Constraining Cosmic Acceleration from Structure Observables

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Outline

- Angular Correlation Function
- Galaxy Clusters
- Cosmic Voids

3D Correlation Function

- Matter density contrast and galaxy number density contrast

$$\delta(\mathbf{x}) = \frac{\delta\rho(\mathbf{x})}{\bar{\rho}_m}\,, \quad \delta_g(\mathbf{x}) = \frac{\delta n_g(\mathbf{x})}{\bar{n}_g}$$

- Connected by galaxy bias $\delta_g = b\,\delta$.
- Matter two-point correlation function $\xi(r)$:

$$\xi(r) \equiv \langle \delta(\mathbf{x})\delta(\mathbf{x}+\mathbf{r})\rangle\,,$$

- $dP(r)$: probability of finding a pair of galaxies separated by r:

$$dP(r) = [1+\xi(r)]dP^{\mathrm{Poisson}}$$

- $\xi(r)$: excess probabiltity (relative to random).

3D Correlation Function

- Probability normalization requires integral constraint:

$$1 = \int dP(r) = \int [1 + \xi(r)] \frac{dV}{V} \rightarrow \int dr\, r^2 \xi(r) = 0$$

- $r \rightarrow 0$: $\xi(r) > 0$, decreasing with r (clustering correlation),
- Intermediate r: $\rightarrow \xi(r) < 0$ (integral constraint)
- $r \rightarrow \infty$: $\xi(r) \rightarrow 0$ (no causal connection).
- BAO feature at scale r_s of the sound horizon at decoupling.

$$\xi(r) \;=\; \int \frac{d^3\mathbf{k}}{(2\pi)^3}\, P(k) e^{i\mathbf{k}\cdot\mathbf{r}}$$

2D Correlation Function

- 3D position vector: $\mathbf{x} = \chi(z)\hat{\mathbf{n}} = (z, \hat{\mathbf{n}})$.
- Easy to measure angles $\hat{\mathbf{n}}$
- Hard to measure radial distances $\chi(z)$ (i.e. redshifts).
- Project 3D density on the line-of-sight within redshift bin i : $z_i < z < z_{i+1}$.

$$
\begin{aligned}
\sigma_i(\hat{\mathbf{n}}) &= \int_{z_i}^{z_{i+1}} dz\, b(z)D(z)n(z)\delta(\mathbf{x}) \\
&= \int_0^{\infty} dz\ f_i(z)\delta(\mathbf{x})
\end{aligned}
$$

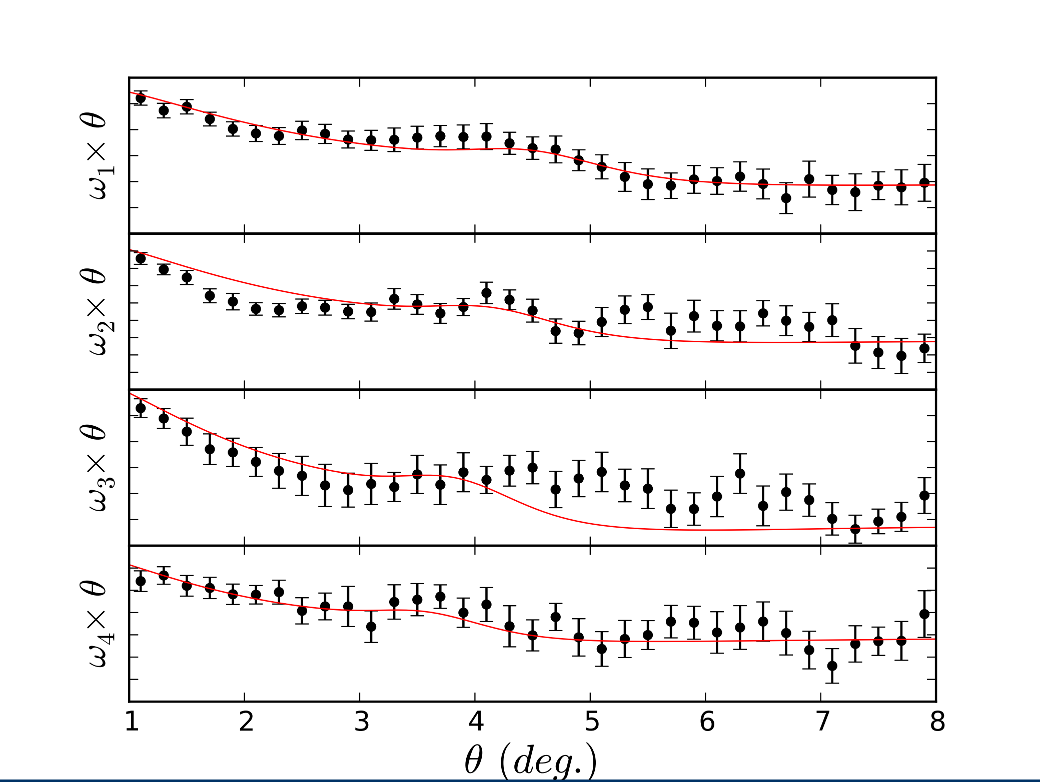
2D Correlation Function

- 2-point Angular Correlation Function (ACF) $\omega_i(\theta)$ for galaxies at redshift bin i:

$$
\begin{aligned}
\omega_i(\theta) &= \langle \sigma_i(\hat{\mathbf{n}}_1)\sigma_i(\hat{\mathbf{n}}_2)\rangle \\
&= \int_0^\infty dz_1\ f_i(z_1) \int_0^\infty dz_2\ f_i(z_2)\xi(r, z_1, z_2)
\end{aligned}
$$

- In practice, additional issues:
  - Photo-zs, $P(z^{\rm phot}|z)$.
  - Redshift Distortions, $P(k) \rightarrow P(k,\mu) = (1+\beta\mu^2)^2 P(k)$
  - Non-linearities, $P(k) \rightarrow P_{\rm NL}(k)$
  - Bias scale dependency, $b(z) \rightarrow b(k,z)$
  - Systematic effects, $\delta_{\rm obs} = \delta + \epsilon\delta_{\rm sys}$
  - Integral constraint for small areas.
  - etc..

