Constraining bias and cosmic growth with WiggleZ 3-point functions

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Outline

- Motivation to 3-point correlations
- The WiggleZ 3-point function
- Galaxy bias and cosmic growth history
- Summary & Outlook

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Where we stand: 2-point statistics

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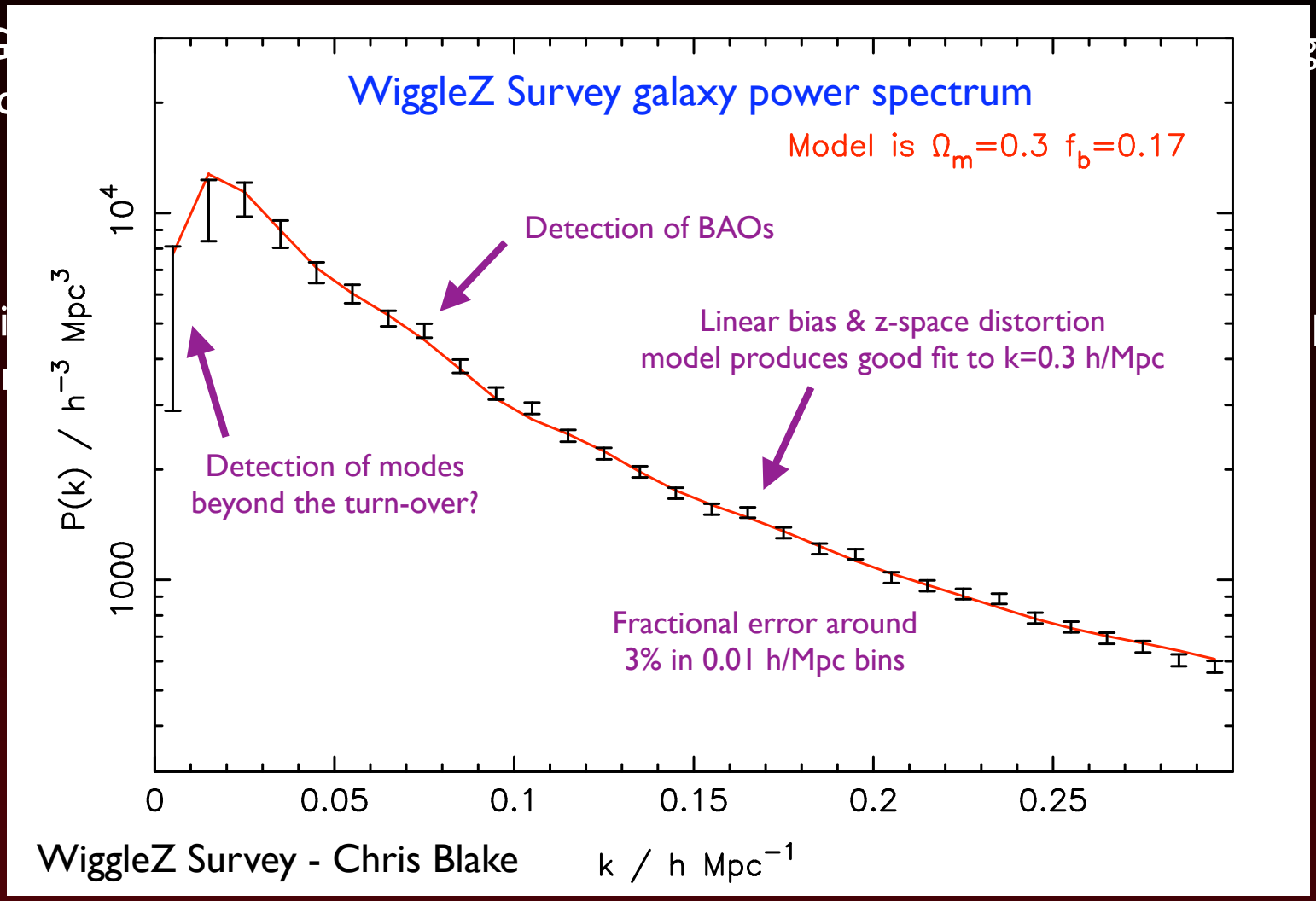
- Fi… …pace): fi…



We can do even more with the galaxy distribution

The 3-point correlation function

- Complete statistical description requires higher-order correlations
- Expensive (computational time) and difficult to understand!

$$\zeta(r_1, r_2, r_3) = \langle \delta_{gal}(r_1)\delta_{gal}(r_2)\delta_{gal}(r_3) \rangle$$

- Probability of finding pairs/triplets of objects

$$dP = n^3(1 + \xi(r_1) + \xi(r_2) + \xi(r_3) + \zeta(r_1, r_2, r_3))dV_1 dV_2 dV_3$$

'random'

correlated pairs

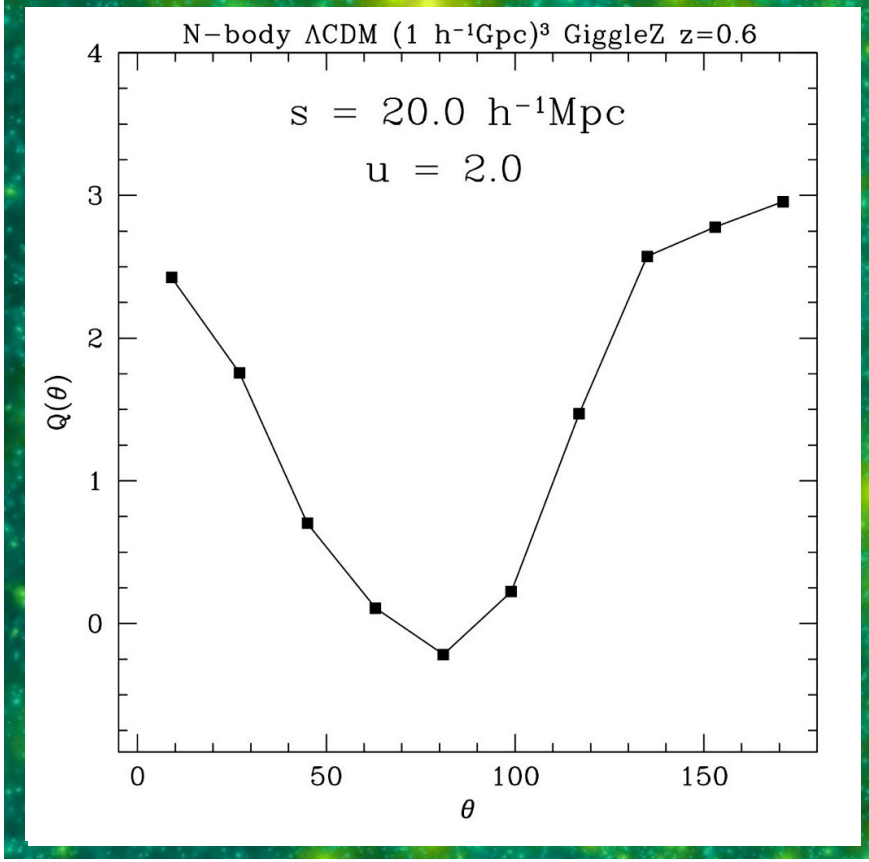
correlated triangles
early times: $\zeta \sim \xi^2$

