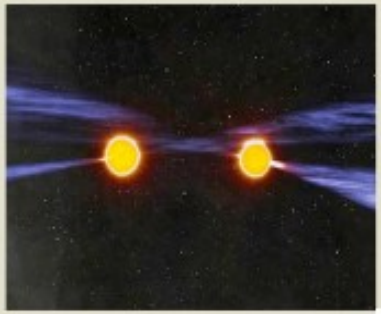
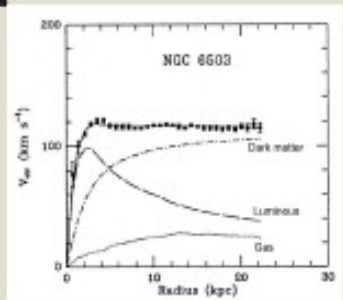
Constraining Dark Energy and General Relativity with Large Scale Structure Surveys

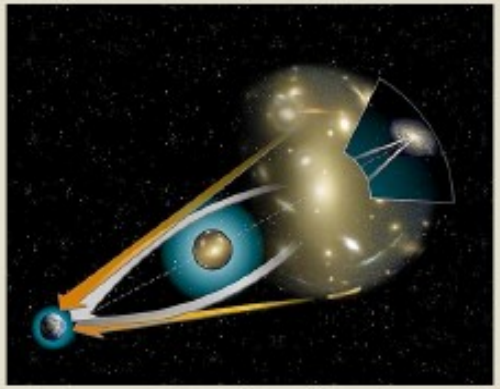
Rachel Bean

Constraints on gravity

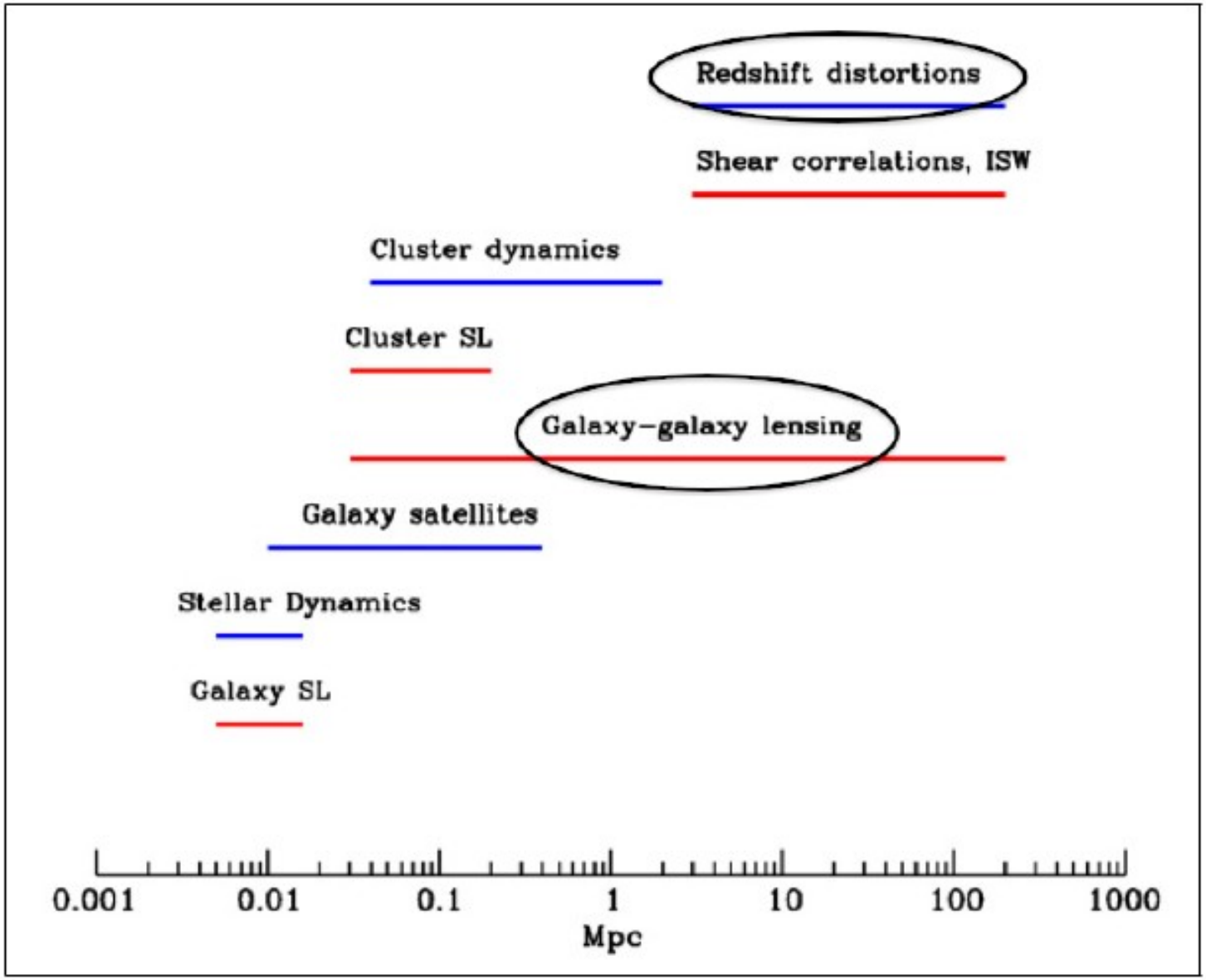


- Terrestrial and Solar System
  - Lab tests on mm scales
  - Lunar and planetary ranging
  - Binary pulsar timing
- Galactic
  - Galactic rotation curves and velocity dispersions
  - Satellite galaxy dynamics
- Intergalactic and Cluster
  - Galaxy lensing and peculiar motions
