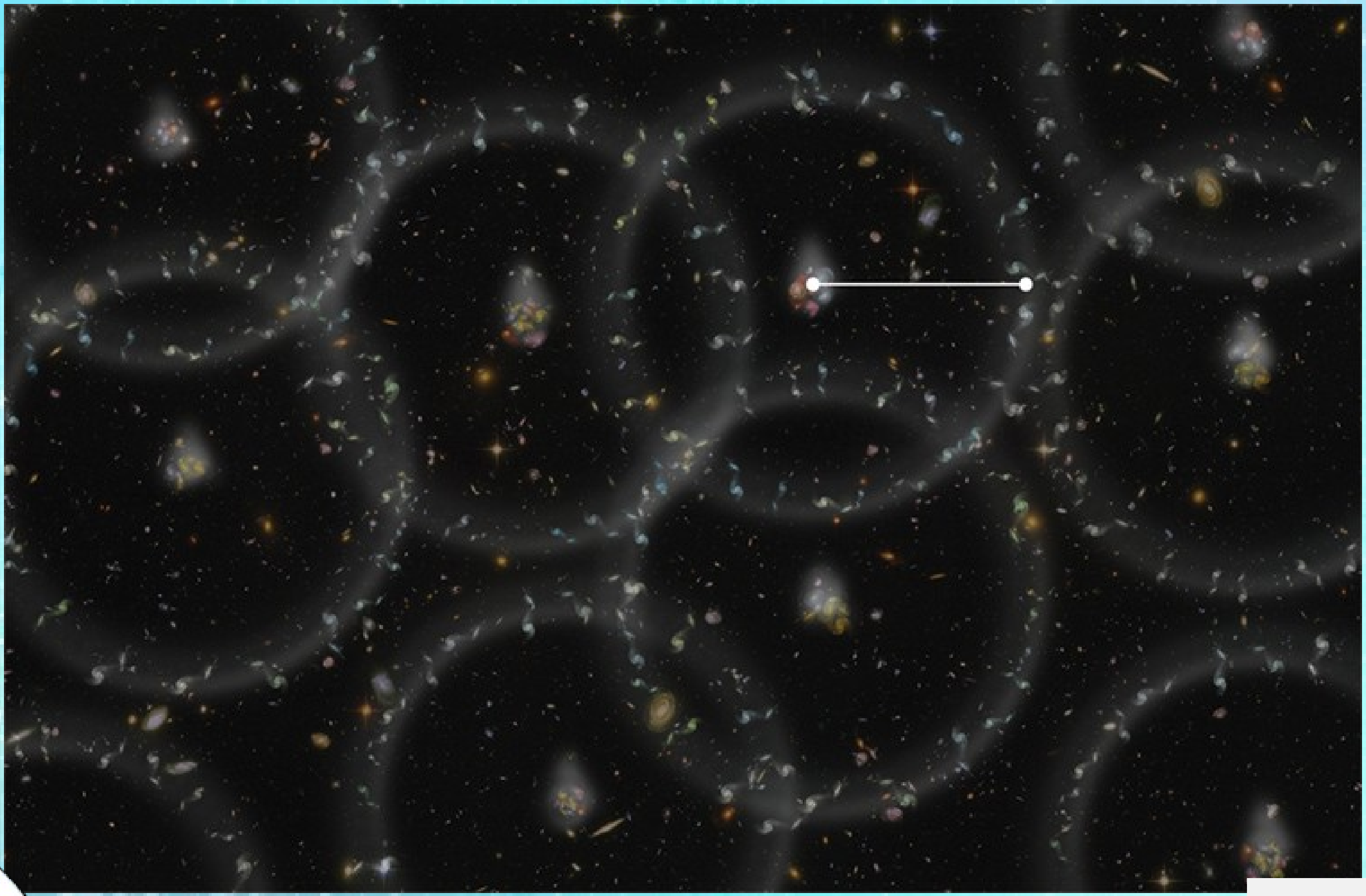
Extracting Cosmology constraints from LSS of BOSS galaxy sample.