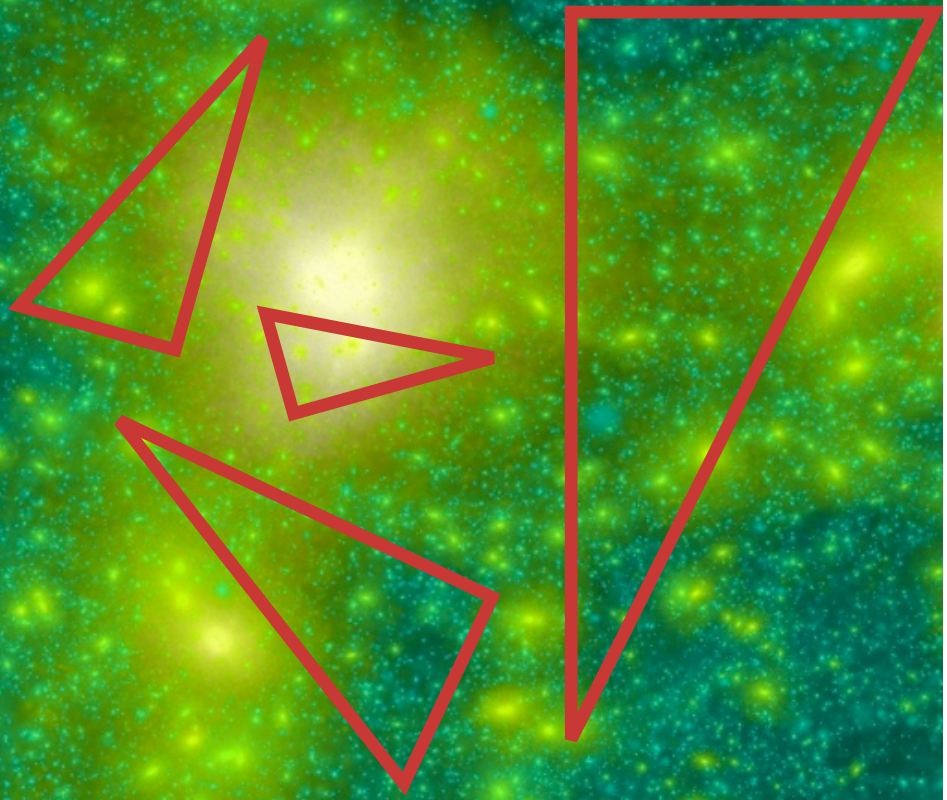
- Related: Bispectrum, count in cells, Minkowski functionals.. etc

The 3PCF of Dark Matter

GiggleZ simulation - Greg Poole et al.

V=1 $(Gpc/h)^3$, 2160^3 particles, m_p=7.5x10^9 M_{sun}/h

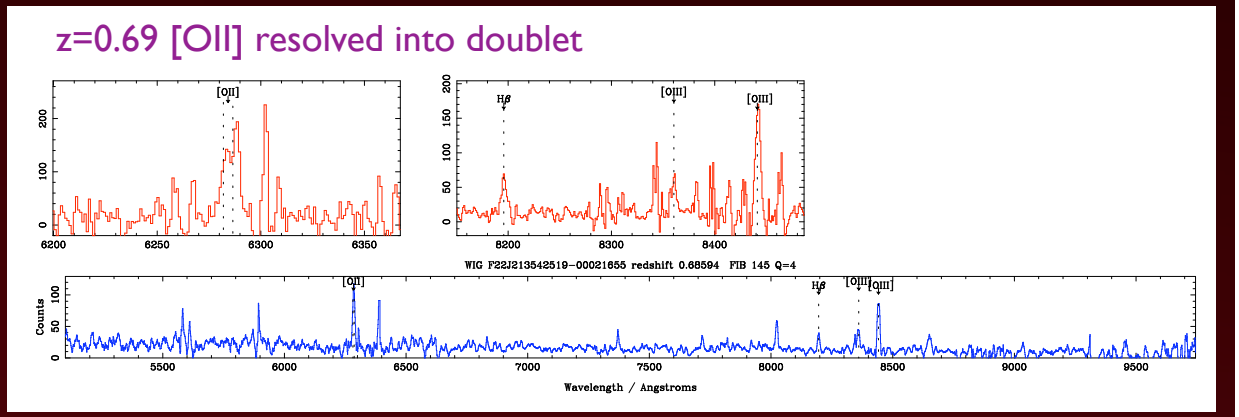




$$Q(s,u,\theta) = \frac{\zeta(r_1,r_2,r_3)}{\xi(r_1)\xi(r_2)+\xi(r_2)\xi(r_3)+\xi(r_3)\xi(r_1)}$$

The WiggleZ Galaxy Survey

- 1000 sq deg from AAT
- 8/2006-01/2011 - Spectroscopic redshifts with AAO Multi-spectrograph
- Follow up UV-selected sources from GALEX
- Color cuts to select high-z emission-type galaxies - short exposures
- Overlap with SDSS, RCS2 fields
- 200,000 galaxies 0.2<z<1
- n ~ 2.5×10^{-4} $(Mpc/h)^{-3}$



Chris Blake

measuring the 3PCF

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$$\xi = \frac{D}{} \quad - RRR$$