  - Cluster dynamical, X-ray & lensing mass estimates
- Cosmological
  - Late times: comparing lensing, peculiar velocity, galaxy position, ISW correlations
  - Early times: BBN, CMB peaks





Jain & Khoury (2010)



Testing GR with galaxy-galaxy lensing and redshift-space distortions

Reina Reyes, Rachel Mandelbaum

A model-independent, robust probe of gravity (Zhang et al. 2007):

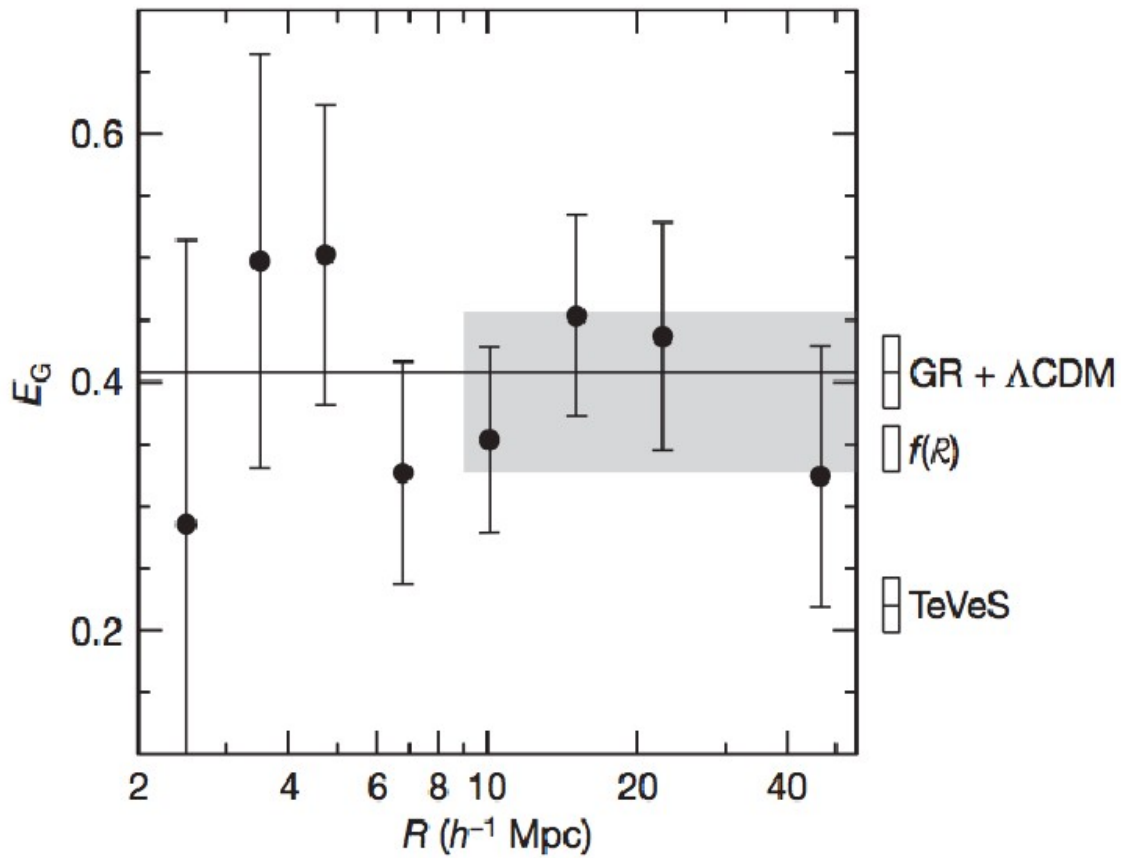
$$E_G \sim \frac{\text{(gravitational lensing)}}{\text{(structure growth)(galaxy clustering)}}$$