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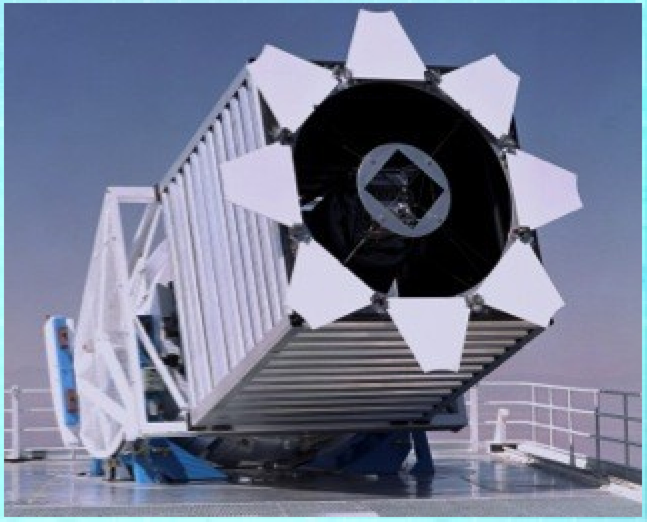
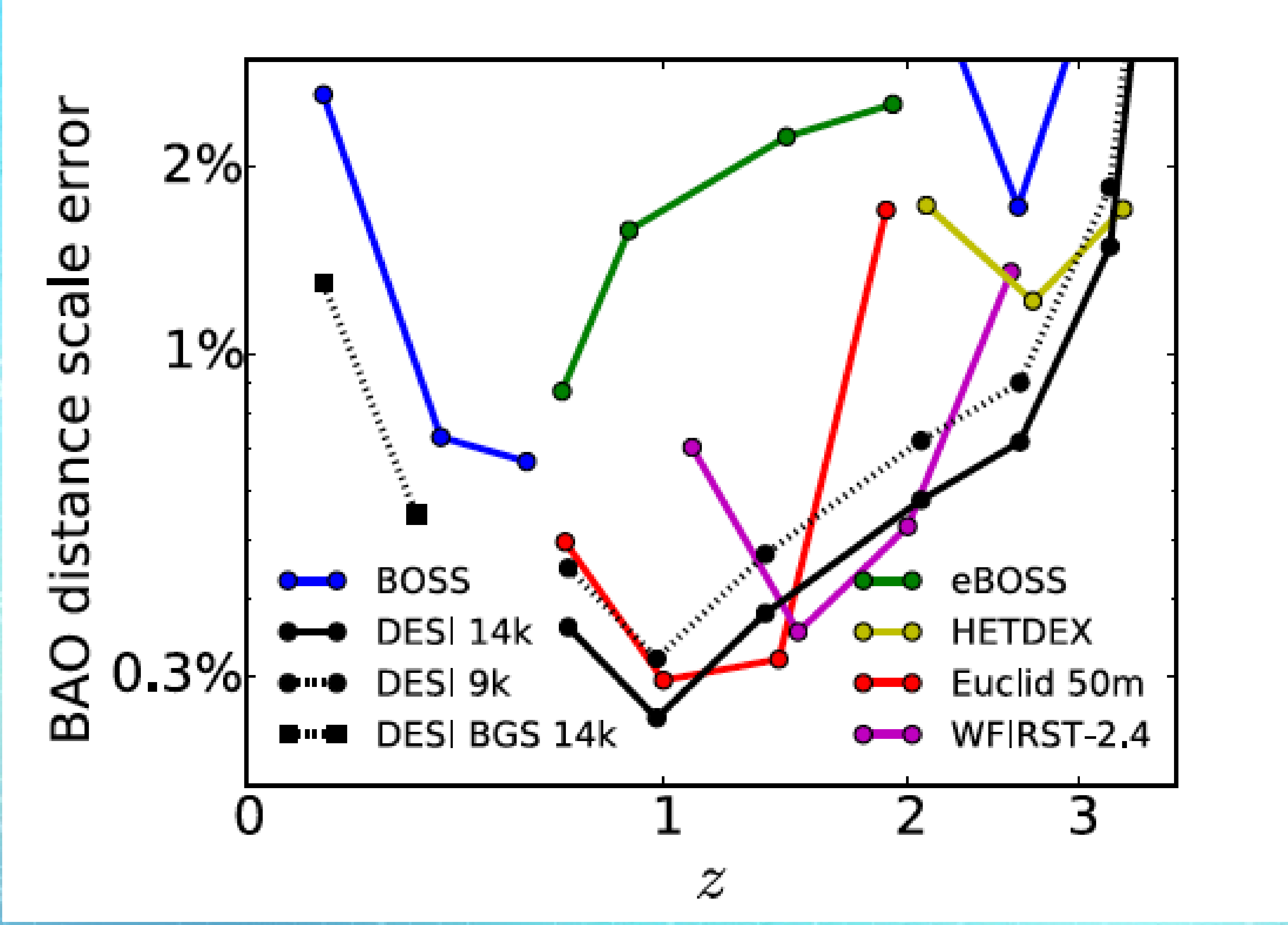
SDSS-III/BOSS

(Sloan Digital Sky Survey-III / Baryon Oscillation Sky Survey)

- Dark time observations from Fall 2009-Spring 2014
- Final data release (DR12) in Dec. 2014
- 1,000-fiber spectrograph, resolution R~2000
- Wavelength: 360-1000 nm
- 10,200 square degrees (~quarter of sky)
- ***Redshifts of 1.35 million luminous galaxies to z = 0.7***
- Lyman-α forest spectra of 230,000 quasars (160,000 redshifts > 2.15)
- ***Largest spectroscopic galaxy data base.***



