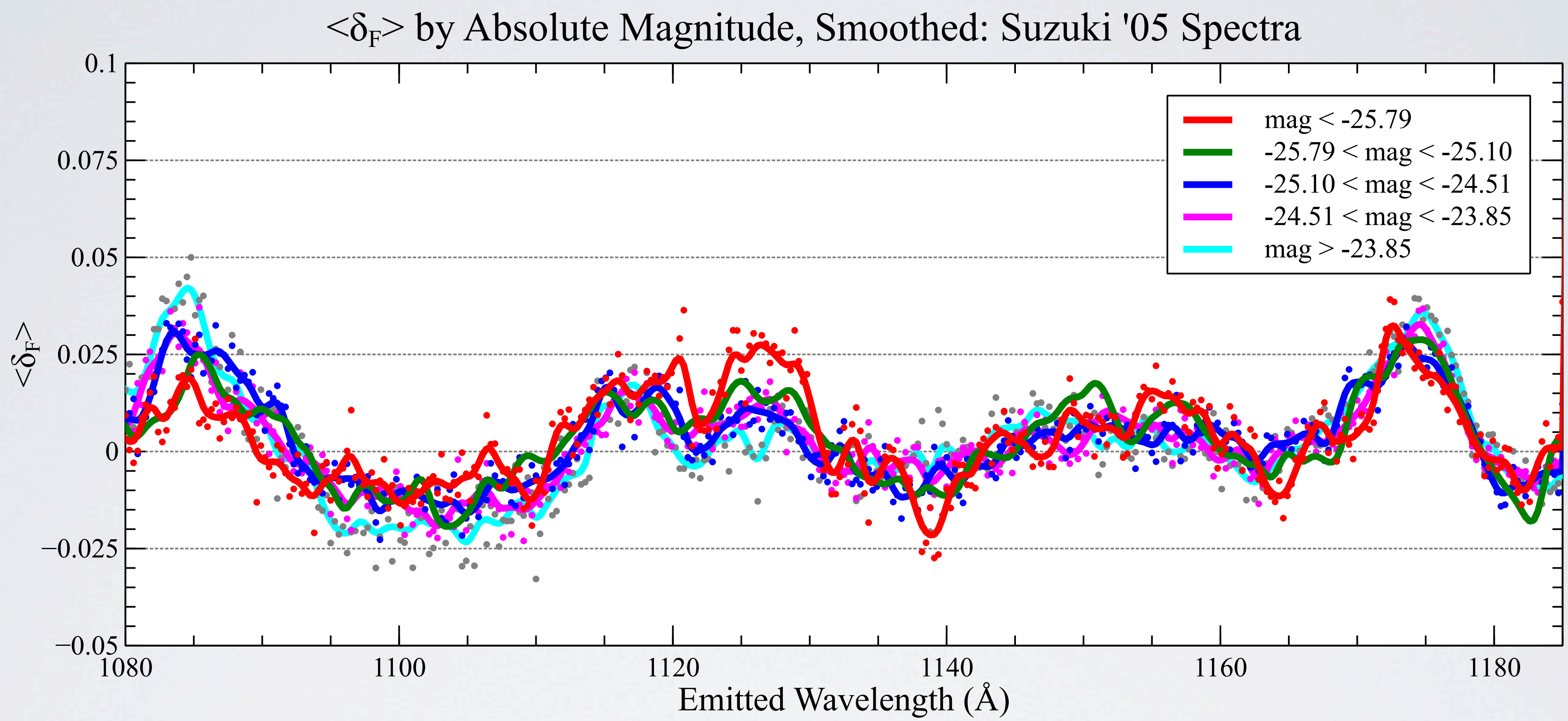
From Lee et al., 1211.5146

CORRECTING THE FOREST (1)



- Stack pixels at observed wavelength: foreground effect
- In addition to cross-correlating KG's original version of the forest, generate a second data set with $\langle \delta_F \rangle (z) = 0$

CORRECTING THE FOREST (2)