Correlation Constrains: DR8



Simoni et al. 2013

- $\omega(\theta)$+photo-z+distortions.
- 600,000 LG's from the CMASS sample of BOSS-DR8
- Area: $\sim$14,000 deg^2
- $0.45 < z^{\rm phot} < 0.65$, 4 bins
- BAO peak position: comoving sound horizon $\theta_s = r_s/D_A(z) \approx 3 - 4$ deg.
- $\Omega_m = 0.28$,
- $f_b = \Omega_b/\Omega_m = 0.21$

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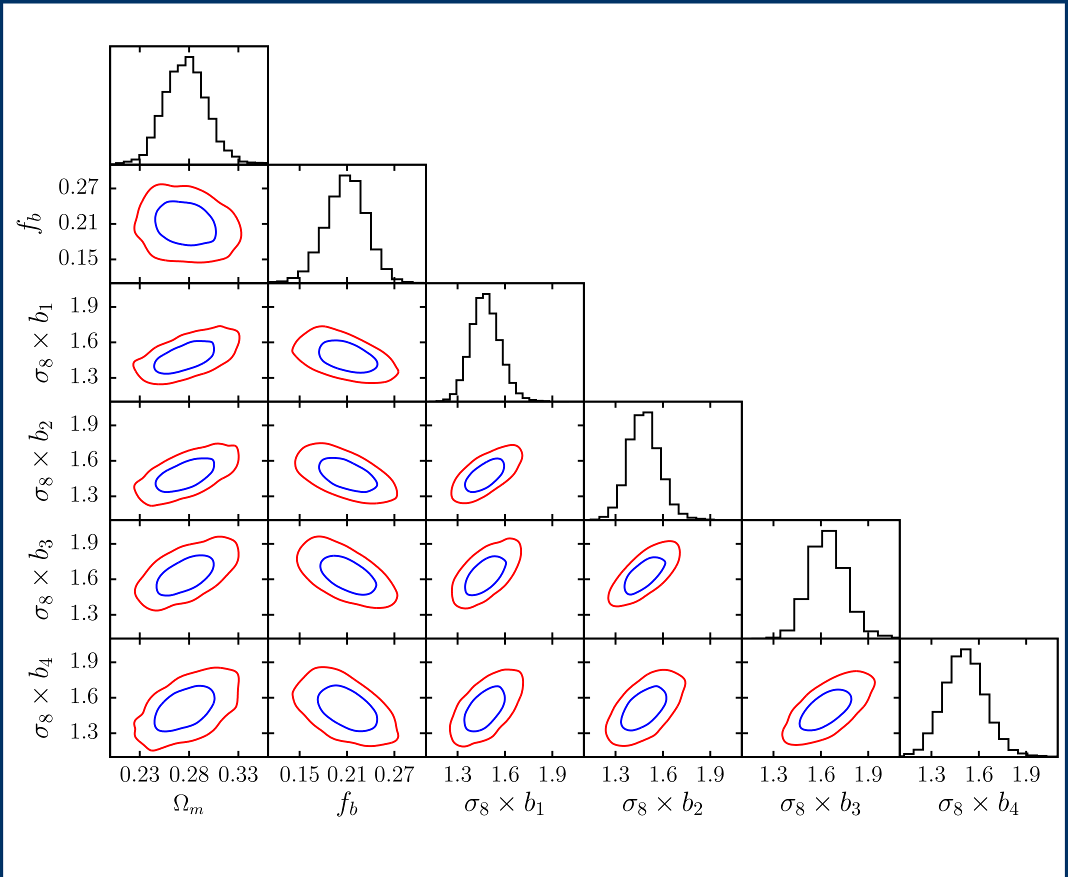