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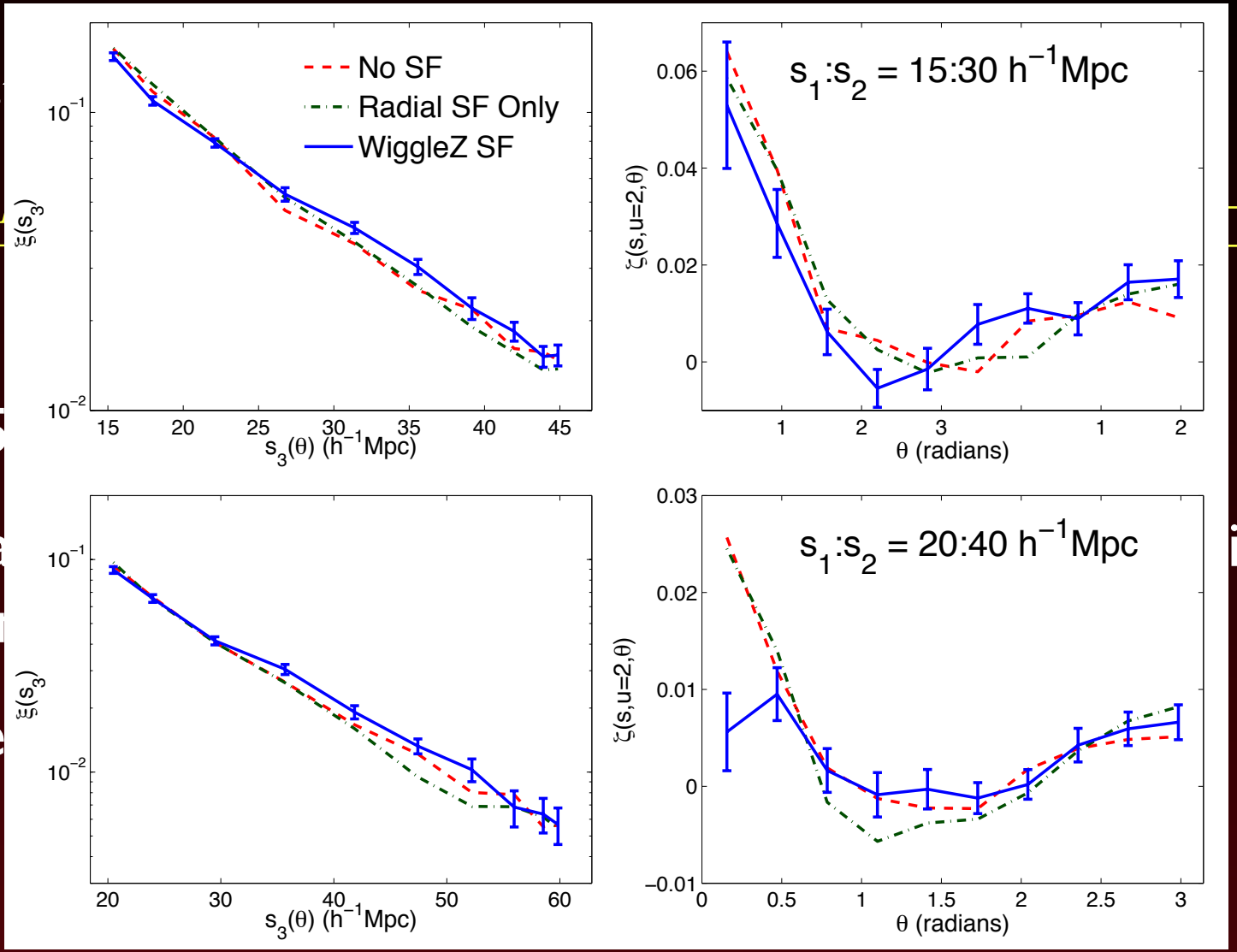
