Combining Spectroscopy with Photometry to Probe Higher Redshift Clustering

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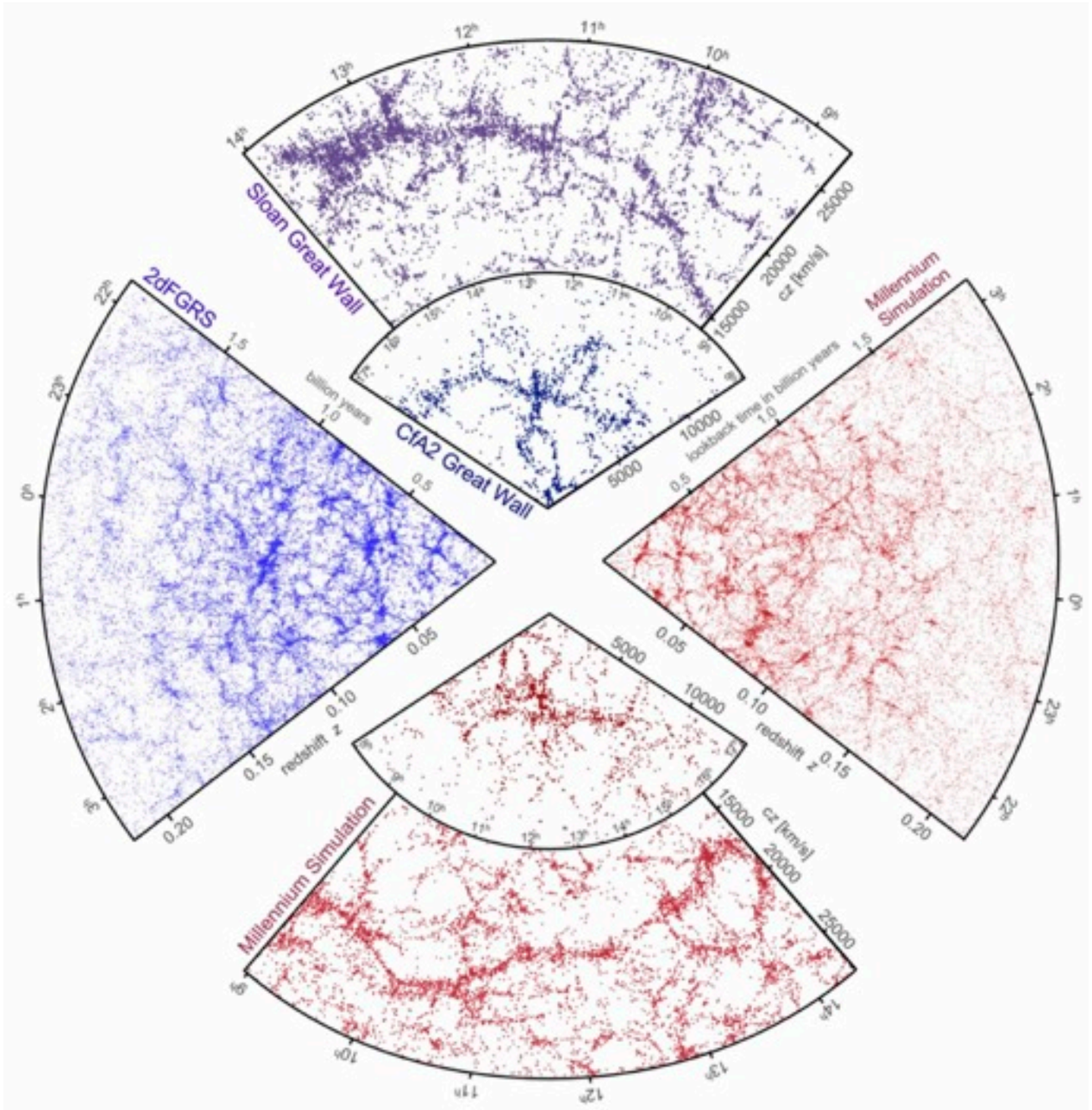
- Quantifying the stochasticity of large-scale structure
- Future prospects for galaxy redshift surveys
- Probing higher redshift clustering

Galaxy Redshift Surveys

- Galaxy redshift surveys use observed galaxy distribution to probe large-scale structure

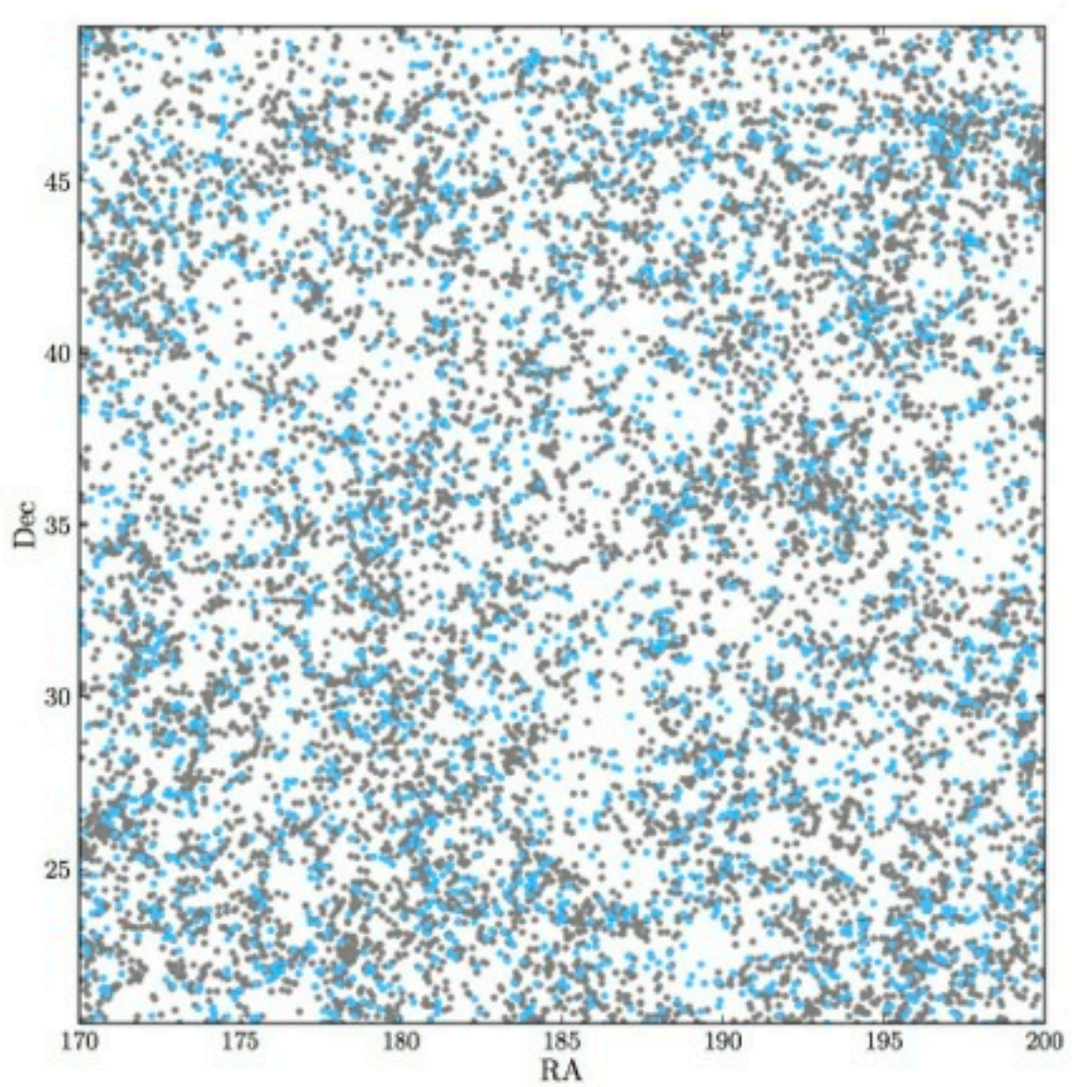
- Surveys target specific populations of galaxies