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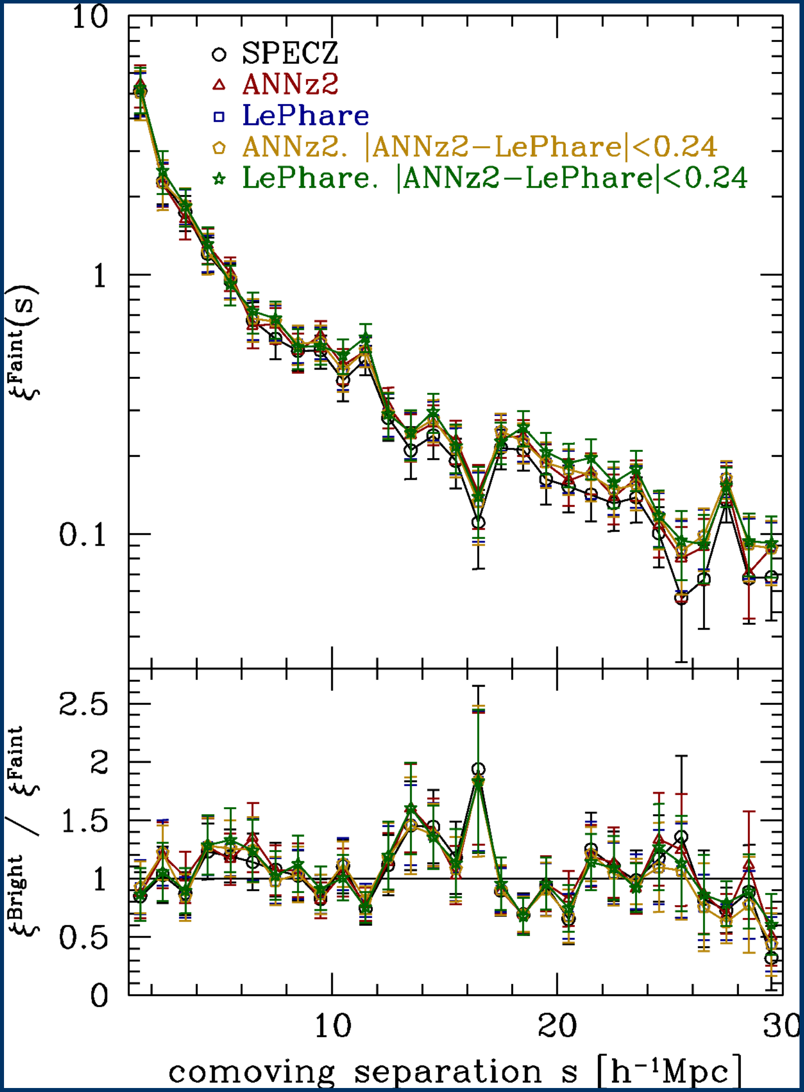
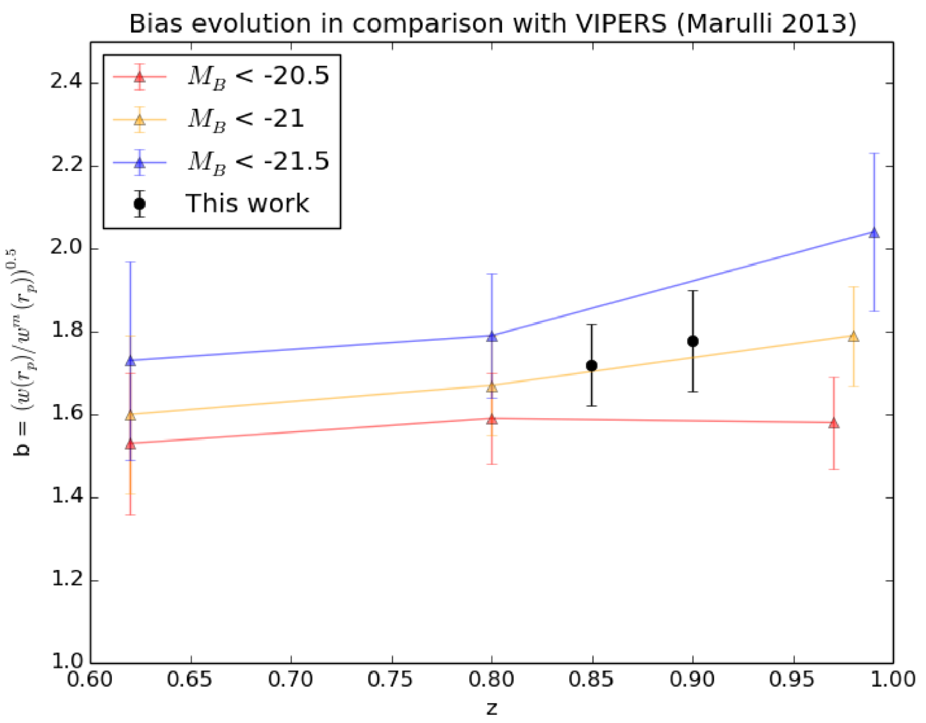
Correlation Constraints: eBOSS/DES



Jouvel et al. in prep.

- $\xi(s)$: Power law + IC.
- Project $w(r_p) = \int d\pi \xi(\pi, r_p)$
- ELG's from eBOSS/DES
- Spectroscopy and Photometry
- Bright and Faint samples
- Area: $\sim$ 10 deg^2
- $0.6 < z, z^{\rm phot} < 1.2$,
- $b_g = \sqrt{w/w_m} \sim 1.5 - 2.0$,