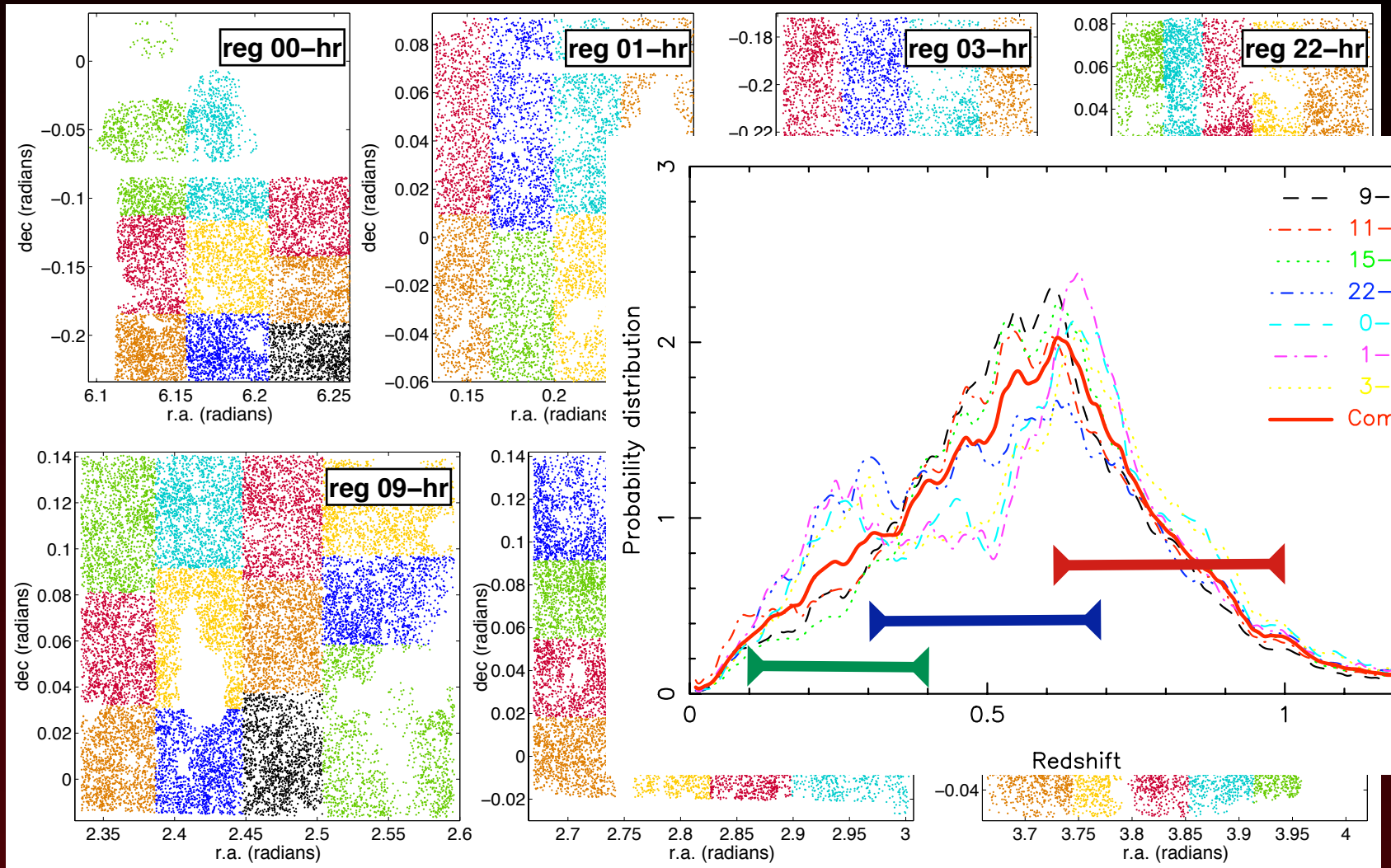
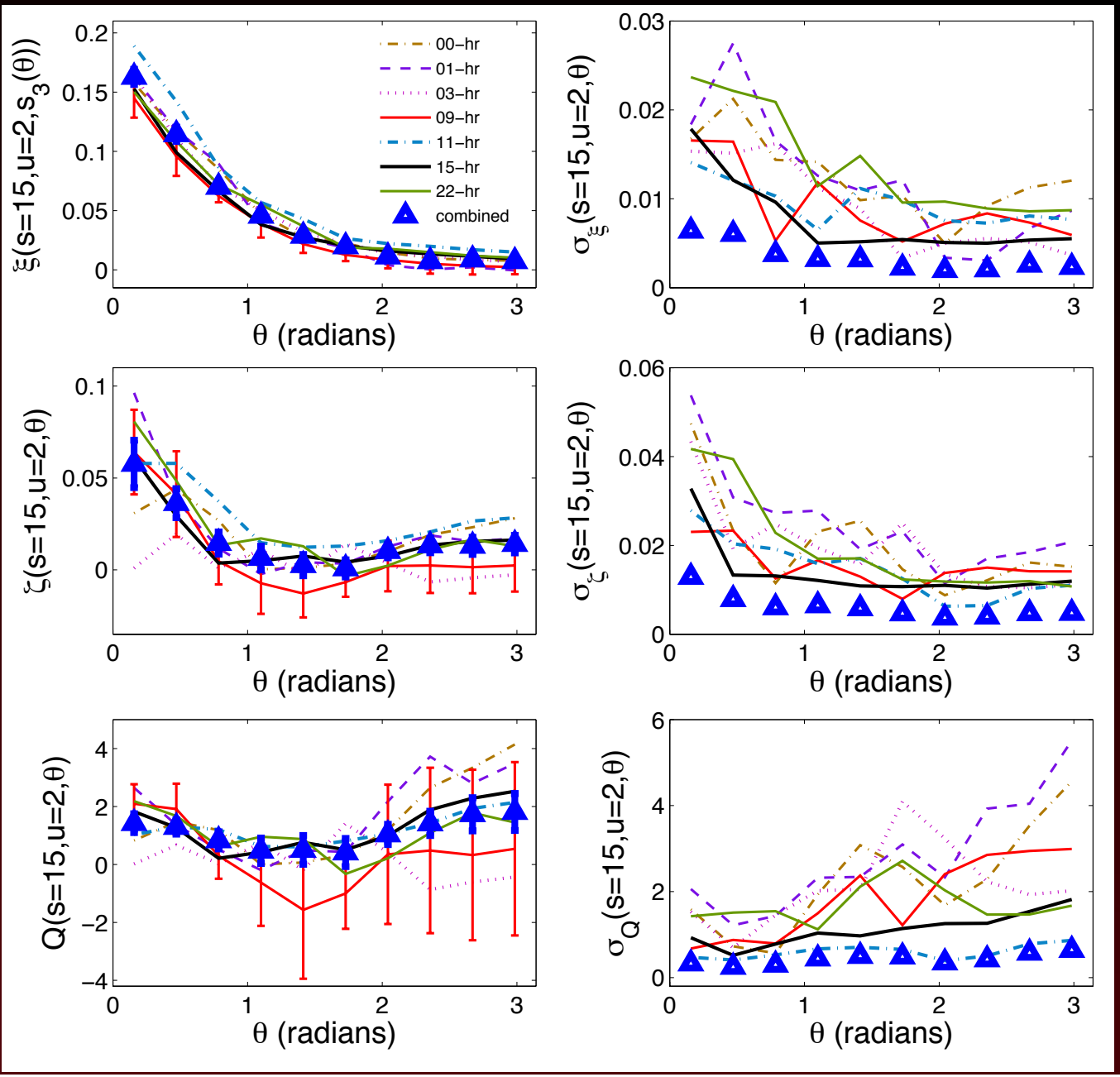