$$E_G = \frac{P_{\delta\nabla(\Psi+\Phi)}}{\beta P_{\delta\delta}}$$

$\longrightarrow$ sensitive to modified gravity (through both R and Q)

$$E_G \propto \frac{1}{b^{-1}} \frac{bA^2}{b^2 A^2}$$

$\longrightarrow$ insensitive to nuisance parameters, b and A



$\langle \mathbf{E_G} \rangle = \mathbf{0.392 \pm 0.065(16\%)}$ at $z = 0.32$ and $R = 10h^{-1}$–$50h^{-1}$Mpc

$\rightarrow$ TeVeS model is ruled out by $> 2.5\sigma$.

Screening mechanism

Bhuvnesh Jain, Scott Dodelson

Tests for environment dependent modifications to GR:
e.g. dwarf galaxies in voids obey different laws of gravity compared to dwarf galaxies that are screened by a large nearby HALO, (e.g. Milky way)

Designing Surveys for Tests of Gravity

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ABSTRACT

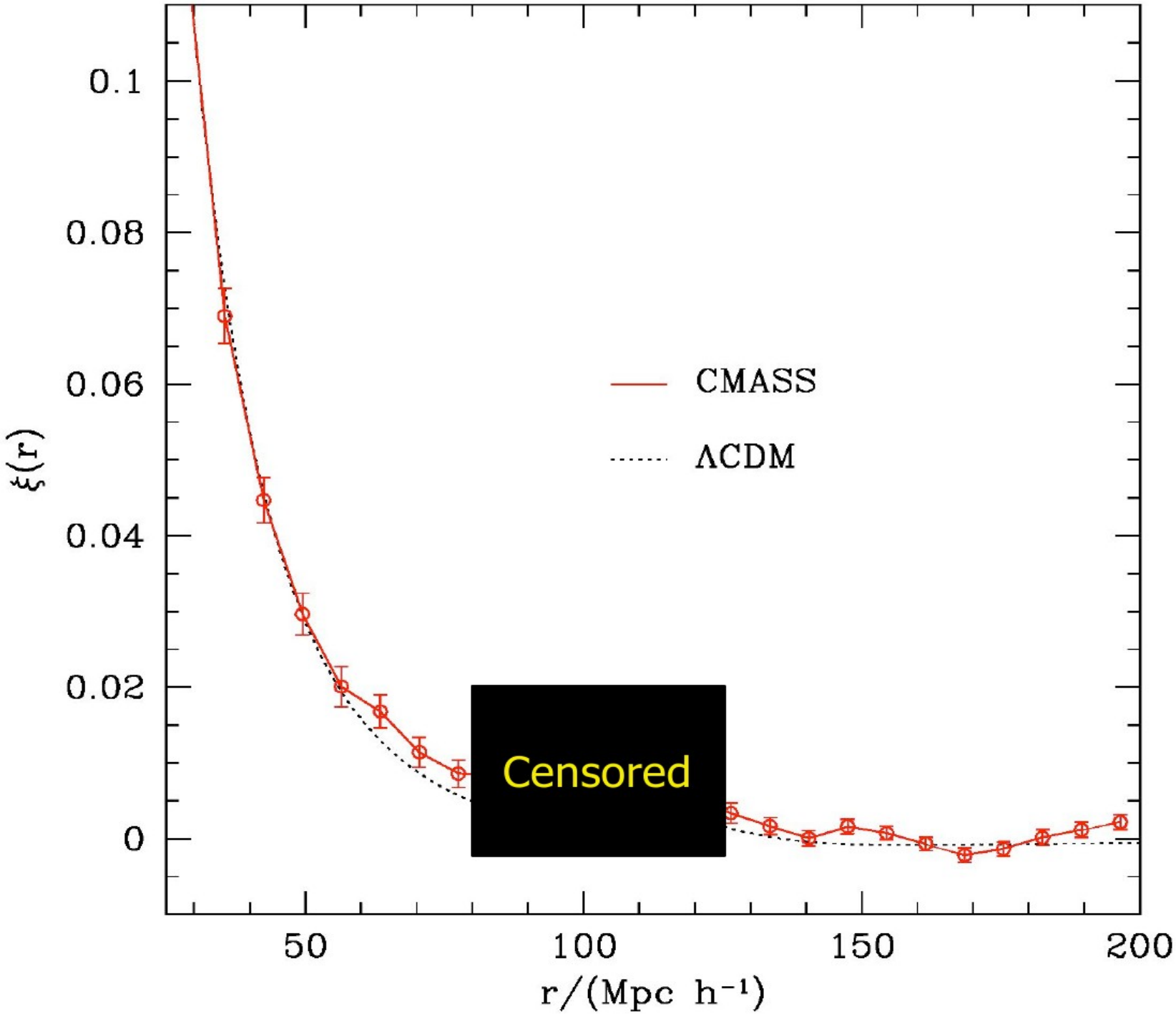
Modified gravity theories may provide an alternative to dark energy to explain cosmic acceleration. We argue that the observational program developed to test dark energy needs to be augmented to capture new tests of gravity on astrophysical scales. Several distinct signatures of gravity theories exist outside the "linear" regime, especially owing to the screening mechanism that operates inside halos like the Milky Way to ensure that gravity tests in the solar system are satisfied. This opens up several decades in length scale and classes of galaxies at low-redshift that can be exploited by surveys. While