Correlation Constraints: eBOSS/DES



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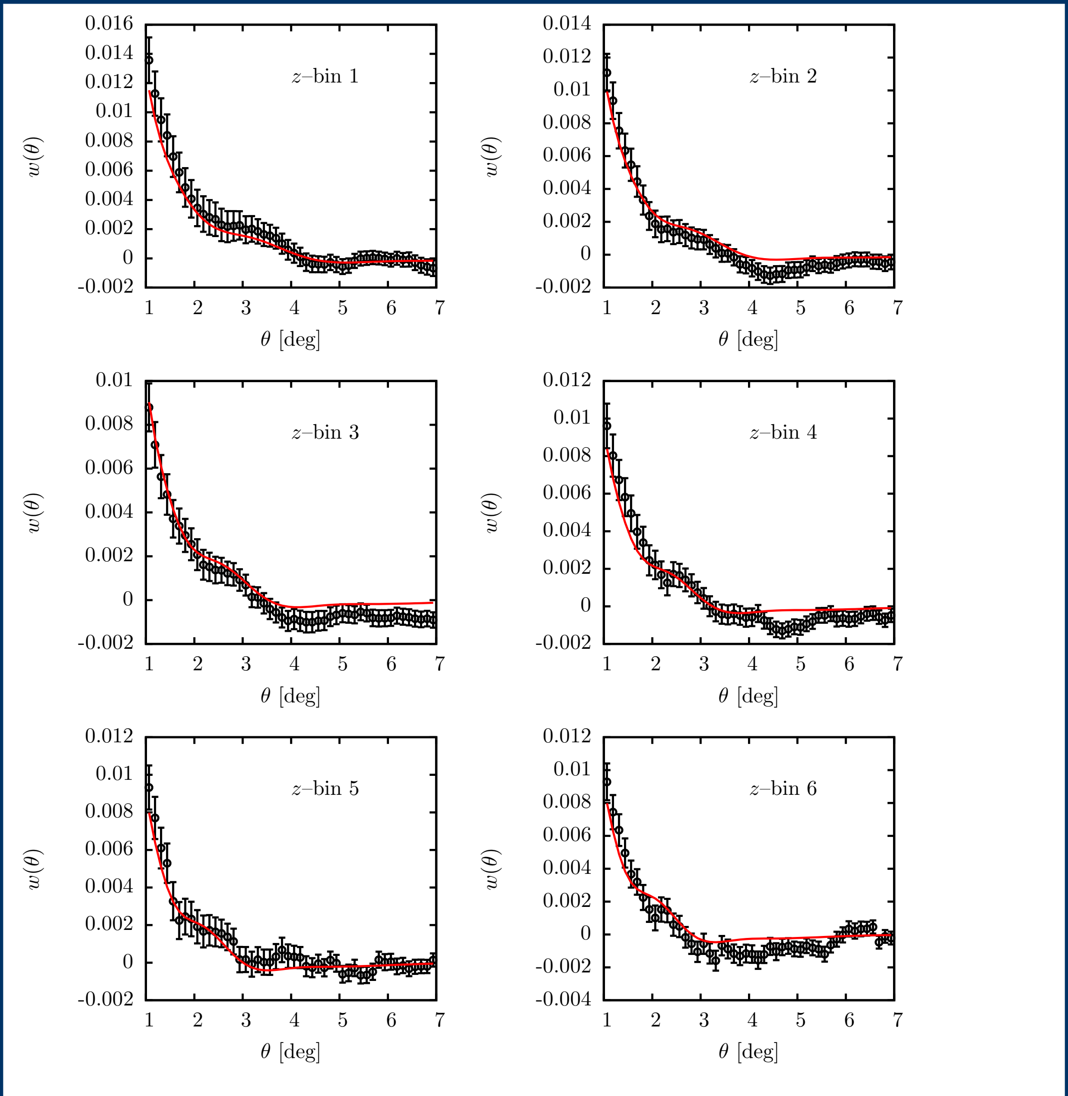
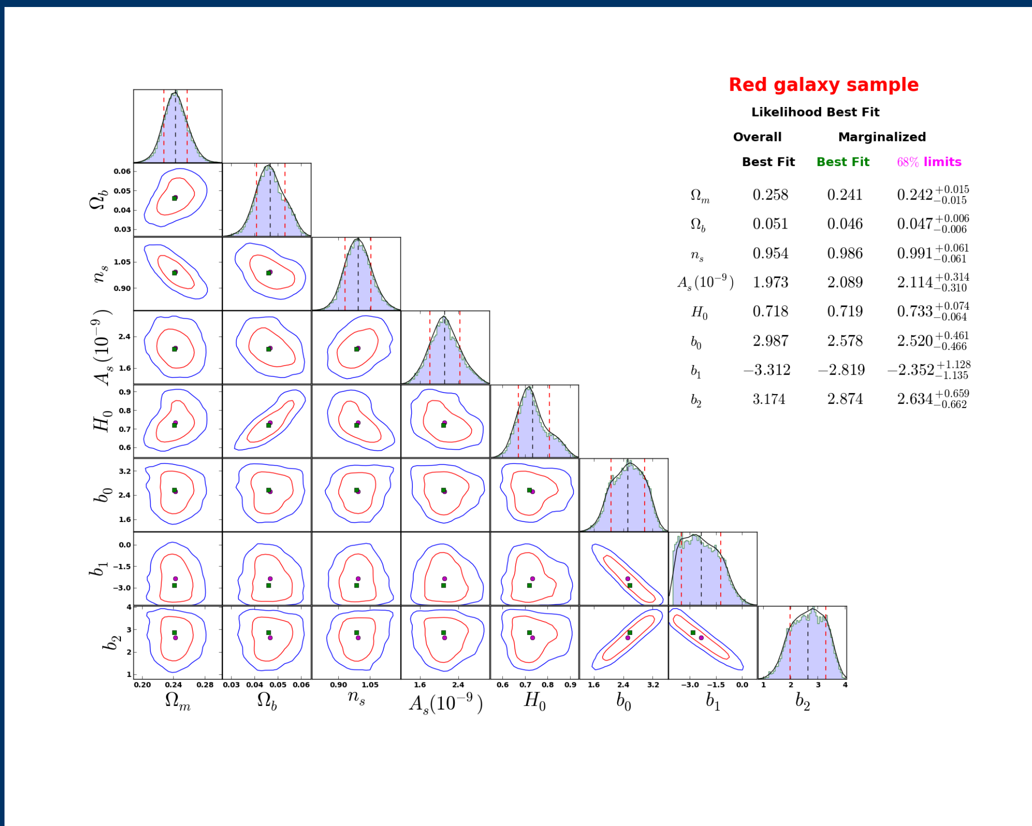
Correlation Constraints: DES sims.



Sobreira, Camacho et al. 2014

- $\omega(\theta)$+photo-z+distortions.
- 10,000,000 Red galaxies from a DES Simulated Catalog.
- Area: $\sim$ 5,000 deg^2
- $0.6 < z^{\rm phot} < 1.2$, 6 bins
- BAO peak position: comoving sound horizon $\theta_s = r_s/D_A(z) \approx 2-3$ deg.
- Peak changes with z. Photo-z bin: Smoothing.
- Lines: theory prediction.

Correlation Constraints: DES sims.



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Systematics

- Linear model for systematics:

$$\sigma^{\rm o}(\hat{\mathbf{n}}) = \sigma^{\rm t}(\hat{\mathbf{n}}) + \epsilon\sigma^{\rm s}(\hat{\mathbf{n}})$$

- Define cross-correlation $w^{ab} = \left\langle \sigma^a\sigma^b \right\rangle$, where $a, b = {\rm o}, {\rm t}, {\rm s}$. Then

$$w^{\rm oo} = \langle \sigma^{\rm o}\sigma^{\rm o} \rangle = \left\langle \sigma^{\rm t}\sigma^{\rm t} \right\rangle + 2\epsilon \left\langle \sigma^{\rm t}\sigma^{\rm s} \right\rangle + \epsilon^2 \left\langle \sigma^{\rm s}\sigma^{\rm s} \right\rangle$$