Selection functions - JK errors

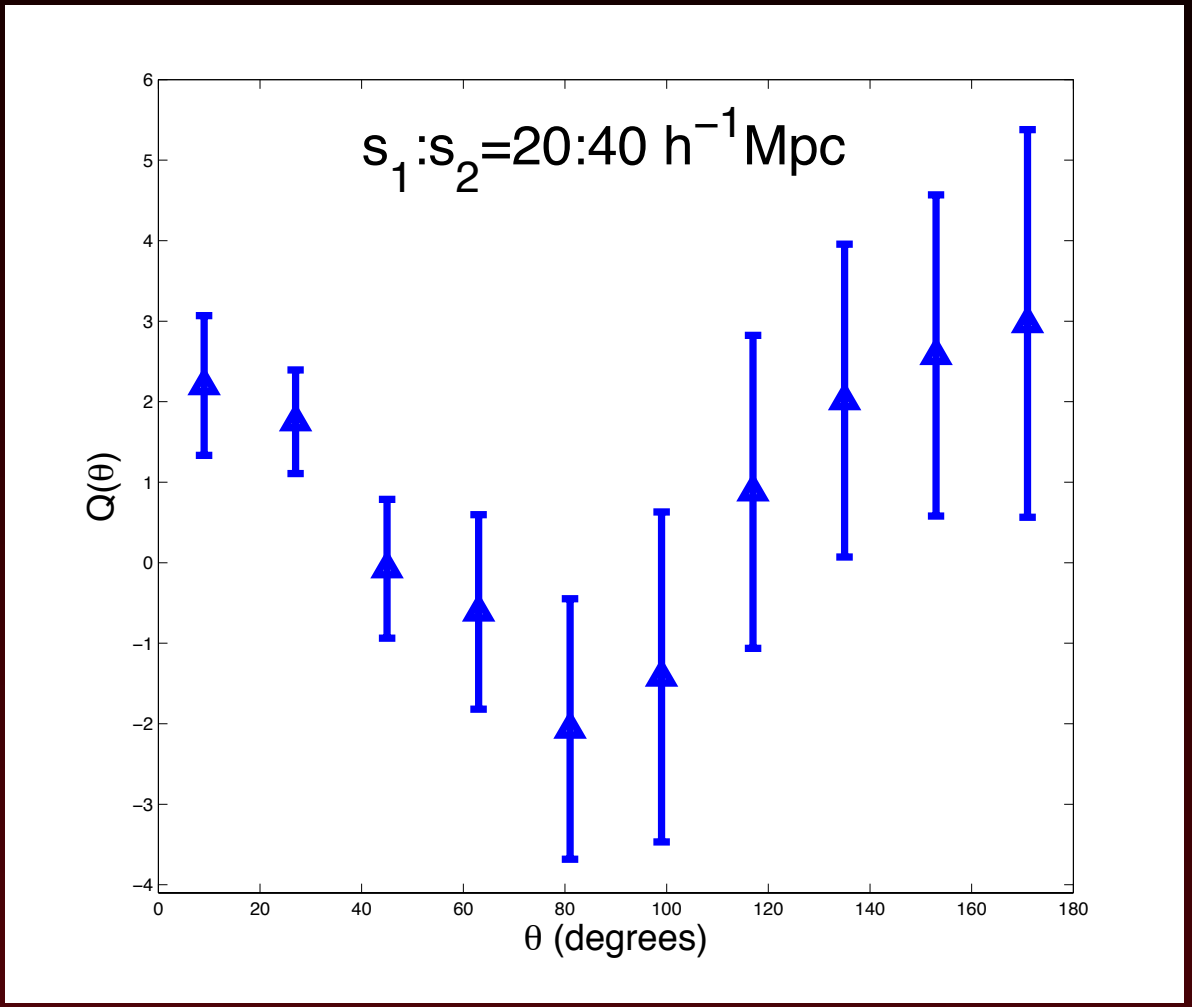


Individual regions at z_{eff}=0.55, s_1:s_2=15:30 Mpc/h



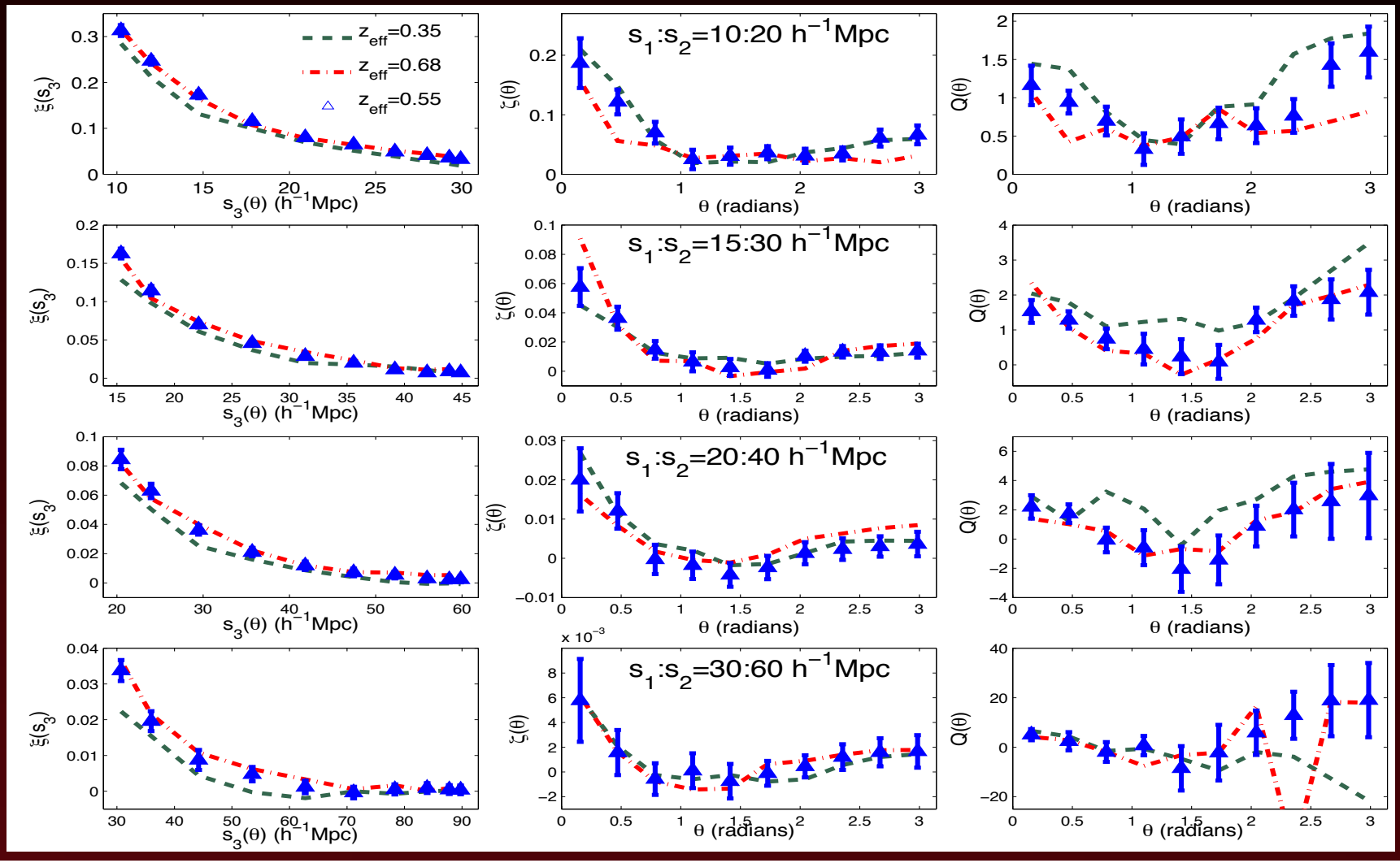
The WiggleZ 3PCF @ z=0.55

- ~120,000 galaxies in 7 different angular regions
- we recover shape dependence! Low S/N on large scales



Redshift dependence

- Two other slices at z_{close}=[0.1,0.4] and z_{far}=[0.6,1.0]
- Total ~ 190,000 galaxies
- s=10,15,20,30 Mpc/h, u=1,2,3 ➙120 configurations up to 120 Mpc/h