Sub-percentage distance measurements



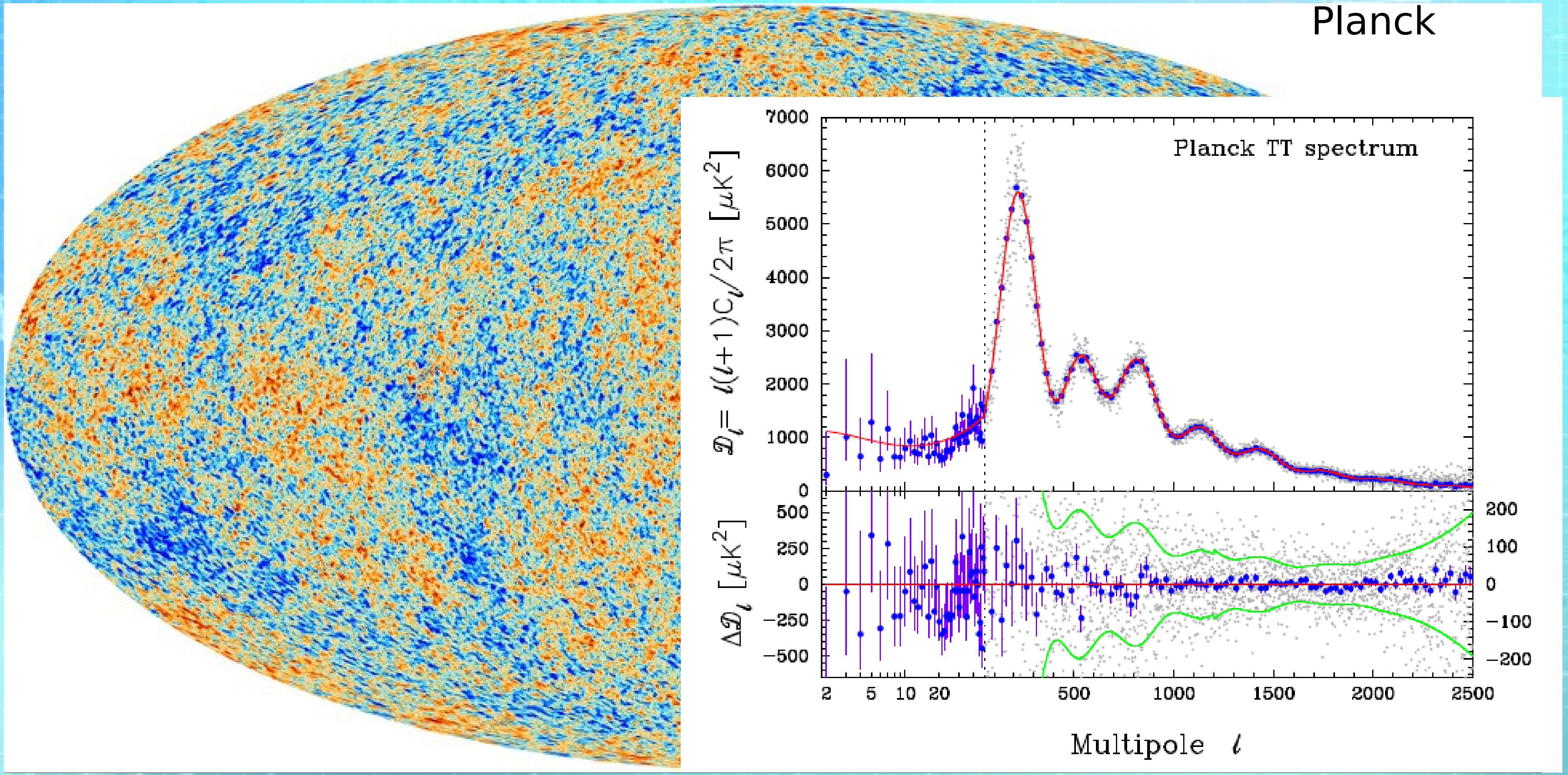
DESI report

Main Goal

Measure Dark Energy

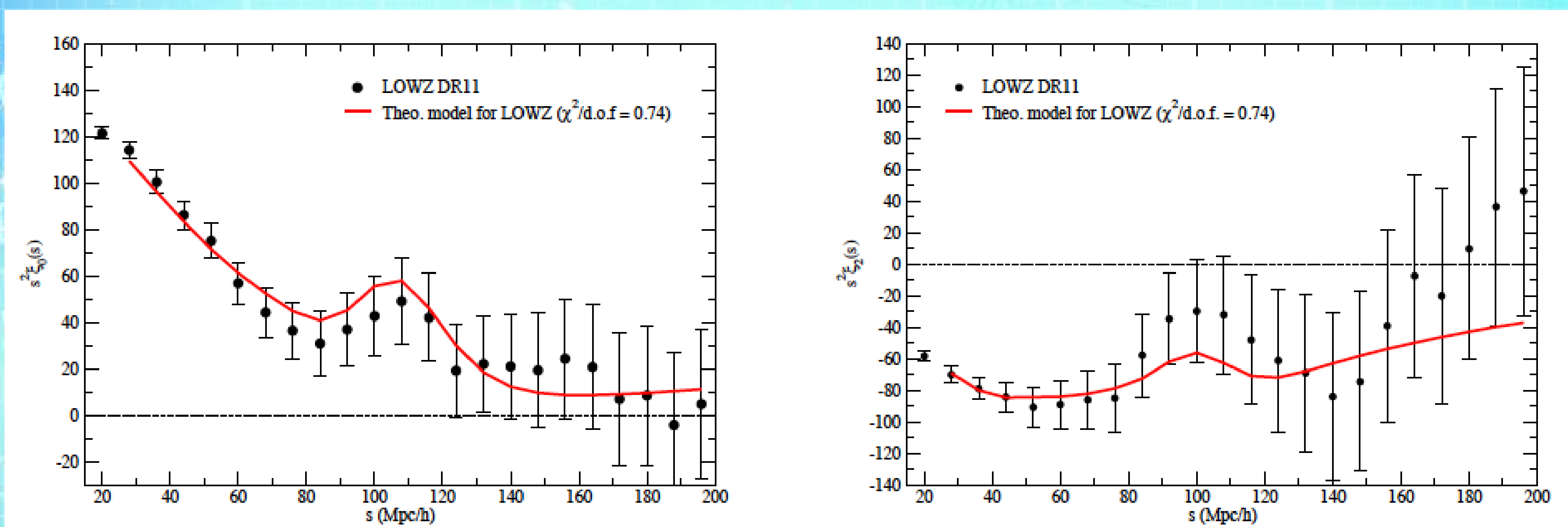
Density distribution from CMB (angular power spectrum)

Planck



Density distribution from Galaxy Sample (correlation function)

$$\delta(\mathbf{r}) = \frac{\rho(\mathbf{r}) - \bar{\rho}}{\bar{\rho}} \longrightarrow \xi(r) = \langle \delta(\mathbf{x})\delta(\mathbf{x}-\mathbf{r}) \rangle$$



Chuang et. al. (2013)

Galaxy sample → Data analysis → Cosmological constraints

Data analysis

- Clustering measurements
- Covariance matrix
- Theoretical model
- MCMC analysis