- Key Question: to what extent does the observed population trace the underlying matter distribution?



Above: Springel, et al. (2006)

Galaxy Redshift Surveys



- Survey galaxy targets include:
  - SDSS-III BOSS: LRGs, CMASS
  - DESI (future): LRGs, ELGs
- Do massive red and blue galaxies in BOSS/CMASS trace the same large-scale structure on intermediate scales (20<R<100 Mpc/h)?

Large-Scale Structure Formalism

- Simplest model:

Density Field:

$$\delta(\mathbf{x}) = \frac{\rho(\mathbf{x})}{\bar{\rho}} - 1 \longrightarrow \begin{aligned} \delta_r(\mathbf{x}) &= b_r \delta(\mathbf{x}) \quad \text{Red} \\ \delta_b(\mathbf{x}) &= b_b \delta(\mathbf{x}) \quad \text{Blue} \end{aligned}$$

Correlation Function:

$$\xi(\mathbf{R}) = \langle \delta(\mathbf{x}) \delta(\mathbf{x}+\mathbf{R}) \rangle \longrightarrow \begin{aligned} \xi_{bb}(\mathbf{R}) &= b_b^2 \xi(\mathbf{R}) \quad \text{Blue} \\ \xi_{rr}(\mathbf{R}) &= b_r^2 \xi(\mathbf{R}) \quad \text{Red} \\ \xi_{br}(\mathbf{R}) &= b_b b_r \xi(\mathbf{R}) \quad \text{Cross} \end{aligned}$$

Correlation Coefficient:

$$r_\xi \equiv \frac{\xi_{br}}{\sqrt{\xi_{bb}\xi_{rr}}} = 1$$

Large-Scale Structure Formalism

- But what if bias is stochastic? Following Dekel & Lahav (1999):

Define a random bias field for g = b,r:

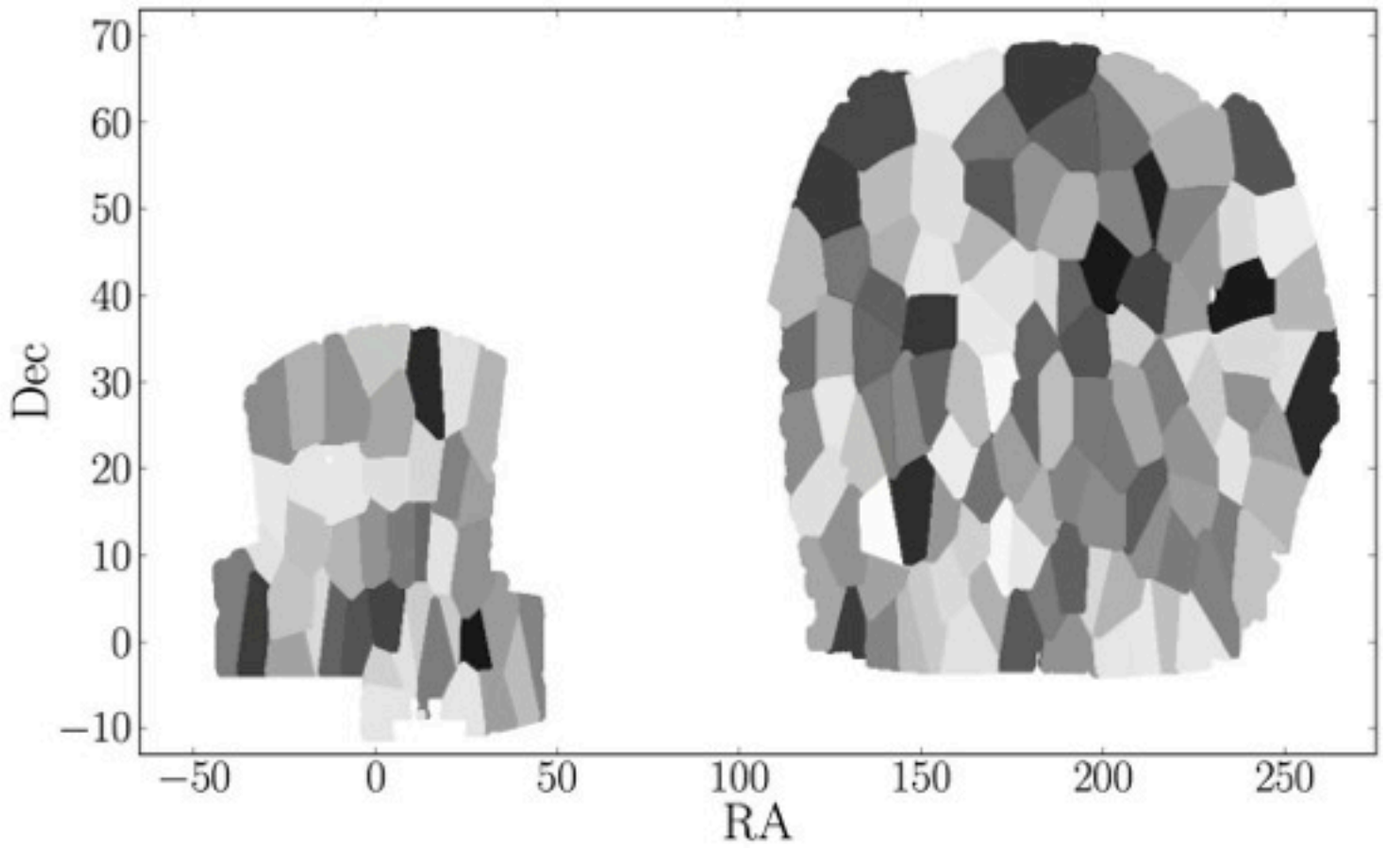
$$\epsilon_g(\mathbf{x}) \equiv \delta_g(\mathbf{x}) - b_g\delta(\mathbf{x})$$