Update on the BOSS/SDSS survey

- >10^6 galaxy spectra LRGs
- 150000 Quasars
- Survey is running for ~1 year

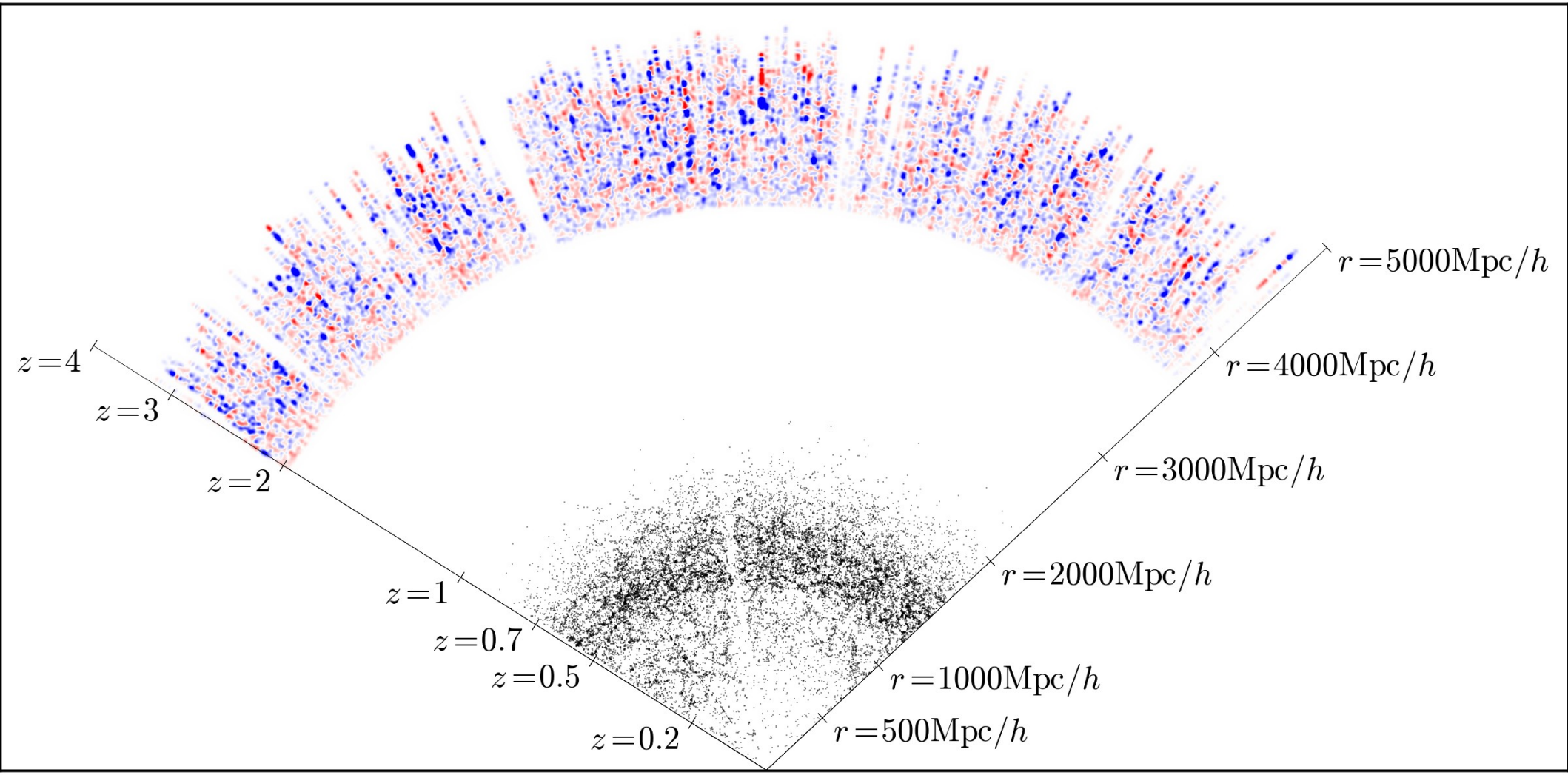
→ Everybody is waiting to see the BAO bump...