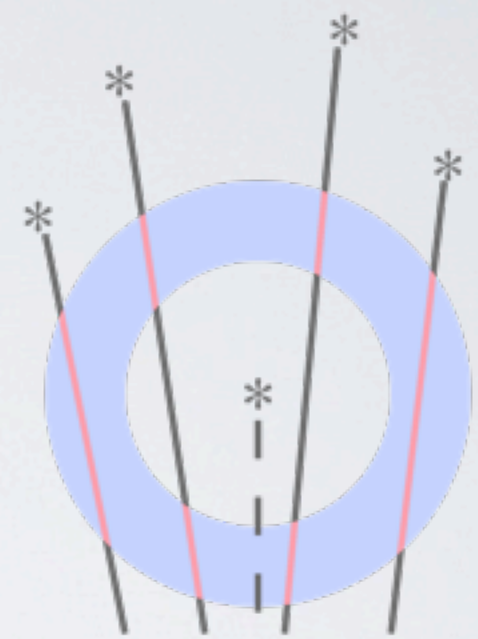
- Stack spectra at emitted wavelengths, bin by quasar magnitude – luminosity dependent fitting errors

- Third corrected data set: fix this, set $\langle \delta_F \rangle (z) = 0$

DD-DR ESTIMATOR

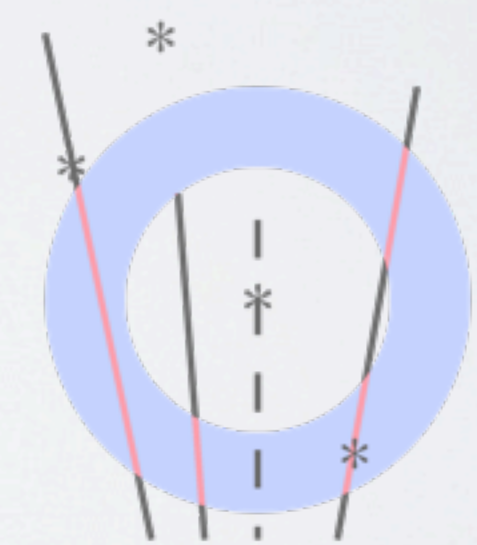
- Naive estimator:

$$\xi_{\mathrm{DD}} = \sum_{\mathrm{QSOs}} \frac{\sum w_i \delta_{F,i}}{\sum w_i}$$



- New Term:

$$\xi_{\mathrm{DR}} = \sum_{\text{Random QSOs}} \frac{\sum w_i \delta_{F,i}}{\sum w_i}$$