Correlation Coefficient:

$$\delta_g(\mathbf{x}) = b_g\delta(\mathbf{x}) + \epsilon_g(\mathbf{x}) \longrightarrow r_\xi \equiv \frac{\xi_{rb}}{\sqrt{\xi_{rr}\xi_{bb}}} \neq 1$$

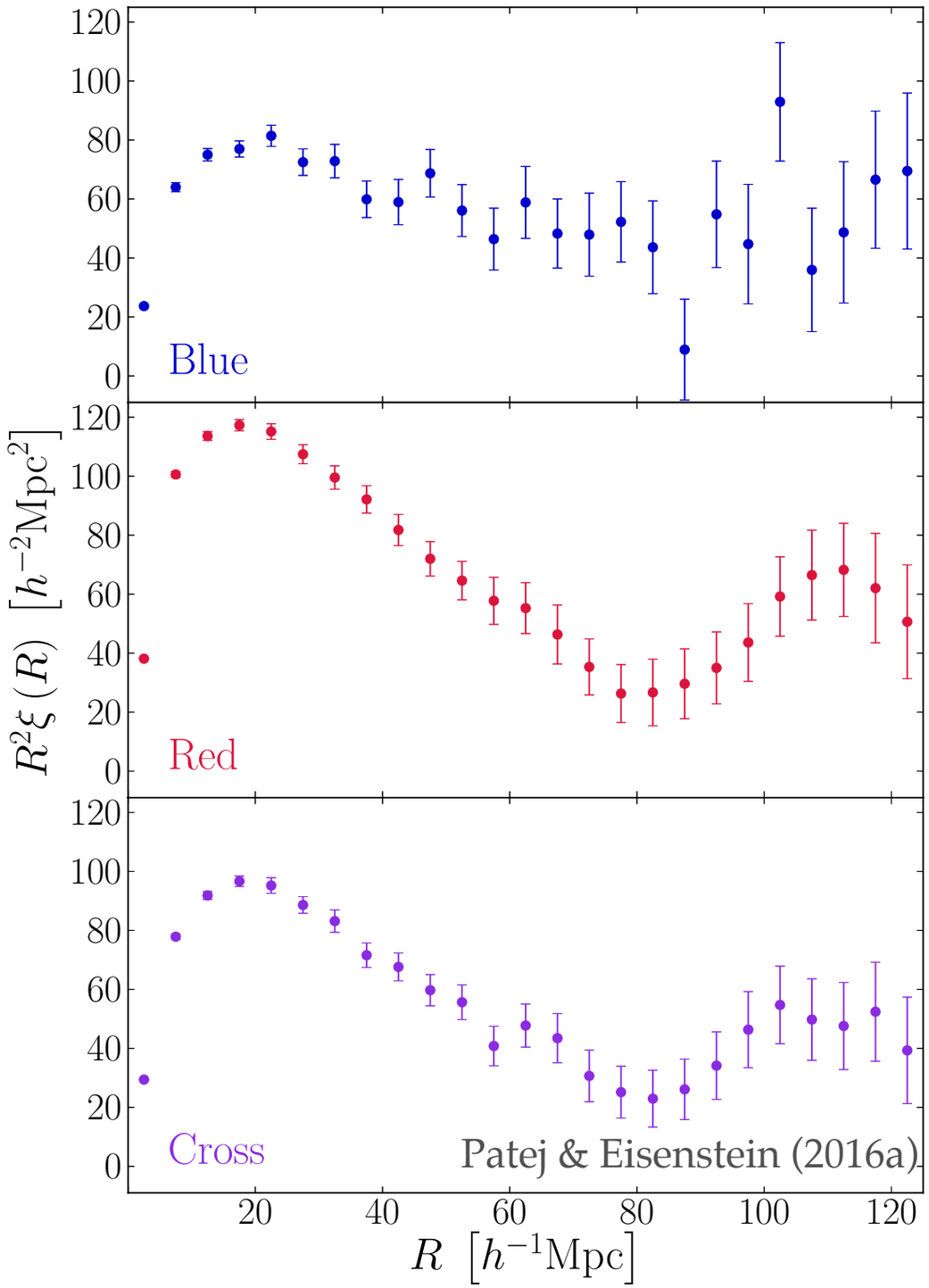
Data

- SDSS DR12 BOSS / CMASS sample of galaxies between $0.55<z<0.65$
- Separate galaxies using Masters et al. (2011) color cut
  - g-i > 2.35 → red: 232,759 galaxies
  - g-i ≤ 2.35 → blue: 61,301 galaxies