Simple bias model

- Inspired by local bias model (Fry & Gaztañaga '93)

$$\delta_{gal} \approx b_1 \delta_{DM} + \frac{b_2}{2} \delta_{DM}^2$$

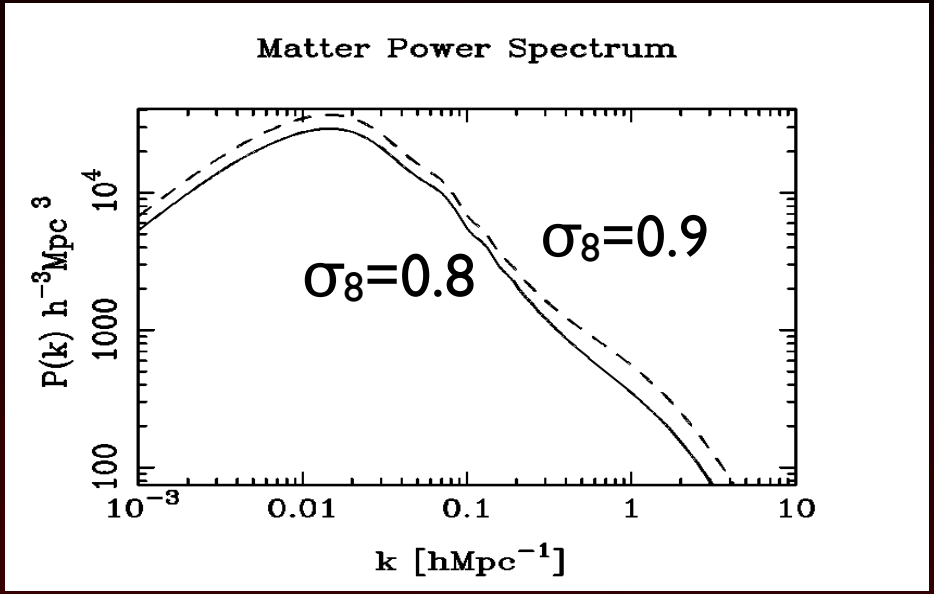
- the 2PCF and 3PCF at leading order (Gaztanaga & Scoccimarro '05)

$$\xi_{gal}(r) = b_1^2 \xi_{DM}(r)$$

$$Q_{gal} \approx \frac{1}{b_1} \left(Q_{DM} + \frac{b_2}{b_1} \right)$$

Constraints on σ_8

- There is an intrinsic degeneracy between the bias and the amplitude of DM perturbations, provided by σ_8, the variance of spheres of R=8 Mpc/h:



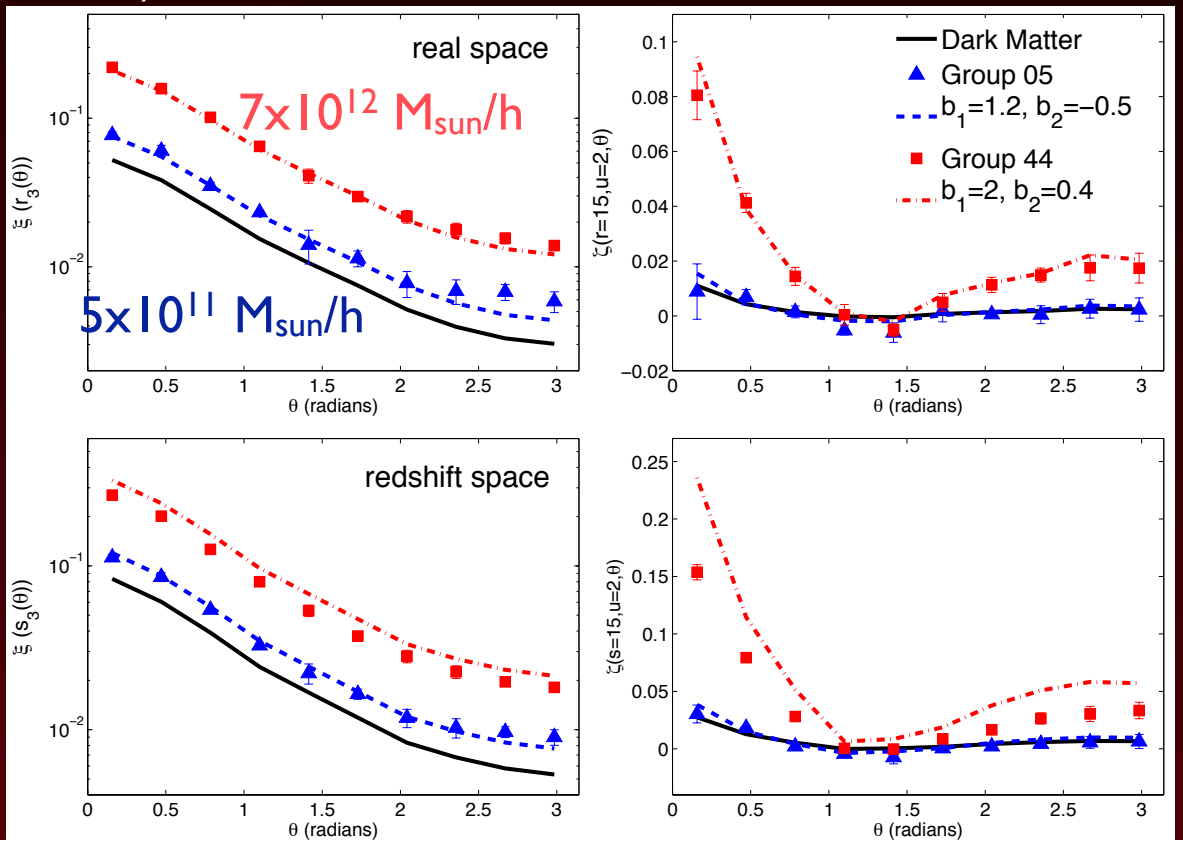
- on large scales and in the local bias model we get (Pan & Szapudi 2005)

$$\xi_{gal}(r) = \left(\frac{\sigma_8}{\sigma_8^{fid}}\right)^2 b_1^2 \xi_{DM}(r) \qquad Q_{gal} \approx \frac{1}{b_1}\left(Q_{DM} + \frac{b_2}{b_1}\right)$$

$$\zeta_{gal}(r_1, r_2, r_3) = \left(\frac{\sigma_8}{\sigma_8^{fid}}\right)^4 \left[b_1^3 \zeta_{DM}(r_1, r_2, r_3) + b_2 b_1^2 (\xi_{DM}(r_1)\xi_{DM}(r_2) + perm)\right]$$

Galaxy Bias + RSD: empirical model

- We measured in GiggleZ halos at z=0.6 the bias parameters in real and redshift space
- For low bias tracers (halos) we found that $b_{i,r} \sim b_{i,z}$ like WiggleZ galaxies! not applicable to LRGs or CMASS galaxies, for instance.
- Systematics deviations much smaller than statistical error (low density and cosmic variance)