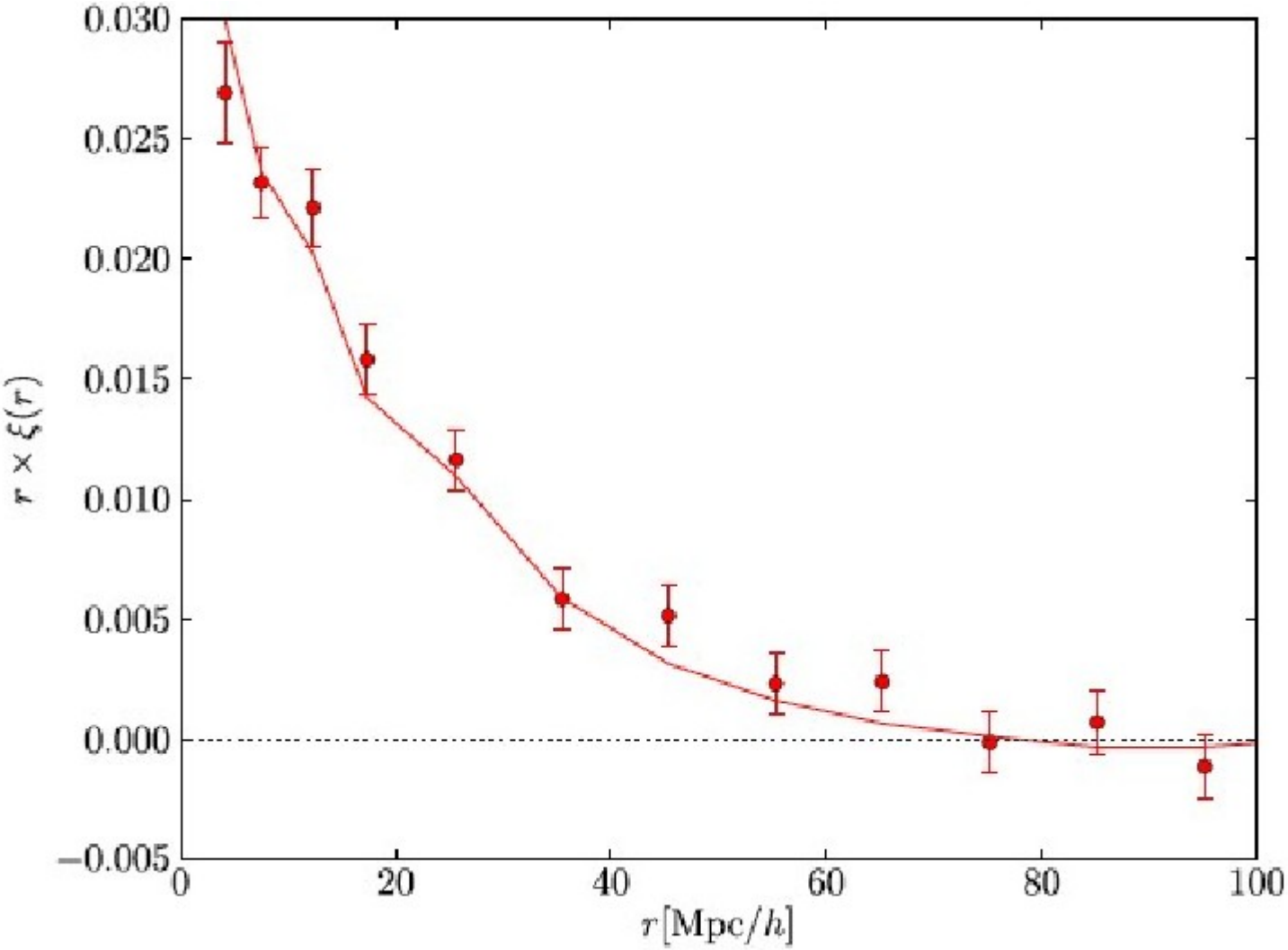
Jeremy Tinker, David Weinberg


0.1
0.08
0.06
0.04
0.02
0
ξ(r)
CMASS
ΛCDM
Censored
50
100
150
200
r/(Mpc h⁻¹)