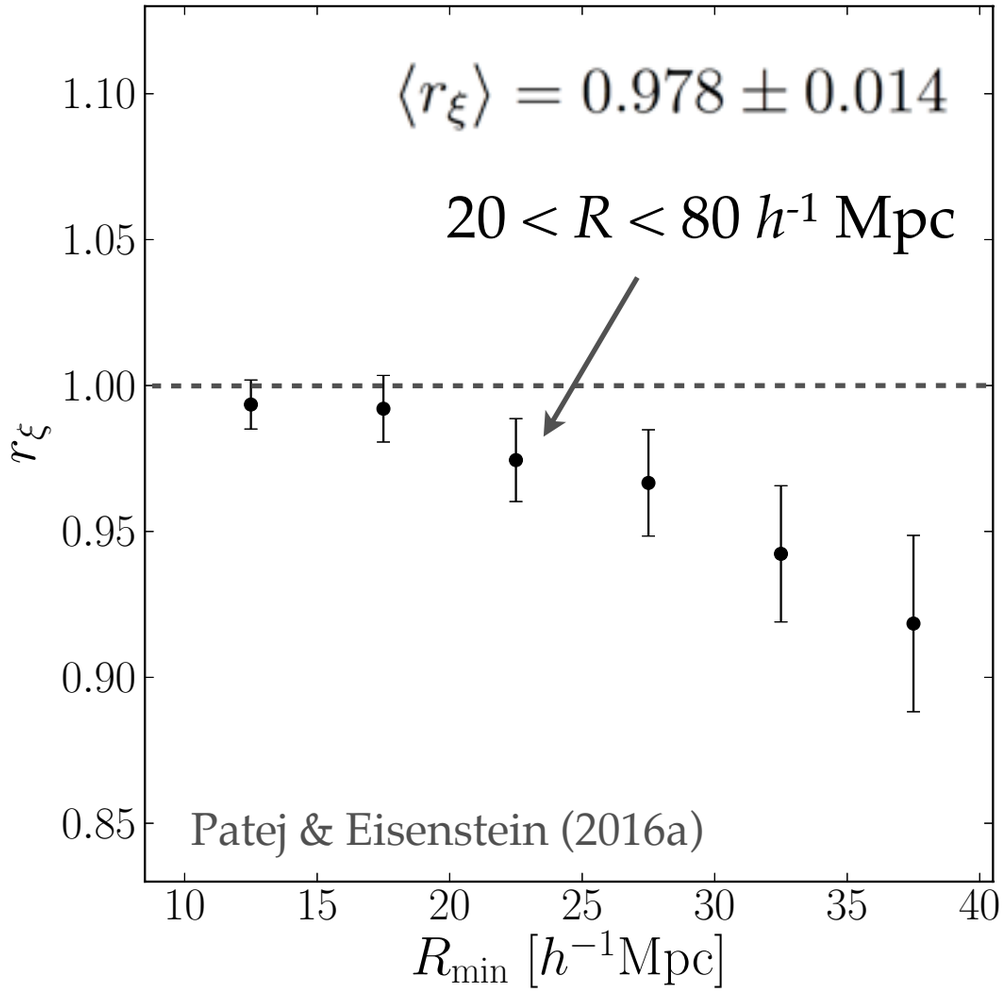
Above: Patej & Eisenstein (2016a)

Measuring r



$$\xi(R) = \frac{\mathcal{DD}(R) - 2\mathcal{DR}(R) + \mathcal{RR}(R)}{\mathcal{RR}(R)}$$

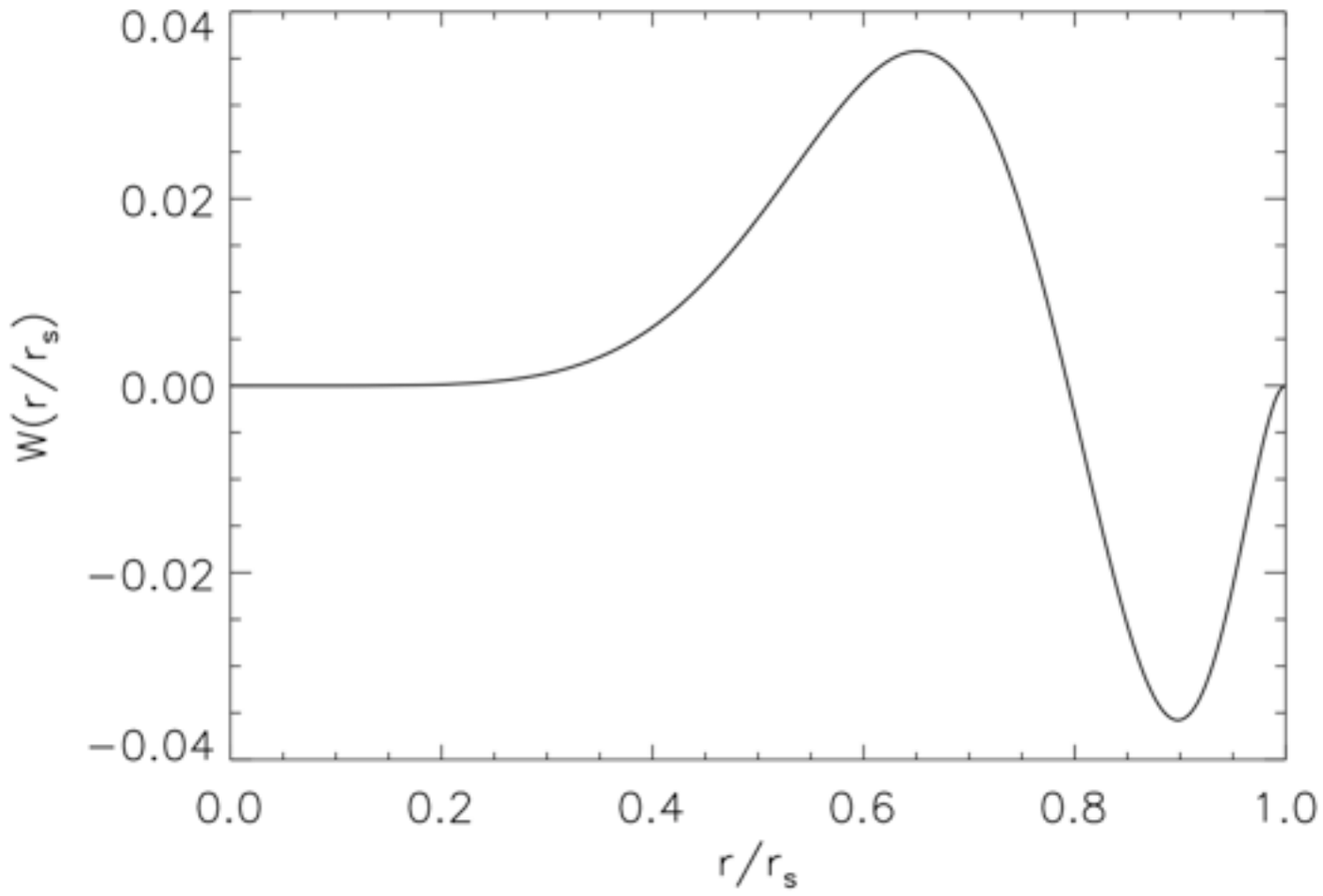
$$r_\xi \equiv \frac{\xi_{rb}}{\sqrt{\xi_r \xi_b}}$$