Cosmological constraints

- $H(z)$
- $D_A(z)$
- $f(z)\sigma_8(z)$
- $\Omega_m h^2$

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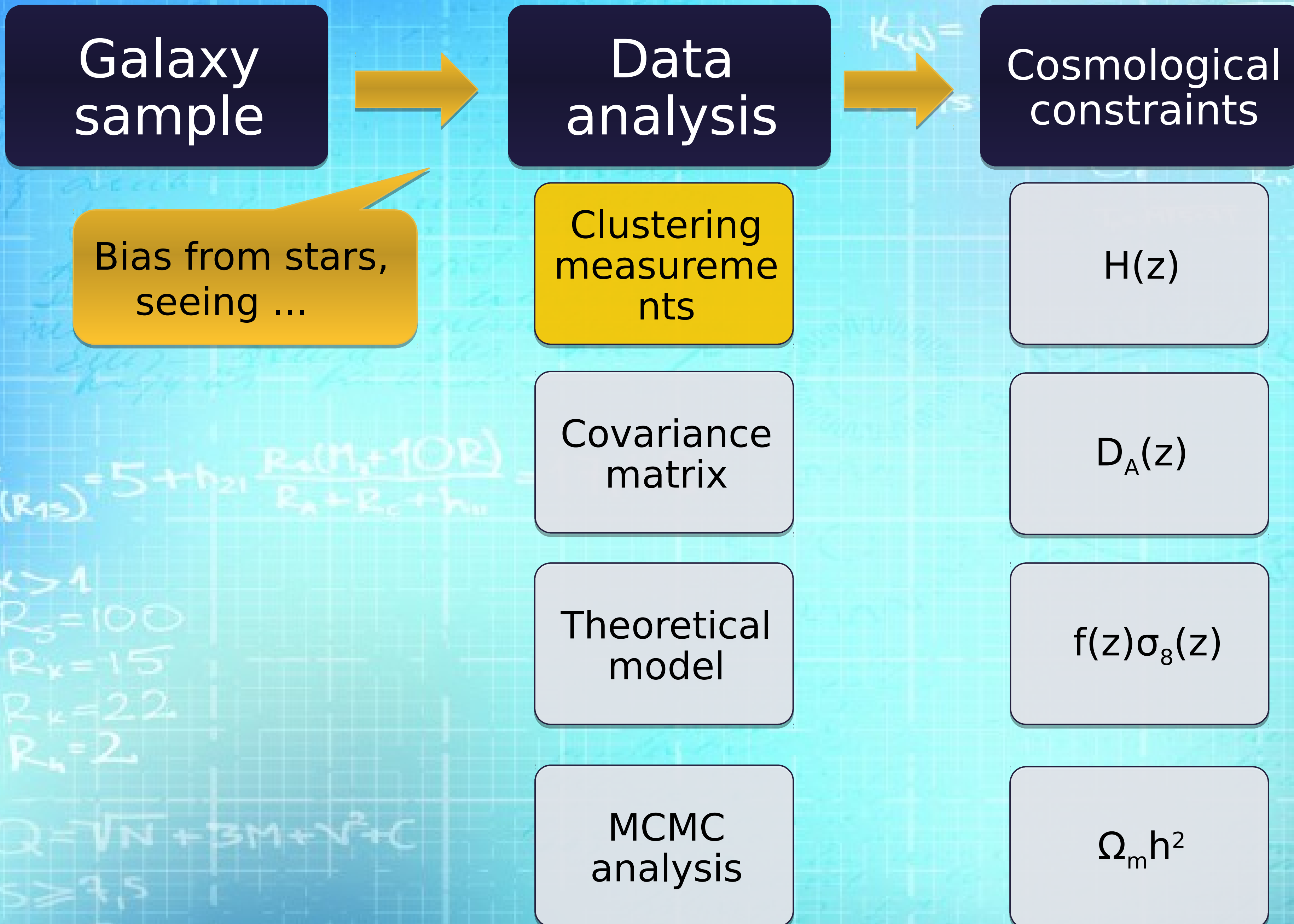
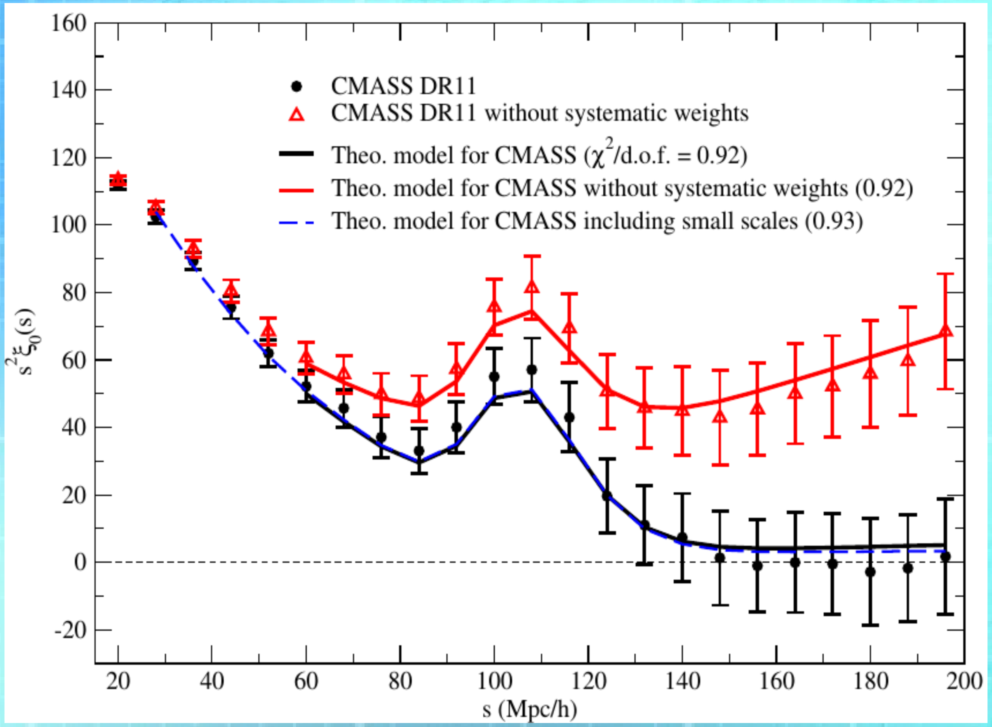
Q: In which step, we might obtain a biased result?