- If systematics and true overdensities uncorrelated, $\left\langle \sigma^{\rm t}\sigma^{\rm s} \right\rangle = 0$,

$$w^{\rm oo} = w^{\rm tt} + \epsilon^2 w^{\rm ss}$$

- Coefficient ϵ can be found considering $w^{\rm os}$:

$$w^{\rm os} = \langle \sigma^{\rm o}\sigma^{\rm s} \rangle = \underbrace{\left\langle \sigma^{\rm t}\sigma^{\rm s} \right\rangle}_{0} + \epsilon \left\langle \sigma^{\rm s}\sigma^{\rm s} \right\rangle \quad \rightarrow \quad \epsilon = \frac{w^{\rm os}}{w^{\rm ss}}$$

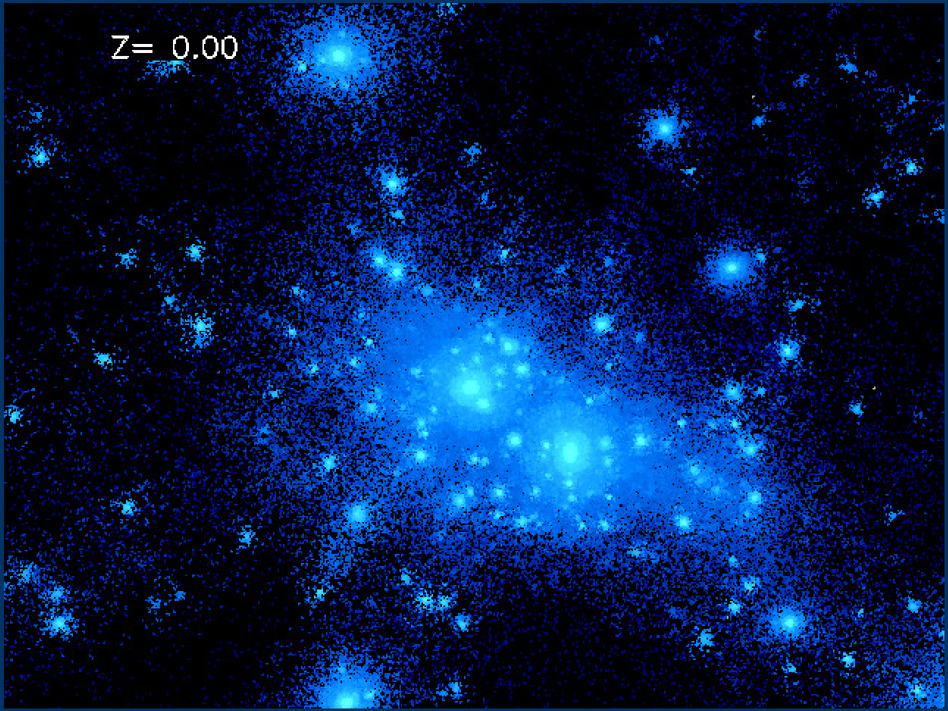
- Finally $w^{\rm tt} = w^{\rm oo} - (w^{\rm os})^2 / w^{\rm ss}$

DES: Ongoing

- Improving analysis for ACF with simulations (more realistic photo-zs, systematics, etc).
- ACF on small scales on Science Verification data. Results coming up soon...
- ACF on large scales in Y1 data starting now.
- Covariance between multiple structure observables (e.g., ACF, lensing, clusters), to avoid double counting the information Fabien Lacasa.

Real Clusters and Simulated Halos

Abell-1689



Andrey Kravtsov

- How to connect theory and observations?

Cluster Abundance Prediction

- Abundance described by mass function:

$$\frac{dn(M,z)}{d\ln M} = f(\sigma)\frac{\bar{\rho}_{\rm m}}{M}\frac{d\ln\sigma^{-1}}{d\ln M}\,, \qquad f(\sigma) \propto \exp\left(-1/\sigma^2\right)$$

where

$$\sigma^2(R) = \int \frac{d^3k}{(2\pi)^3}|\tilde{W}(kR)|^2 P_m^L(k,z)\,, \qquad R = (3M/4\pi\bar{\rho}_{\rm m})^{1/3}$$

- Exponential sensitivity to cosmology via $P_m^L(k,z)$, as long as precise measurements of M and z.

Cluster Counts: Perfect Case

- Number density in mass bin α:

$$\bar{n}_\alpha(z) = \int_{M_\alpha}^{M_{\alpha+1}} d\ln M \frac{dn(M,z)}{d\ln M} \, ,$$

- Number counts in redshift bin i:

$$\bar{N}_{\alpha i} = \int_{z_i}^{z_{i+1}} \underbrace{dz \frac{D^2(z)}{H(z)}}_{dV\text{: volume}} \bar{n}_\alpha(z) \, ,$$

where comoving distance:

$$D(z) = \int_0^z \frac{dz}{H(z)}$$

Real Case

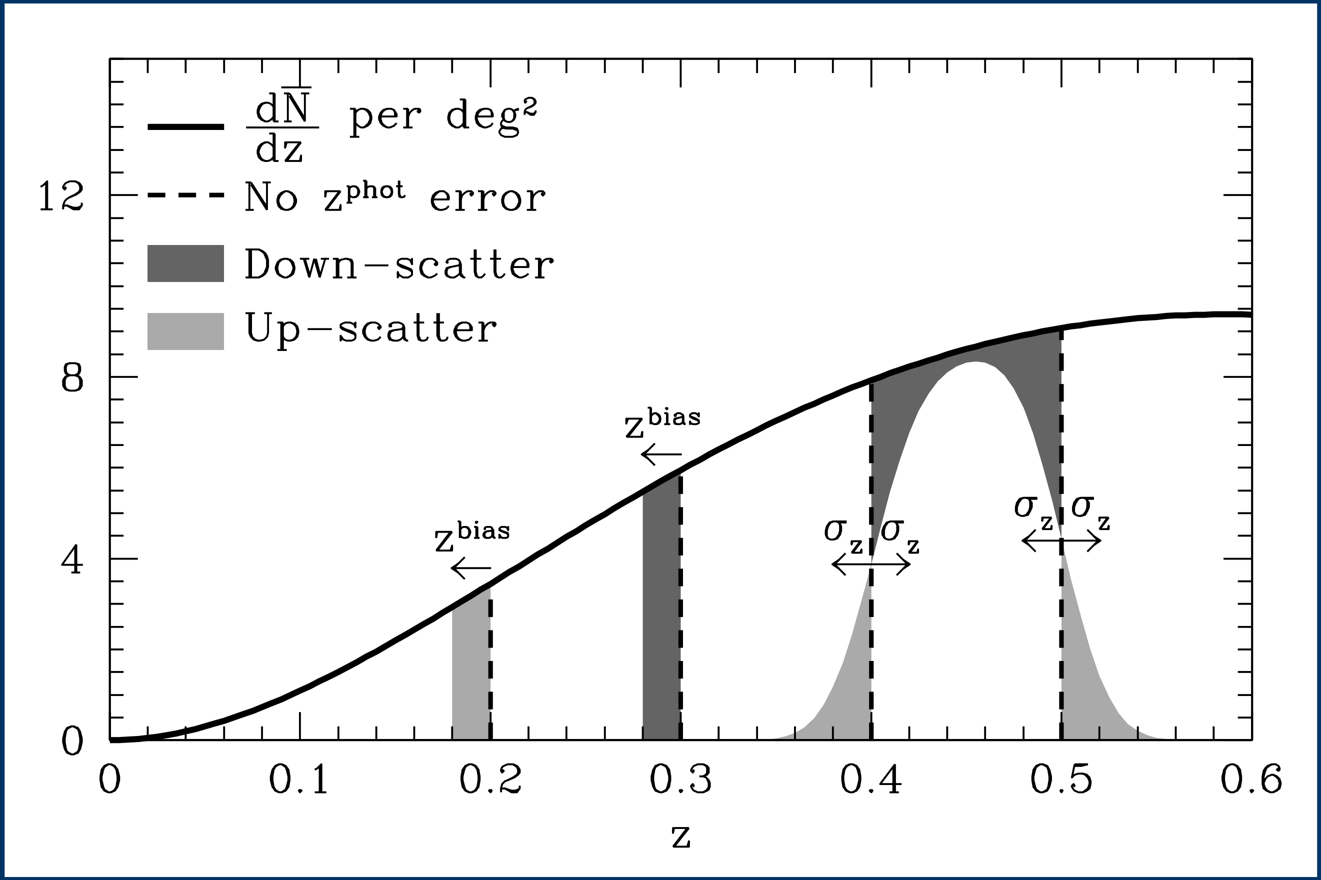
- In reality, must account for real-life issues:
- Mass-observable relation mean and scatter, redshift evolution, photo-z errors, completeness, purity, etc.

$$
\begin{aligned}
\bar{N}_{\alpha i} &= \int_{z_i^{\rm phot}}^{z_{i+1}^{\rm phot}} dz^{\rm phot} \int dz \frac{D^2(z)}{H(z)} P(z^{\rm phot}|z) \\
&\times \int_{M_\alpha^{\rm obs}}^{M_{\alpha+1}^{\rm obs}} d\ln M^{\rm obs} \int d\ln M \, P(M^{\rm obs}|M) \\
&\times \frac{dn(M,z)}{d\ln M} \times \frac{c(M,z)}{p(M_{\rm obs}, z^{\rm phot})}
\end{aligned}
$$

Cluster Photo-zs

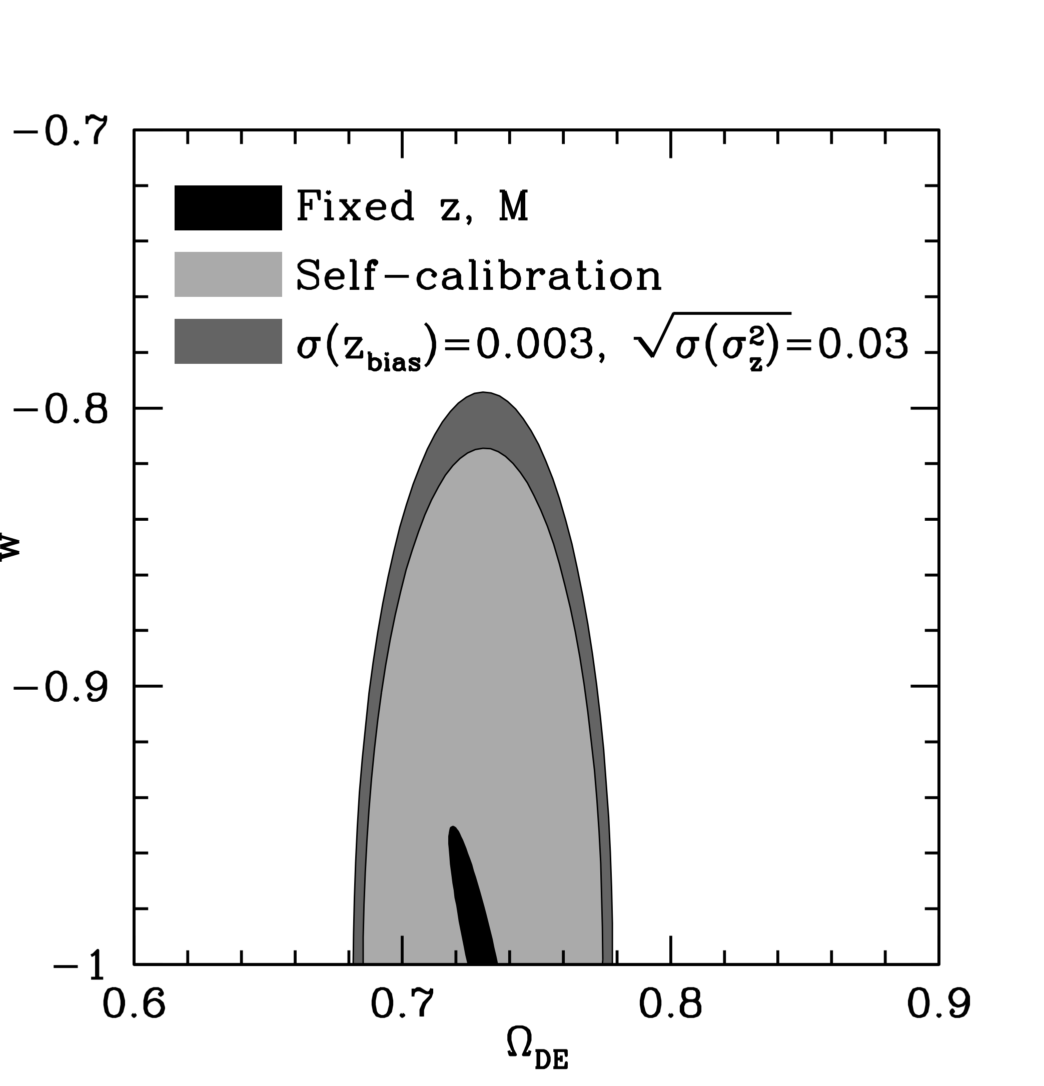
- z^{bias}: systematic shifts in dN/dz.