Measuring r

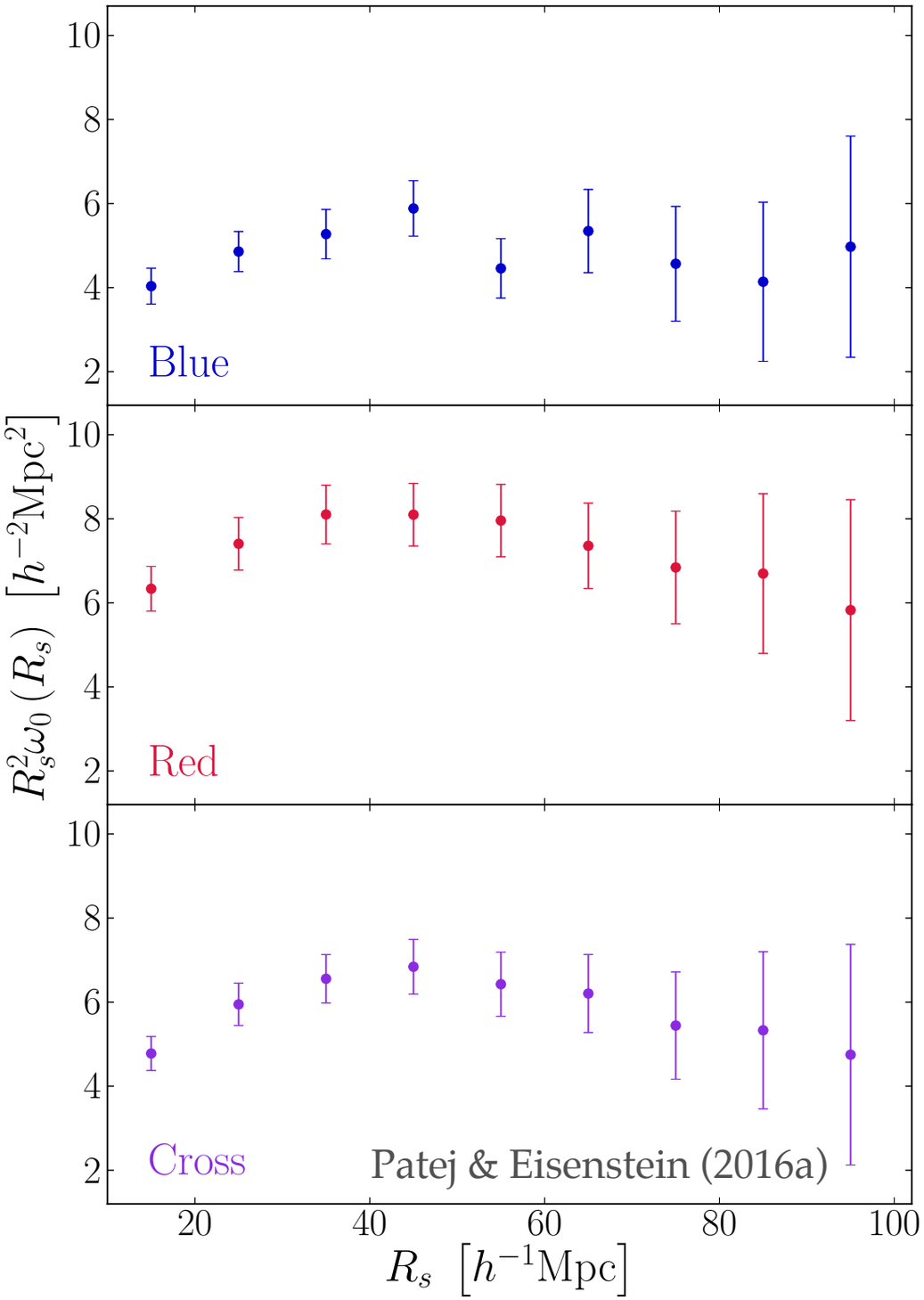
- Also consider Xu, et al. (2010) statistic:

$$\omega(r_s) \equiv 4\pi \int r^2 dr W(r, r_s) \xi(r)$$



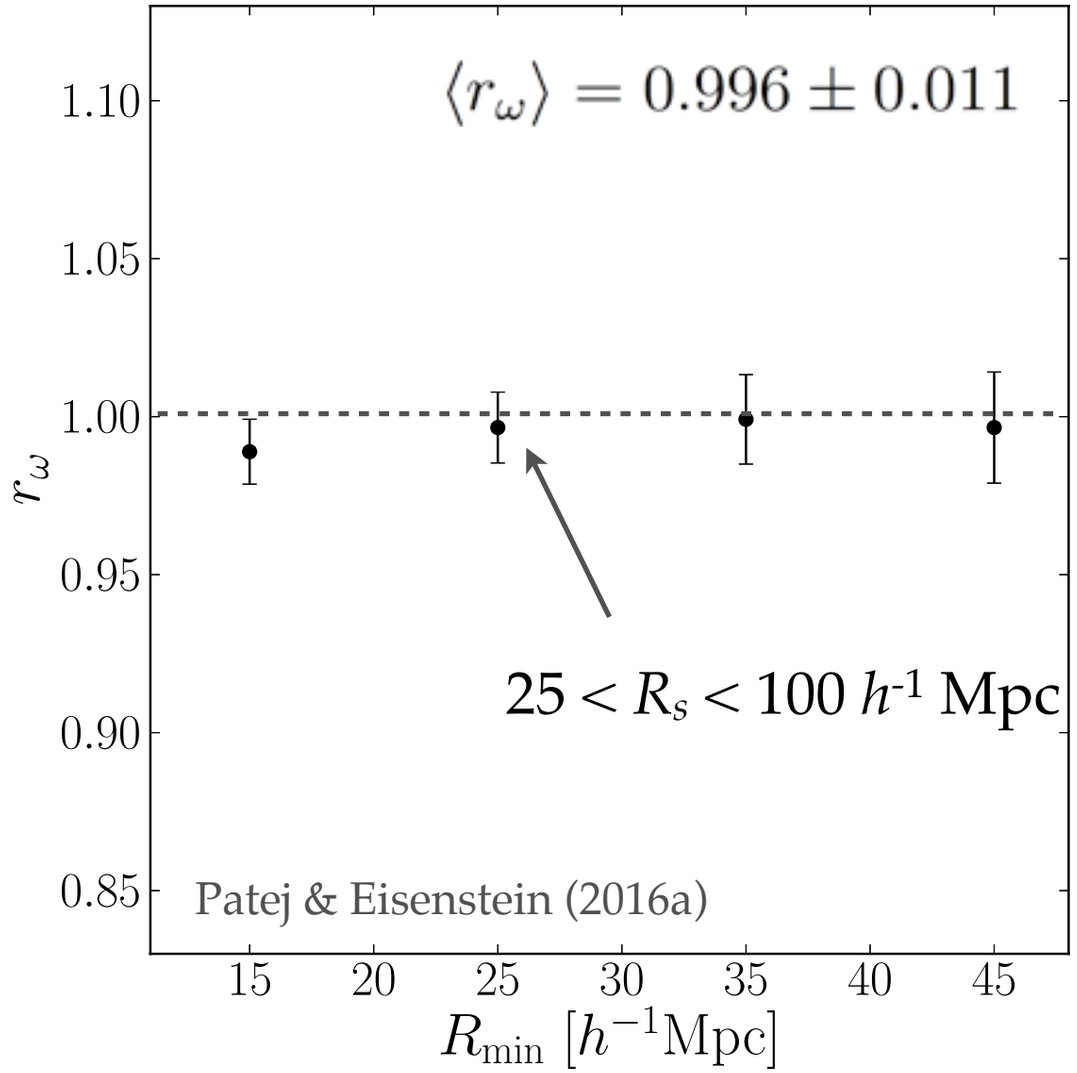
Above: Xu, et al. (2010)