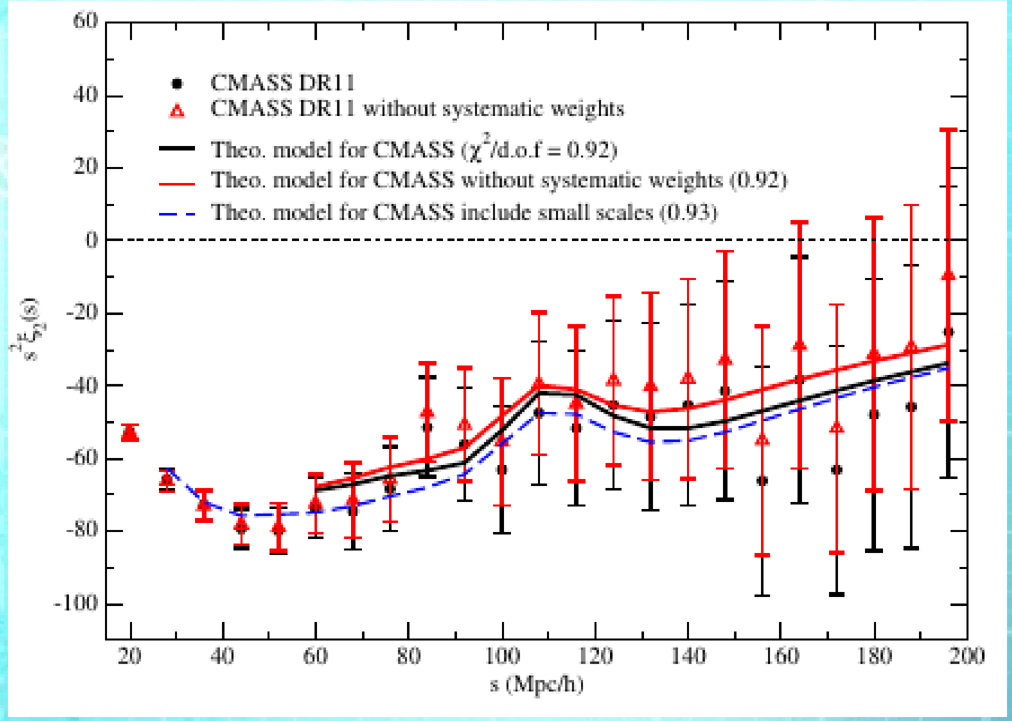
A: **All of them!**


Galaxy sample
Bias from stars, seeing ...
Data analysis
Clustering measurements
Covariance matrix
Theoretical model
MCMC analysis
Cosmological constraints
H(z)
$D_A(z)$
$f(z)\sigma_8(z)$
$\Omega_m h^2$

Clustering Measurements (Chuang et. al. 2013)

- bias mainly from stars. Higher density regions, cannot measure every object.





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Bias from mock catalog

Covariance matrix

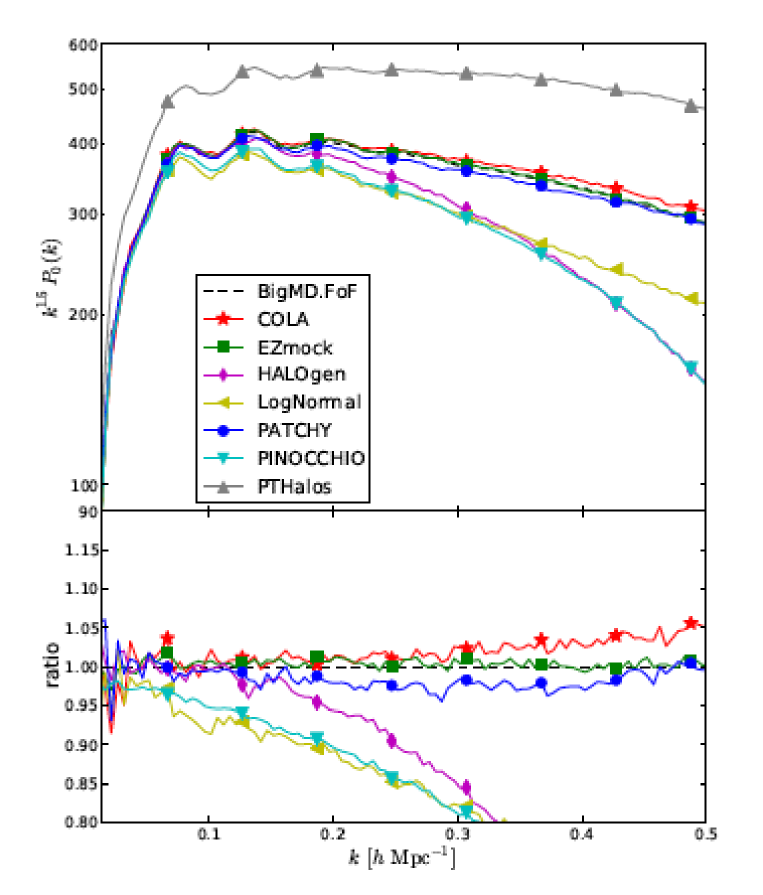
- We need thousands of mock catalogs to build up the covariance matrix of the clustering measurements.
- Most reliable mocks coming from N-body simulations.
- They take too much time, not practical.
- We need an alternative way.
- Also needed higher than 2-point order statistics.