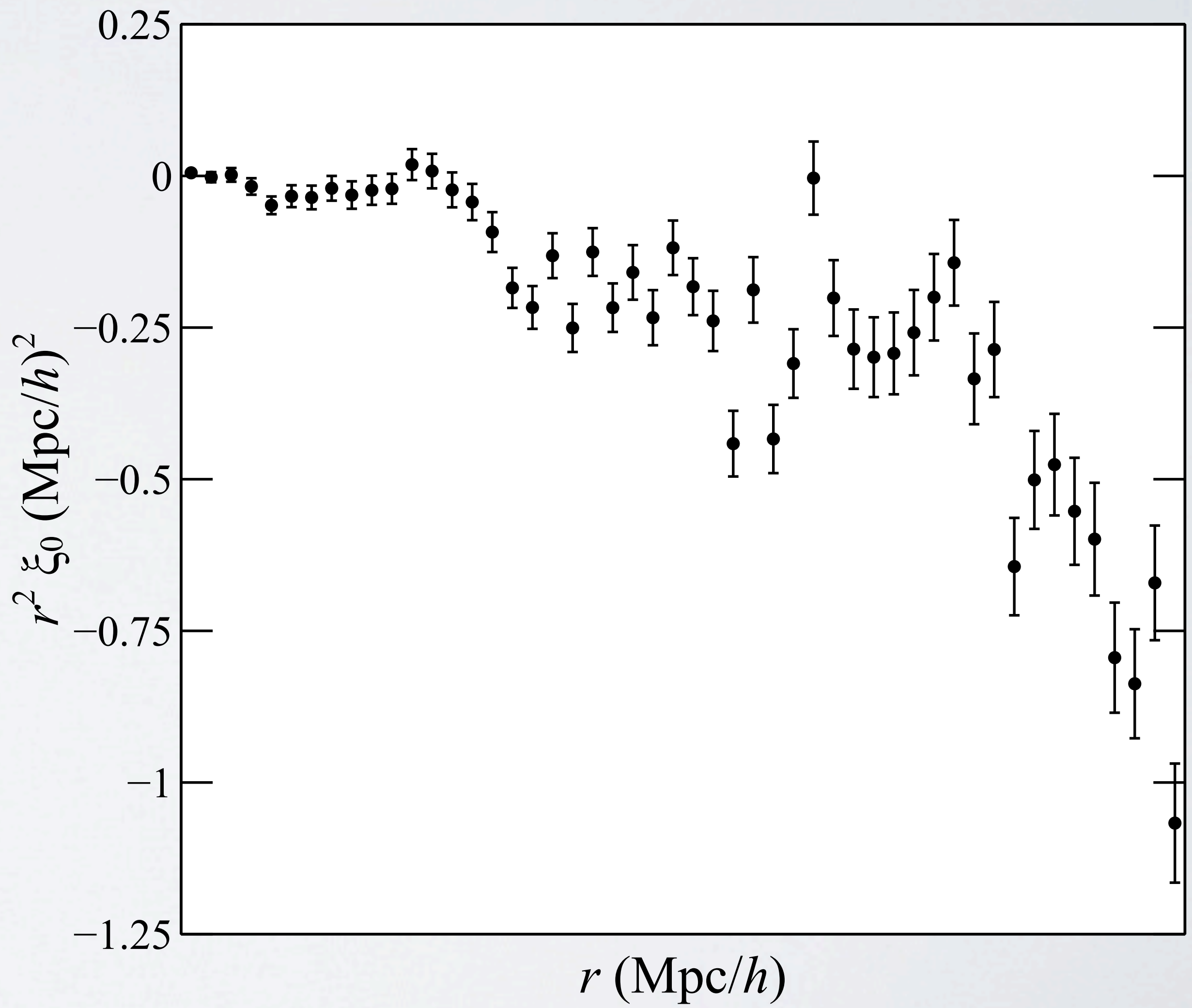


- Improved Estimator

$$\xi_{\mathrm{DD-DR}} = \xi_{\mathrm{DD}} - \xi_{\mathrm{DR}}$$

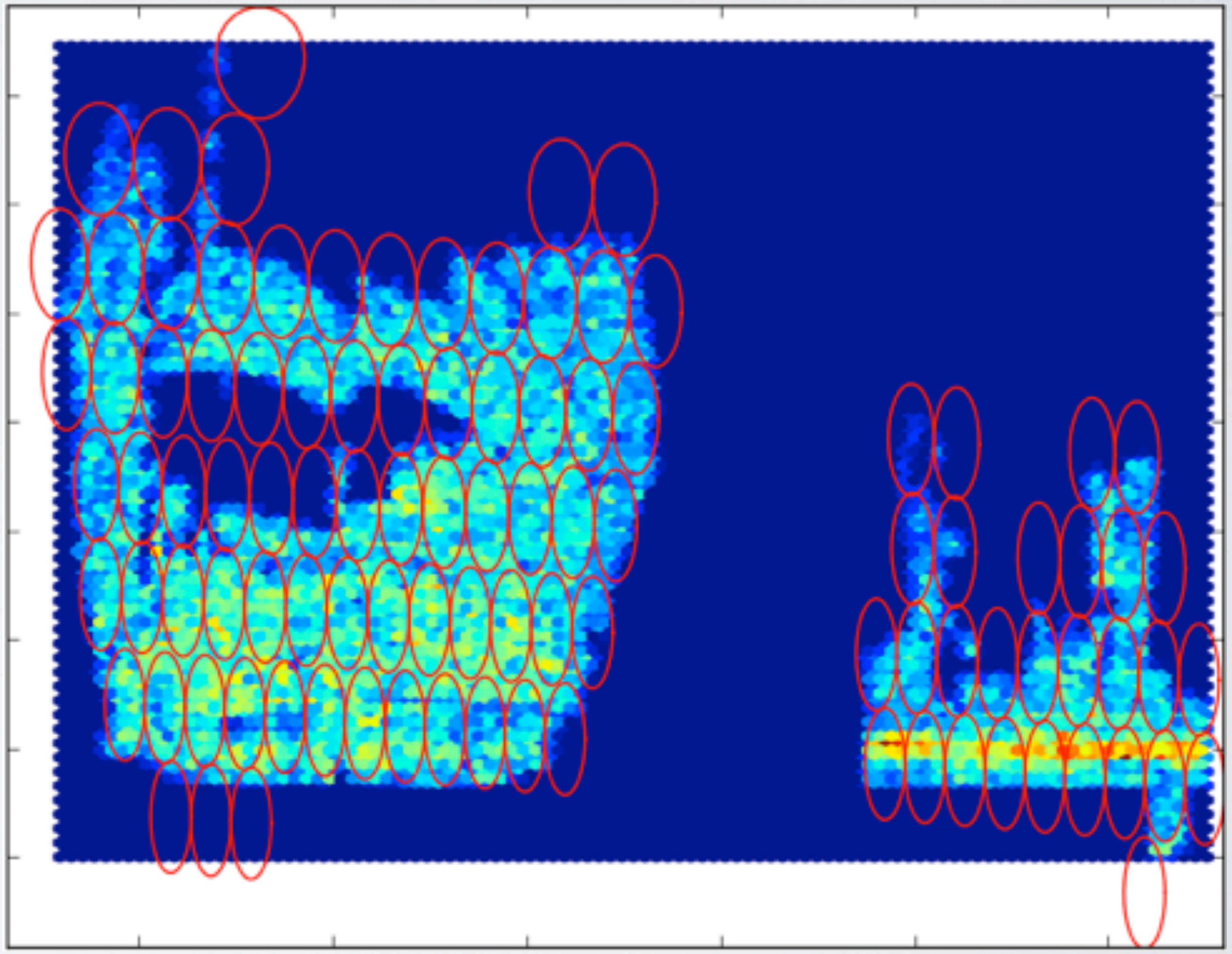
GENERATING "RANDOM" QUASARS

- Goal is to mimic density of quasar survey (not uniform)
- Our method: reassign observed redshifts and observed angular coordinates
- Result is small, probably non-zero



COVARIANCE MATRIX

- One approach: Bootstrap, regions are 72 discs of radius 10° (~600 Mpc/h at z=2)
- For each bootstrap realization, draw until $\sum w_i$ in range r=28-40 Mpc/h matches the DD cross-correlation