  σ_z: random scatter in different bins. Compensating effects.



Lima and Hu 2007

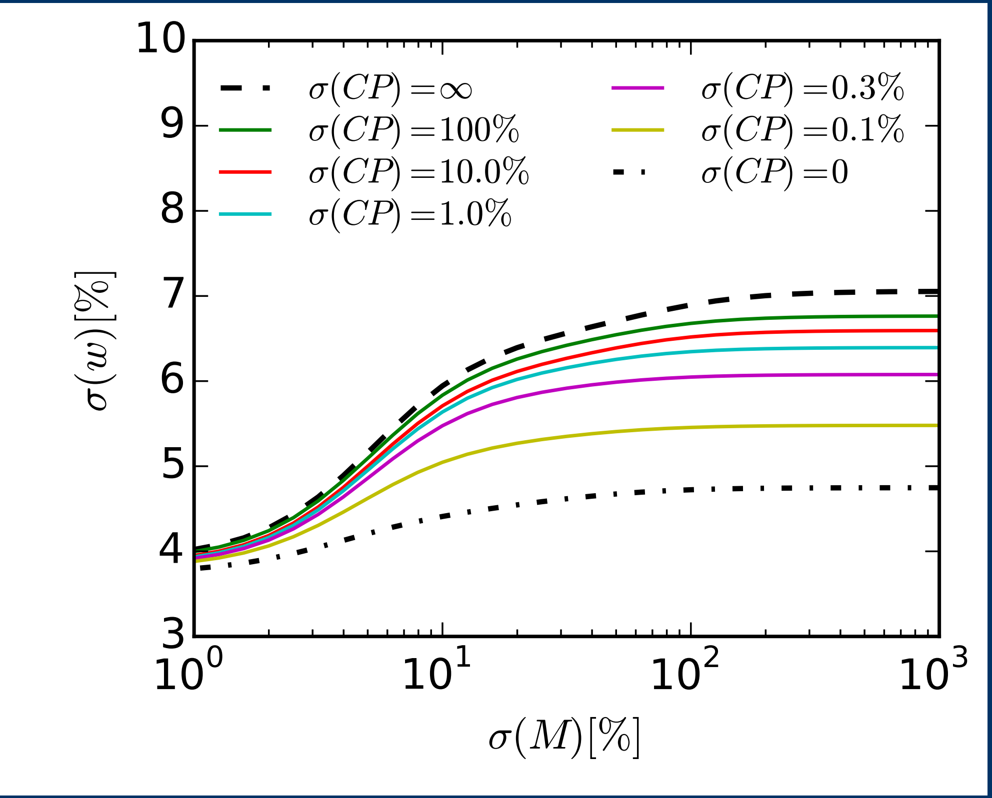
Mass-observable and Photo-zs



Lima and Hu 2007

- Fisher matrix constraints on Dark Energy: $\Omega_{\rm DE}$ e w.
- High precision with perfect M and z.
- No precision calibrating M with abundance only.
- Precision restored with self-calibration (abundance + clustering).
- Uncertainty on photo-z errors for 10% degradation in w.