MultiDark

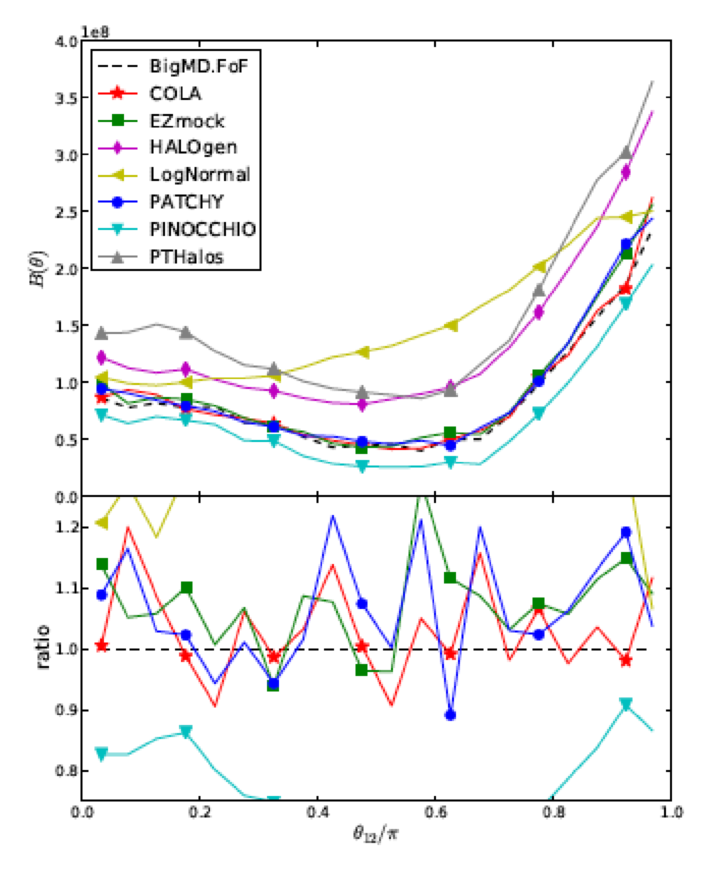
Multimessenger Approach for Dark Matter Detection

Mock comparison project (Chuang et. al. 2014)

P(k)



B(θ)



Only COLA, EZmock and **PATCHY (we could assign masses and bias to it)** reach the percentage accuracy at small scales for 2 and 3-point statistics.

Galaxy sample → **Data analysis** → **Cosmological constraints**

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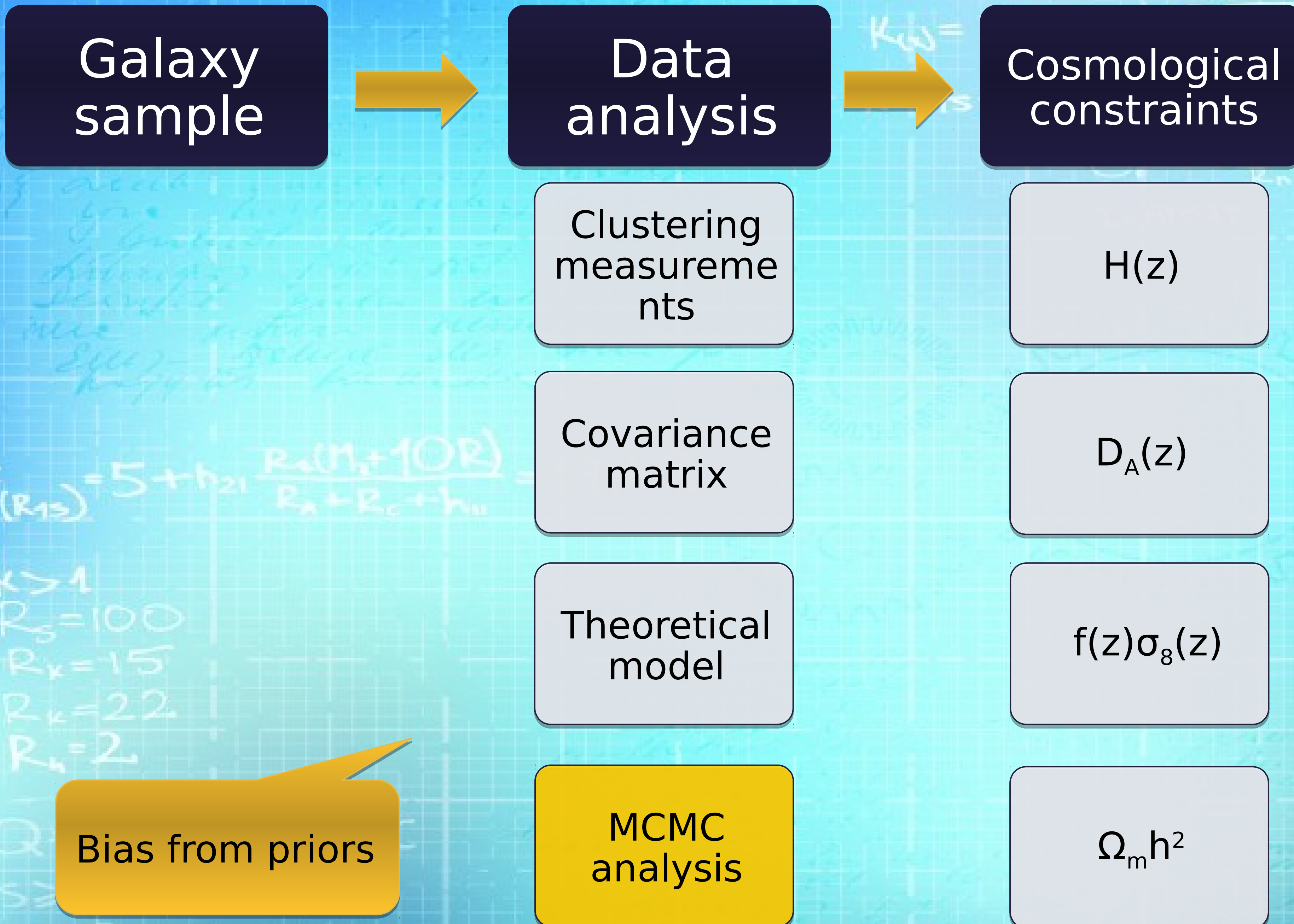
Bias from non linear evolution studies (distance range)