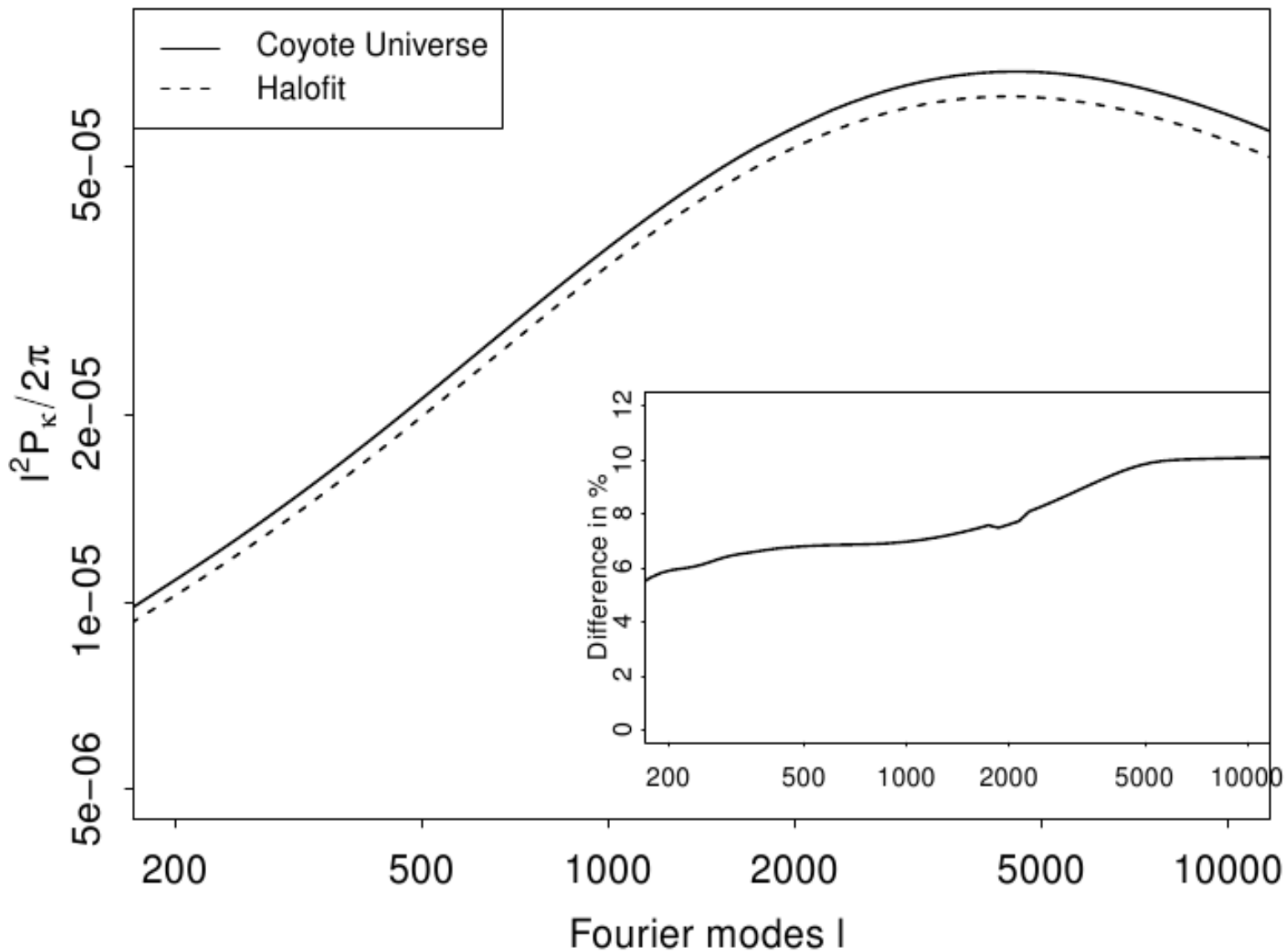
The Lyman-alpha forest in 3-d: First year BOSS results

Anze Slosar, Andreu Font-Ribera, et al., in prep.




0.030
0.025
0.020
0.015
0.010
0.005
0.000
−0.005
0
20
40
60
80
100
$r \times \xi(r)$
$r\,[\mathrm{Mpc}/h]$

Accurate theoretical predictions for non-linear structure growth



Combining all LSS probes – cross correlations

Data vector:

$$\begin{pmatrix} E^{\gamma} \\ E^{\gamma g} \\ E^{g} \end{pmatrix}$$

Covariance:

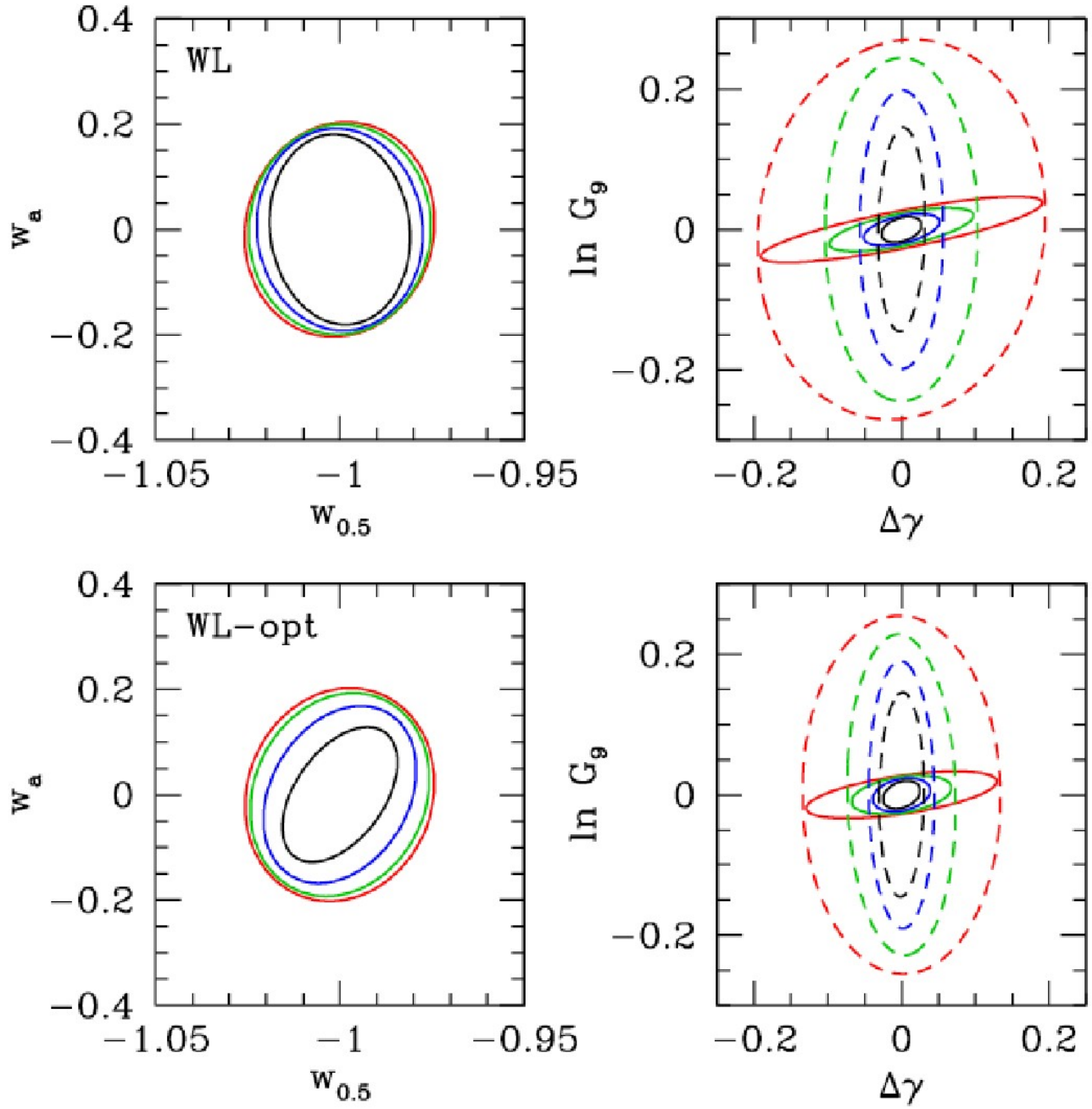
$$\mathbf{C} = \left(\begin{array}{c|c|c} \mathrm{Cov}(E^{\gamma}E^{\gamma}) & \mathrm{Cov}(E^{\gamma}E^{\gamma g}) & \mathrm{Cov}(E^{\gamma}E^{g}) \\ \hline \mathrm{Cov}(E^{\gamma g}E^{\gamma}) & \mathrm{Cov}(E^{\gamma g}E^{\gamma g}) & \mathrm{Cov}(E^{\gamma g}E^{g}) \\ \hline \mathrm{Cov}(E^{g}E^{\gamma}) & \mathrm{Cov}(E^{g}E^{\gamma g}) & \mathrm{Cov}(E^{g}E^{g}) \end{array}\right)$$

Include Magnification → see Eric Huff's talk

Outlook to the far future (stage 4 missions)

LSST, Euclid, WFIRST

David Weinberg, Michael Mortonson



Left: Errors on w(z=0.5) and w_a for fiducial SN and BAO and fiducial WL errors scaled by ×4, ×2, ×1, /2.

Right: Errors on G_9 and $\Delta\gamma$. Solid contours assume w_0-w_a model, dashed contours a general w(a) model.

Summary

1) General concepts to constrain DE and GR

2) Results from recent/ongoing surveys (SDSS/BOSS)

3) Outlook to near future surveys (DES, HSC, HALO)

4) Discussion of systematic error sources

5) Accuracy of theoretical assumptions: e.g., numerical simulations, HOD-modeling, mass definitions

6) Outlook to stage 4 surveys (LSST, Euclid, WFIRST)

7) Lots of small group discussion on specific projects