Measuring r



$$\omega(r_s) = \frac{V}{N_D^2}\sum_j \frac{W(r_j, r_s)}{\Phi(r_j)}$$

$$r_\omega = \frac{\omega_{br}}{\sqrt{\omega_{rr}\omega_{bb}}}$$

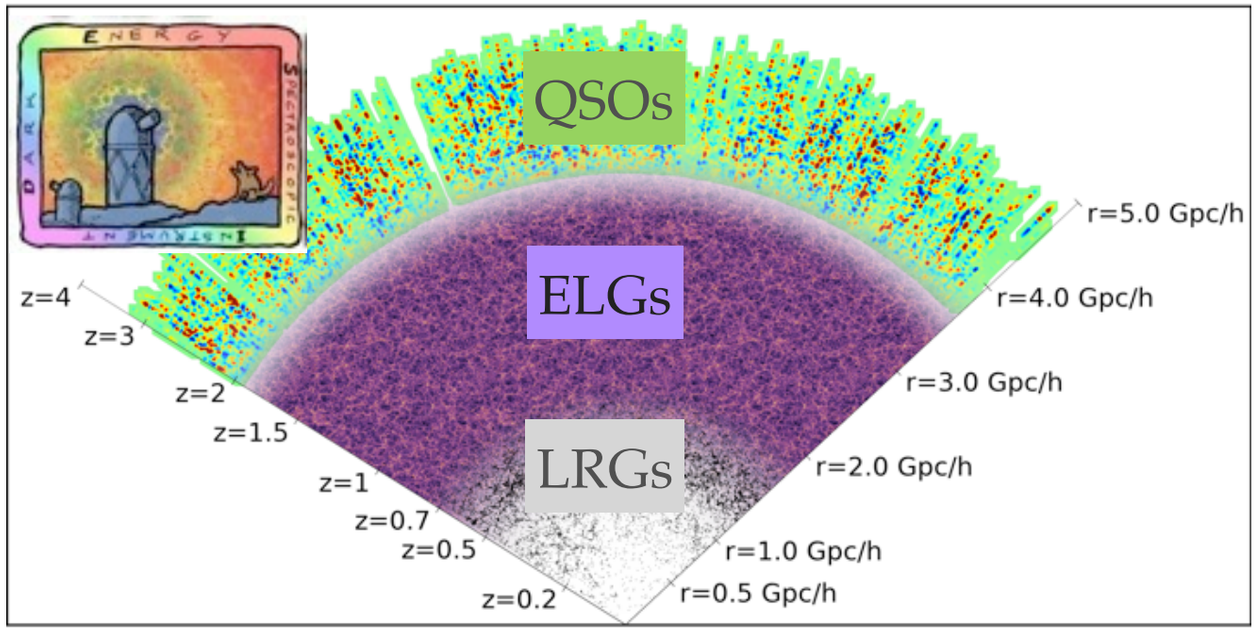


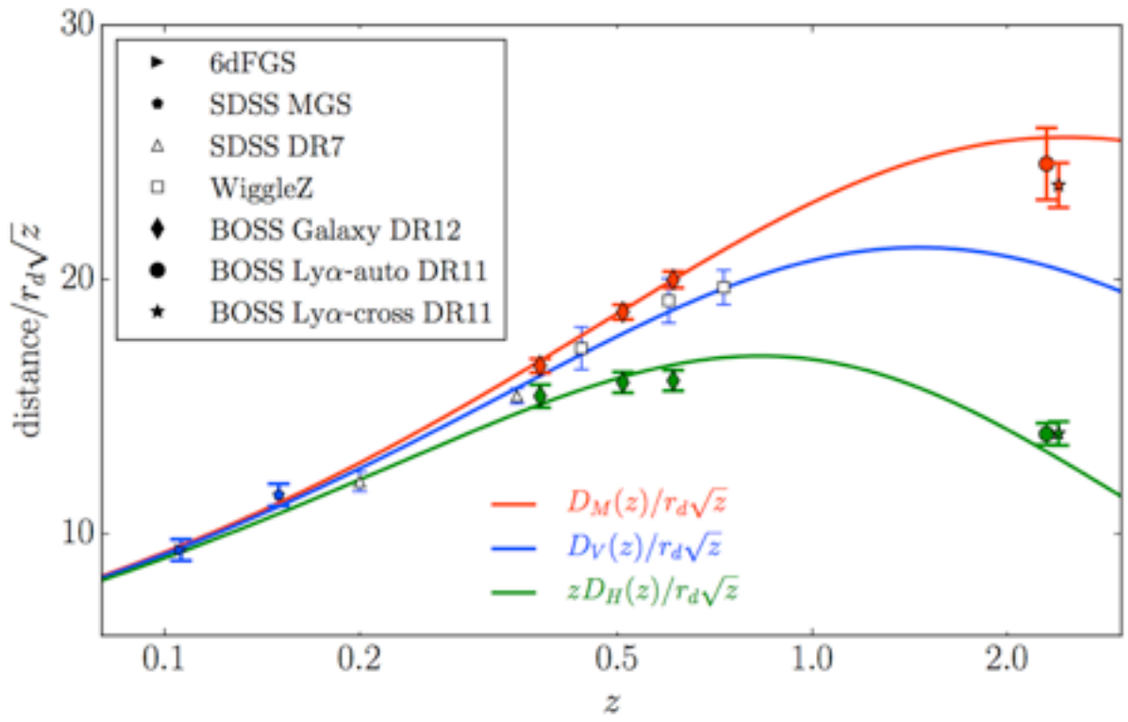
Summary

- At the sensitivity of BOSS, we find that red and blue galaxies at z~0.6 do trace the same large-scale structure
- We find 2σ lower bounds of $r > 0.95$ using correlation functions and $r > 0.974$ using the ω statistic