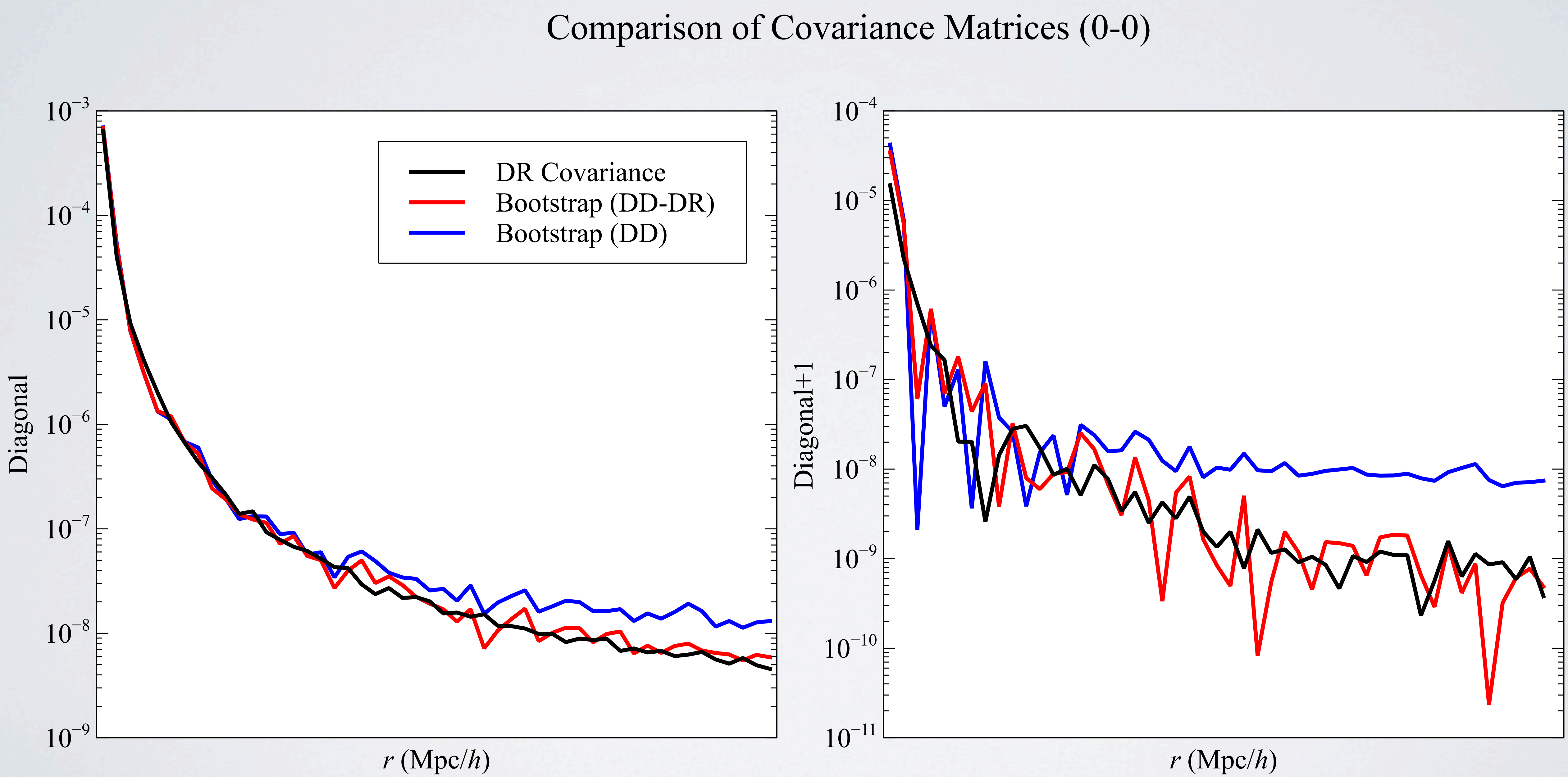
COVARIANCE MATRIX

- Alternative approach: use different realizations of the DR correlator.