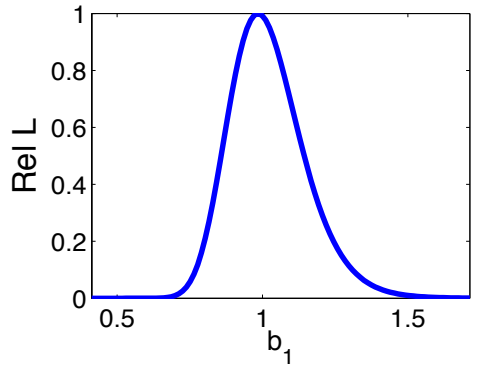


s_1:s_2=15:30 Mpc/h

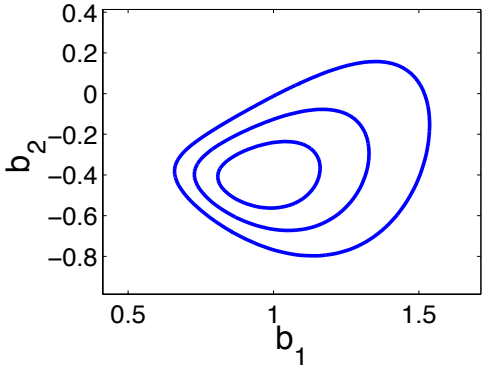
empirical model: What we do

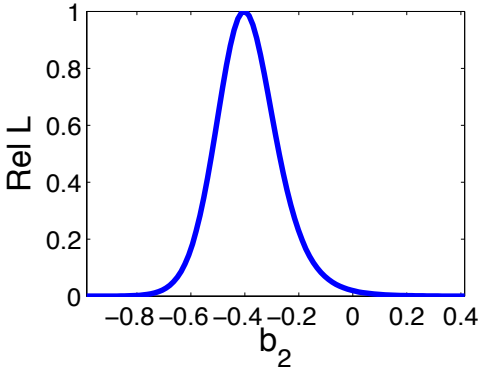
- Measure 2PCF and 3PCF in redshift space for WiggleZ galaxies
- Covariance matrix using JK resampling. Use higher eigenmodes (SVD) to avoid numerical noise (Gaztañaga & Scoccimarro '05)
- Measure 2PCF and 3PCF in redshift space of Dark Matter on GiggleZ simulation at effective redshift of samples
- Use the local bias model relations to model the galaxy correlations
- MLE analysis for the bias parameters and $\sigma_8(z)$ - Compare data with biased DM from GiggleZ
- Limitation: *only constraints on $\sigma_8(z)$*, no other cosmo parameters

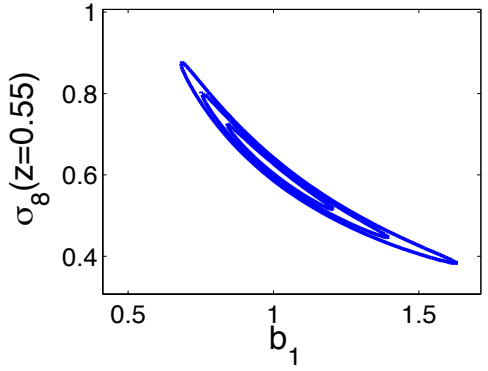
Results at z=0.55

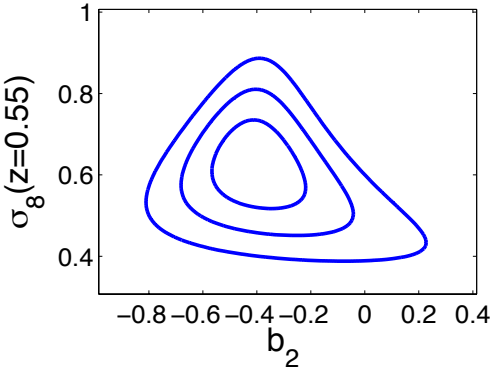


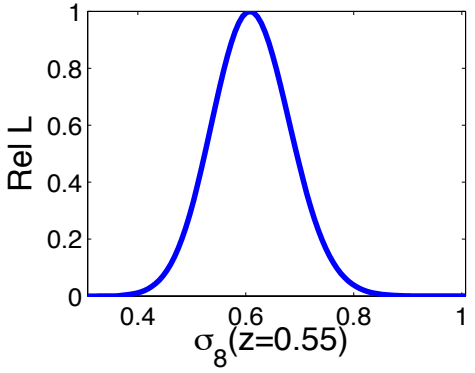
- Comparing WiggleZ 3PCF to GiggleZ at z=0.55
- 10<s<30 Mpc/h, 1<u<3, 20<s_3<120 Mpc/h
- MLE analysis for b_1,b_2 and σ_8
- χ2/dof =0.96