Future Prospects

- The Dark Energy Spectroscopic Instrument (DESI) is the next generation galaxy redshift survey, set to begin in late 2019
  - Successor to SDSS/BOSS & eBOSS
  - Spectra for ~30 million objects
  - Enable BAO measurements out to high redshift with galaxies and quasars





Above left: Image courtesy of A. Dey
Above right: Alam, et al. (2016)

DESI Imaging Surveys

- Three imaging surveys (see legacysurvey.org) are currently underway to provide target selection for DESI:
  - DECam Legacy Survey (DECaLS)
  - Mosaic z-band Legacy Survey (MzLS)
  - Beijing-Arizona Sky Survey (BASS)

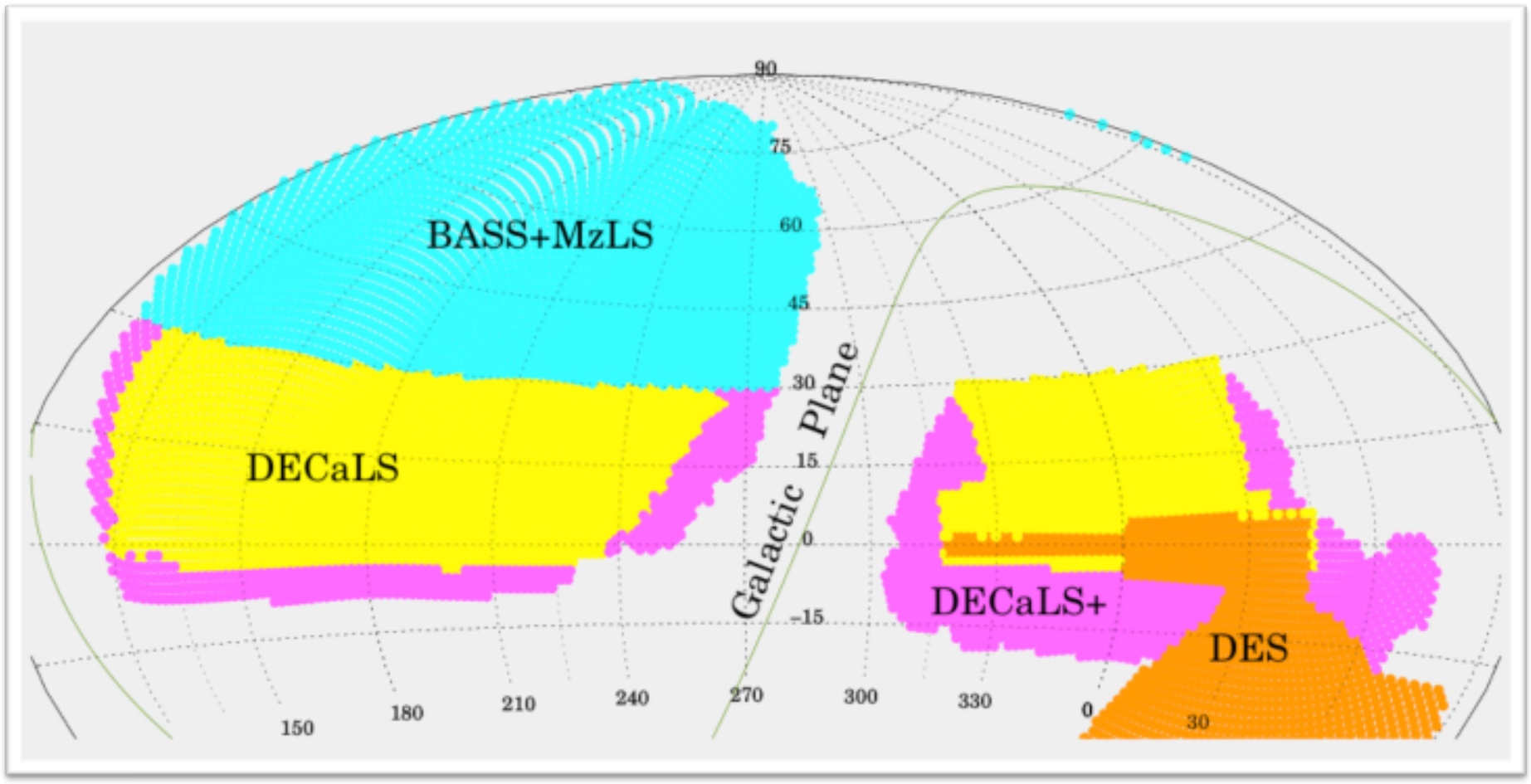
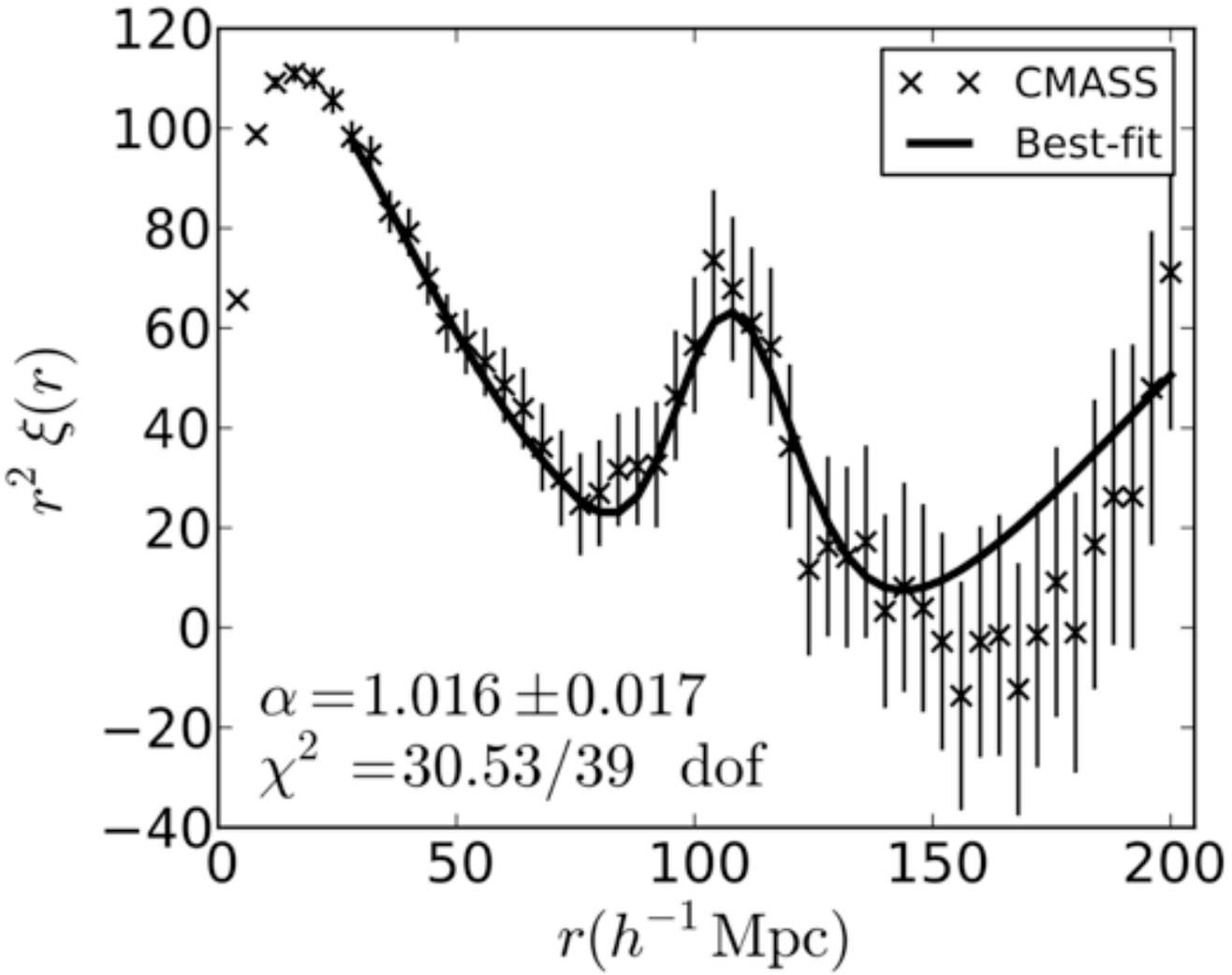