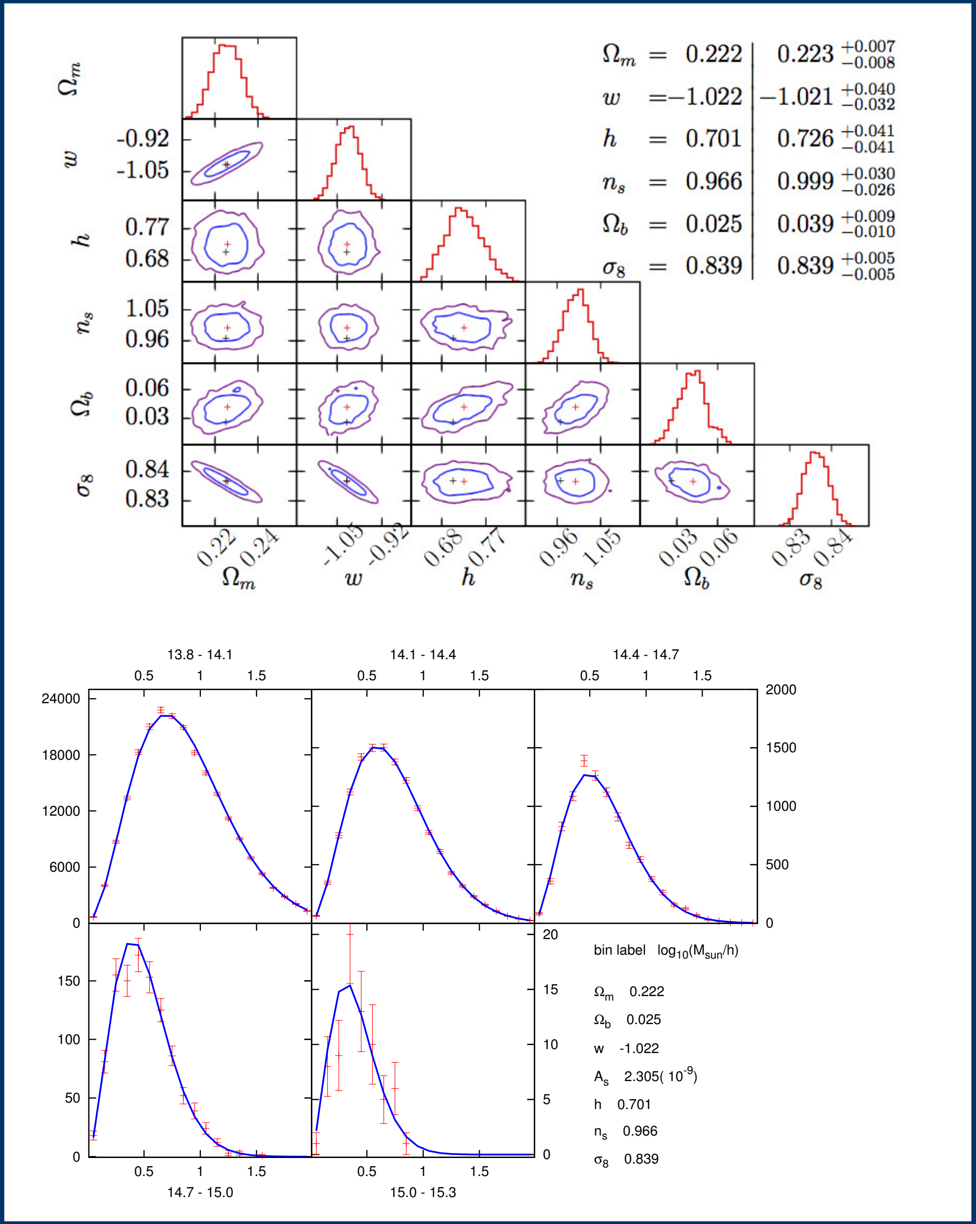
Completeness and Purity



Aguena and Lima, in prep.

- Fisher matrix constraints on Dark Energy: $\Omega_{\rm DE}$ e w.
- A fixed functional form for c and p with a few paramters can be reasonably well self-calibrated along with the cosmology.
- However real case likely worse at low masses, as more parameters for cluster selection become necessary.
- See Michel Aguena's poster for details.

DES Simulations



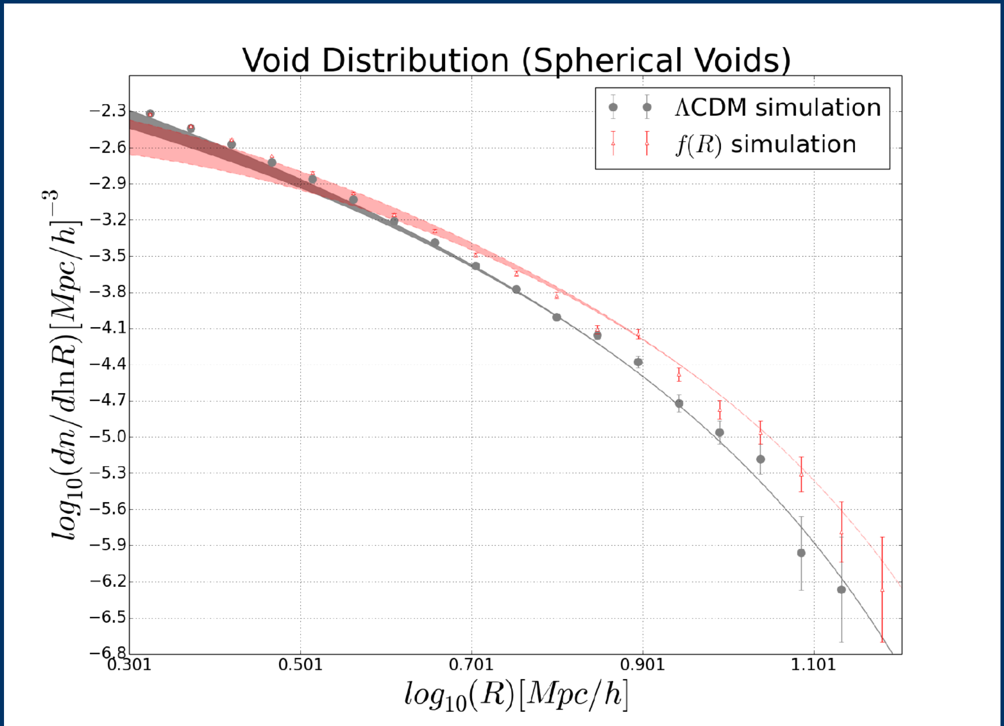
- BCC halos.
- MCMC analysis consistent with Fisher prediction and BCC cosmology.
- Currently testing for BCC clusters.

Aguena and Lima, in prep.

Ongoing

- Cluster Finders (RedMaPPer, WAZP, C4, VT, etc.) being tested on simulated and DES Science Verification data.
- Characterization of Selection Function (Completeness and Purity) based on simulations and agreement with detections in other wavelengths (SZ, X-ray).
- Characterization of mass-observable relation through simulations and multiple observables (richness, lensing, X-ray, SZ).
- All the way to cosmology.
- Check out poster from Michel Aguena and talk to him about some of these issues.

Cosmic Voids



Voivodic, Lima, Mota, in prep.

- Spherical expansion model for void growth and abundance.
- Potential for discriminating dark energy from modified gravity.
- Next: Profiles for voids.
- Viable modified gravity $\rightarrow$ screening mechanisms (chameleon, Vainshtein, etc.). MG effects minimized for halos and maximized for voids.