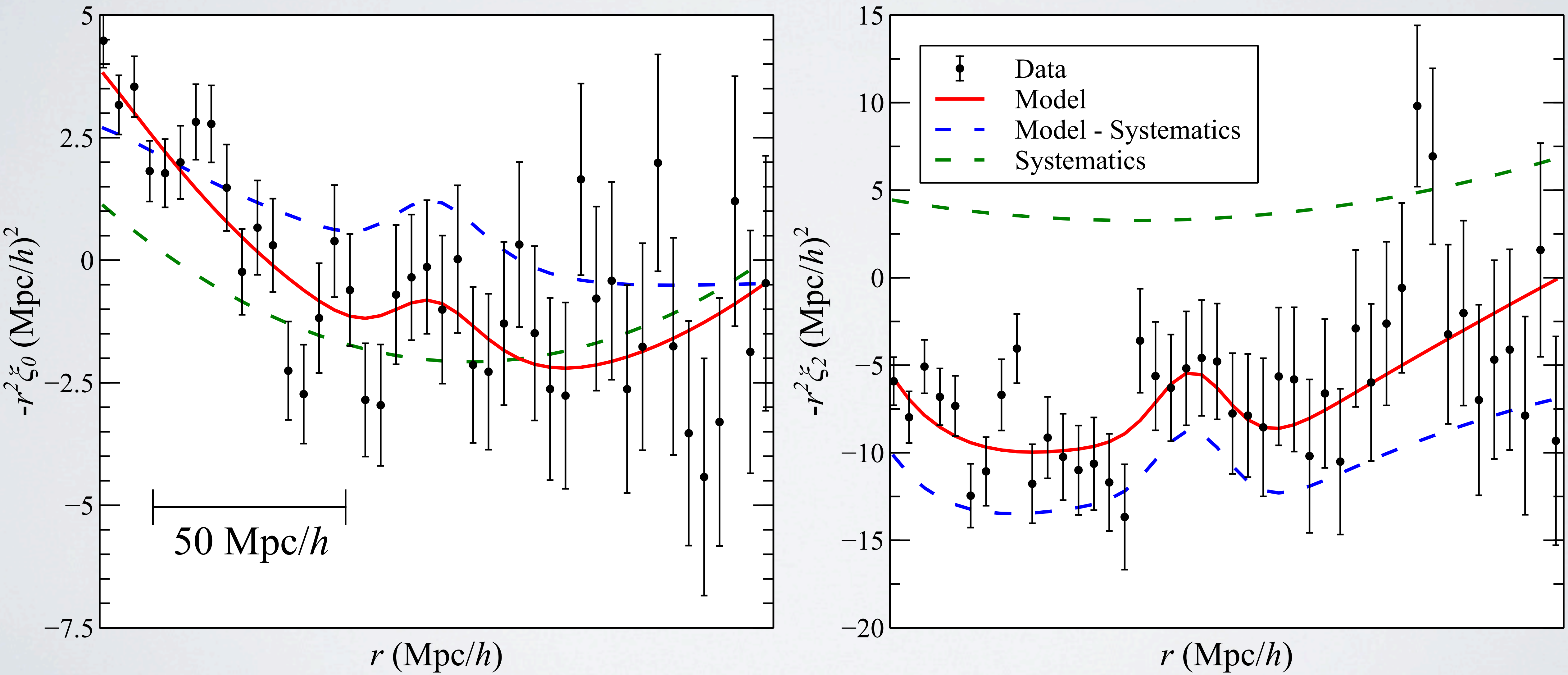
- Pros: Can generate many different sets of random QSOs, compute correlator reliably to large distances (e.g. 200 Mpc/*h*)

- Cons: Covariance matrix will be missing contribution from QSO autocorrelation

COVARIANCE MATRIX



MONOPOLE AND QUADRUPOLE



ANISOTROPIC FITTING

- Basic ansatz for cross-correlations:

$$P_{\mathrm{cross}} = \sqrt{P_{\mathrm{Ly}\alpha} P_{\mathrm{QSO}}}$$

- Basic approach from Xu et al. '12: Linear theory + Kaiser effect + non-linear broadening

- Deviations from Planck cosmology parametrized by

$$r_{||} = \alpha(1+\epsilon)^2 r_{||,\mathrm{obs}},\ r_{\perp} = \frac{\alpha}{1+\epsilon} r_{\perp,\mathrm{obs}}$$