Image courtesy of A. Dey

Baryon Acoustic Oscillations

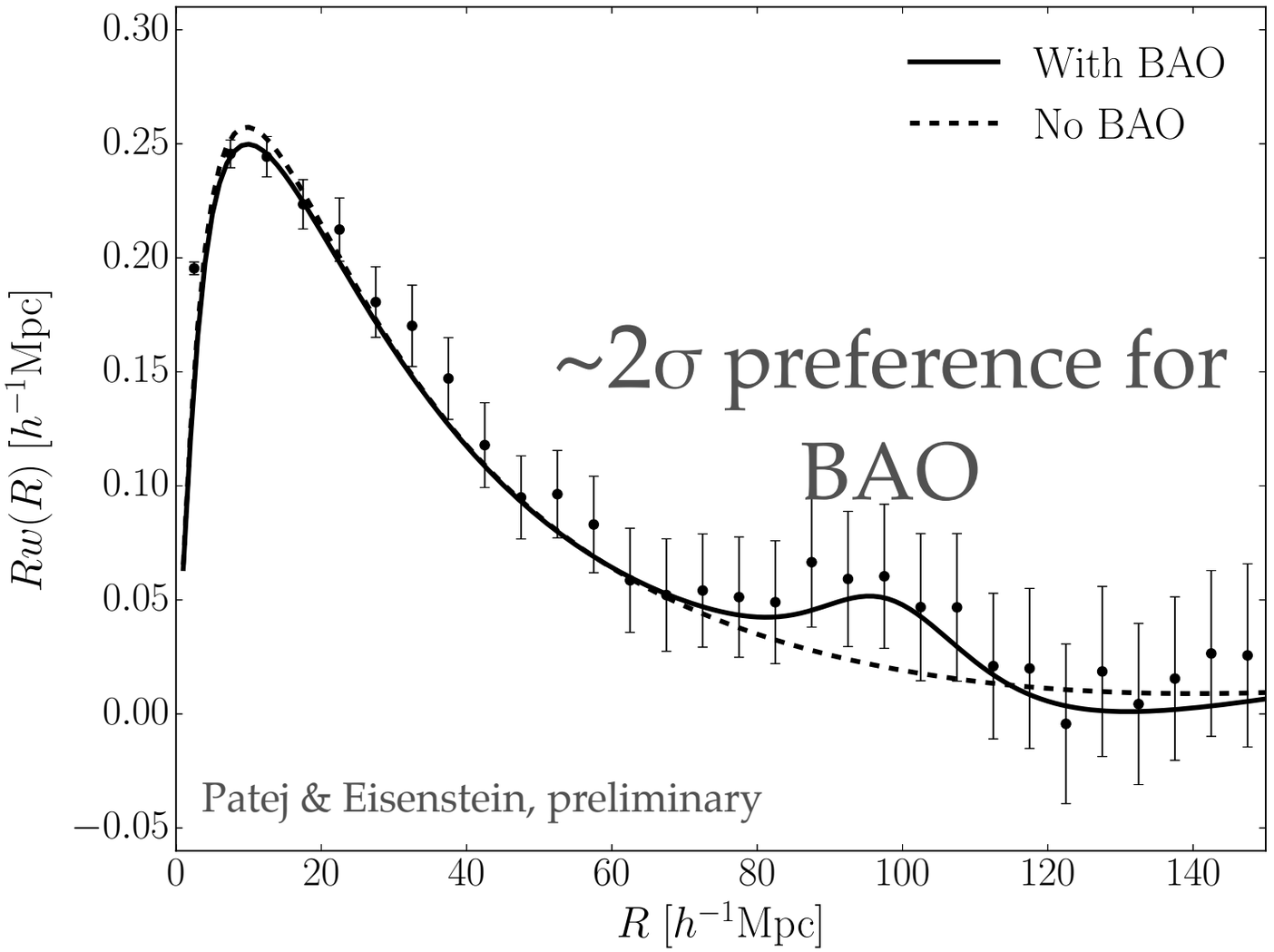


Above: Anderson, et al. (2012)

- BAO: relic peak in the clustering of galaxies
- Standard ruler in cosmology
- Limited by requirement of sufficiently dense spectroscopy

BAO in Sparse Samples

- While DESI will provide BAO measurements to z~1 and beyond, we may be able to get a head start with the imaging surveys...



Summary & Prospects

- Verified that massive red and blue galaxies trace the same large-scale structure at z~0.6 in BOSS/CMASS
- Prospects for measuring BAO using DESI & imaging surveys