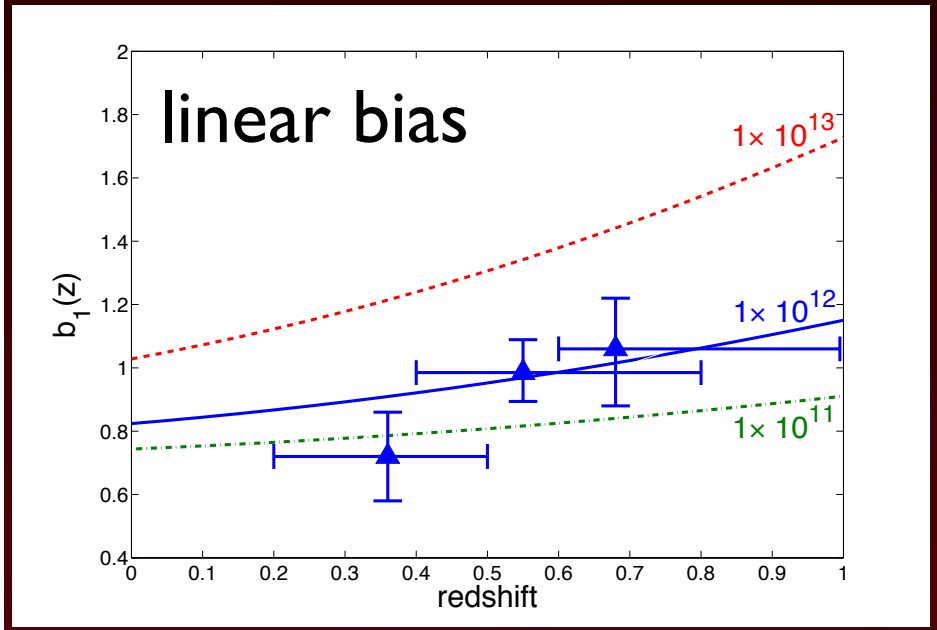


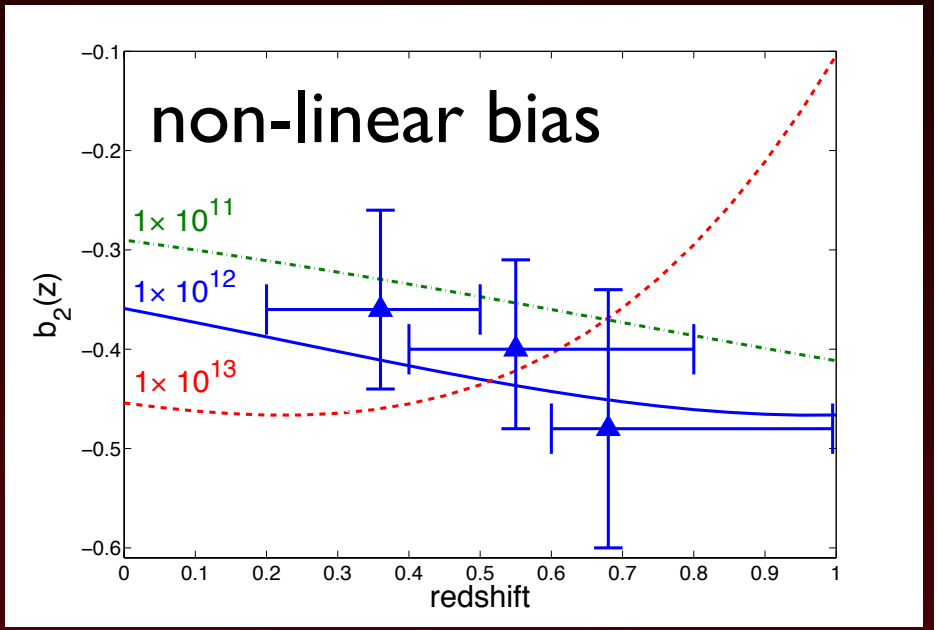




Evolution of the bias parameters

- Halo model connects bias with average mass of halos hosting WiggleZ galaxies (Sheth-Tormen 99, Scoccimarro 2001)
- $M_{\text{WiggleZ halo}} \sim 1 \times 10^{12}$ Msun/h
- Not totally accurate due to emission-line galaxy luminosity does not correlate to mass as good as other types (eg. LRGs)
- Significant detection of (non-zero) non-linear bias (also in LRGs)



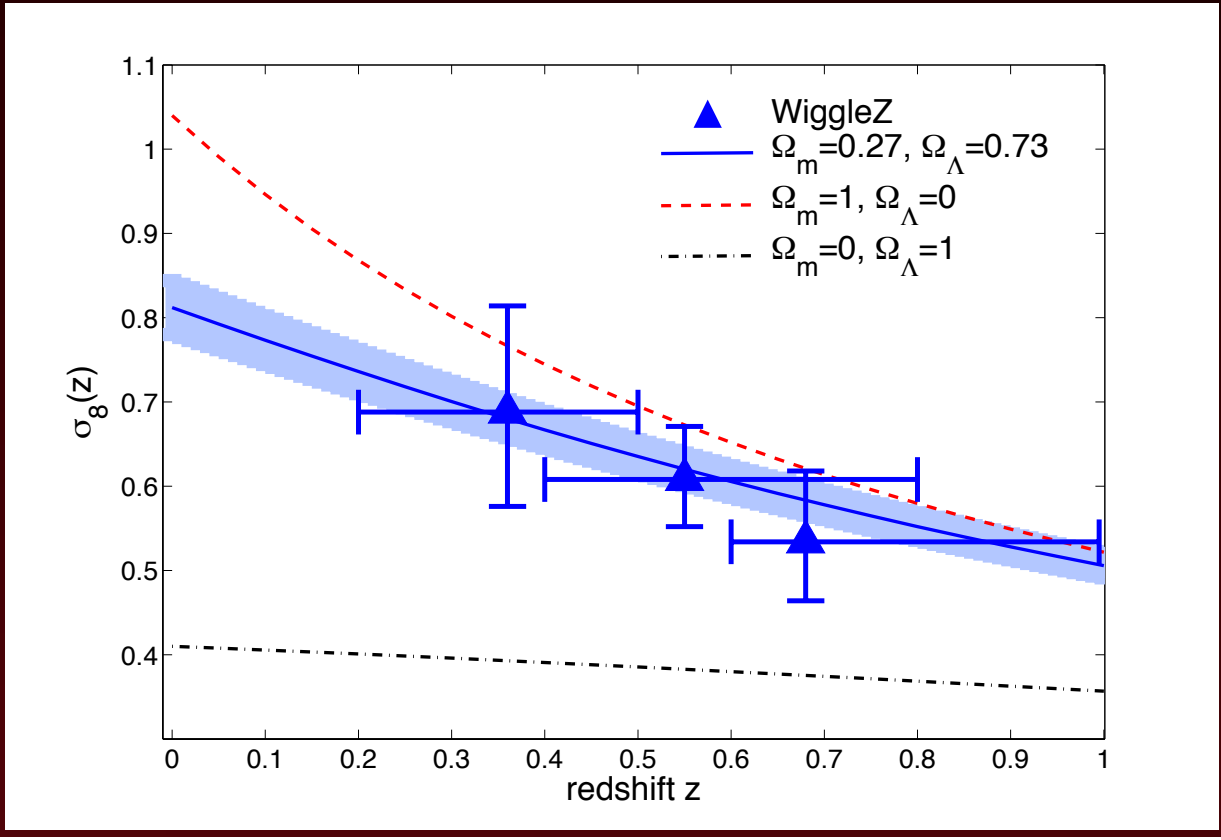


Evolution of cosmic growth

- 3PCF helps measure evolution of σ_8, independent of bias

$$\sigma_8(z) = \frac{D(z)}{D(z=0)}\sigma_8(z=0)$$

- $\sigma_8(z=0)=0.79\pm0.07$, consistent with LCDM evolution



Summary

- The 3PCF is a complementary measure of clustering, which provides information about bias of galaxies and cosmological parameters
- Measure the galaxy 3-point function up to z~0.7, highest redshift up to date
- We put constraints on linear and nonlinear bias parameters of WiggleZ galaxies, as well as σ_8 as a function of redshift
- ΛCDM gets to live another day

The Future

$$Q_{gal} \approx \frac{1}{b_1}\left(Q_{DM} + \frac{b_2}{b_1}\right) ?$$

- For Las Campanas, SDSS Main sample & LRG, 2dF the simple bias model work, but WiggleZ last survey where we can apply 'naive' bias model
- Must improve modeling for BOSS, HETDEX, TAIPAN, WALLABY, Euclid et al: bias & RSD - PNG?
- Bias+RSD are complicated
- Alternative models: Halo Model, Sub-abundance halo matching, etc. Or alternative statistics? Let me know your ideas!
- More higher-order coming up so *stay tuned!*

Gracias!