- Account for systematics using polynomials

$$A_\ell(r) = \frac{a_{\ell,0}}{r^2} + \frac{a_{\ell,1}}{r} + a_{\ell,2}$$

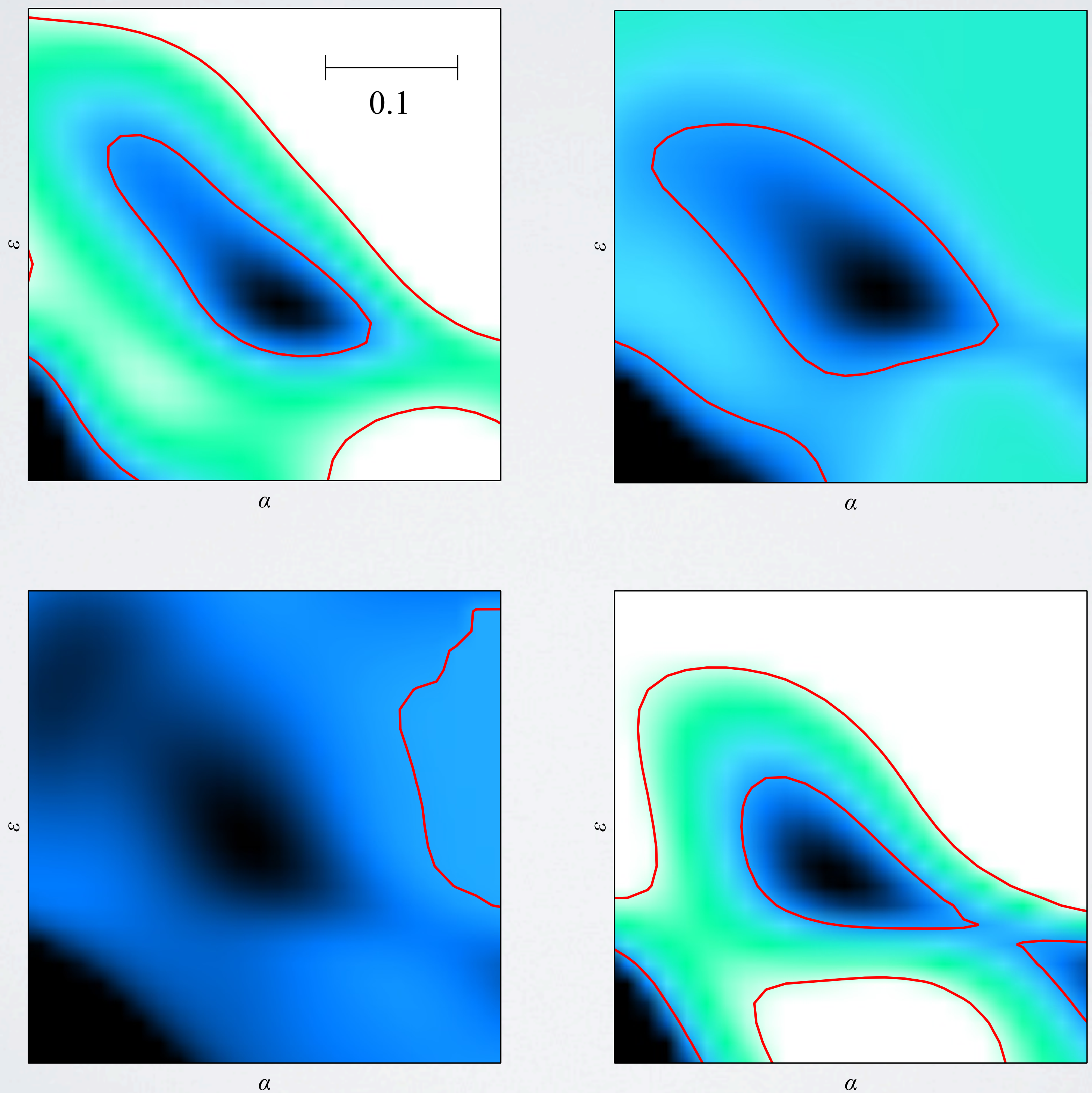
$\alpha - \varepsilon$ FITTING: FOUR FORESTS

No Corrections

$\langle \delta_F \rangle (z) = 0$

Mean Transmission Correction

Luminosity dependent corrections, and $\langle \delta_F \rangle (z) = 0$



AVERAGED LIKELIHOOD SURFACE

- How do we interpret these likelihood surfaces?
- Our guess: systematic uncertainty associated with continuum fitting.
- Average together likelihood surfaces to get a result that incorporates this uncertainty. Sys ~ 0.5 x Stat