Theoretical model

- We don't know how to put galaxies into dark matter haloes.
- Many non linear evolution models available: SPT, LPT, iPT, CLPT, **CLPT-GSRSD** (**convolution lagrangian perturbation theory – gaussian streaming redshift space distortions** Wang, Reid & White)
- Solution: stick to linear and quasi-linear scales i.e. cut off scales lower than ~ 40 Mpc/h.


Galaxy sample
Data analysis
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Clustering measurements
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MCMC analysis
Bias from priors
H(z)
$D_A(z)$
$f(z)\sigma_8(z)$
$\Omega_m h^2$

MCMC analysis (CAMB, COSMOMC)

- 8 parameters to be fitted:
  - H, $D_A(z)$, $\Omega_m h^2$, β and $b\sigma_8$ are well constrained (Independent of dark energy model)
  - $\Omega_b h^2$, ns and f are NOT well constrained by LSS.
- How to handle those parameters not well constrained by galaxy clustering? We need **PRIORS**

MCMC analysis (priors)

- In many studies, either $\Omega_m h^2$, $\Omega_b h^2$, n_s and f were fixed, or 1σ priors on $\Omega_m h^2$, $\Omega_b h^2$, n_s from CMB were adopted. Dangerous if we combine with these measurements with CMB later!

- We use very wide flat priors:
  - $\Omega_b h^2$,($\pm 10\sigma_{planck}$), n_s ($\pm 10\sigma_{planck}$), f(0.5-1)
  - We call it **single-probe** measurement
  - Can only be done with fast model.

Robust against systematics

	$r = 56 - 200h^{-1}$Mpc (fiducial)	$r = 64 - 200h^{-1}$Mpc	no systematic weights
$H(0.57)$	98.0 ± 6.8	98.3 ± 7.5	99.7 ± 7.7
$D_A(0.57)$	1359 ± 84	1362 ± 97	1325 ± 90
ω_m	0.161 ± 0.035	0.162 ± 0.041	0.176 ± 0.043
β_C	0.319 ± 0.075	0.304 ± 0.076	0.300 ± 0.086
$b_C\sigma_8(0.57)$	1.128 ± 0.096	1.14 ± 0.11	1.156 ± 0.114
$R_{fid}^{-1}H^{-1}(0.57)$	0.01065 ± 0.00033	0.01063 ± 0.00036	0.01073 ± 0.00037
$D_A(0.57)/R_{fid}$	1413 ± 26	1415 ± 24	1410 ± 24
$f\sigma_8(0.57)$	0.354 ± 0.059	0.341 ± 0.061	0.338 ± 0.066
$D_V(0.57)/R_{fid}$	2077 ± 26	2077 ± 26	2080 ± 27
$R_{fid}^{-1.0}H^{-1}(0.57)$	0.01065 ± 0.00033	0.01063 ± 0.00036	0.01073 ± 0.00037
$D_A(0.57)/R_{fid}^{0.96}$	1411 ± 26	1413 ± 24	1407 ± 23
$f\sigma_8(0.57)\omega_m^{0.45}$	0.153 ± 0.021	0.148 ± 0.025	0.152 ± 0.023
$D_V(0.57)/R_{fid}^{0.97}$	2075 ± 25	2075 ± 26	2076 ± 26
α_C	1.024 ± 0.013	1.023 ± 0.013	1.025 ± 0.013
ϵ_C	-0.014 ± 0.014	-0.015 ± 0.014	-0.011 ± 0.014

$$R_{fid} \equiv \frac{r_s}{r_{s,fid}}$$

Chuang et. al. 2013

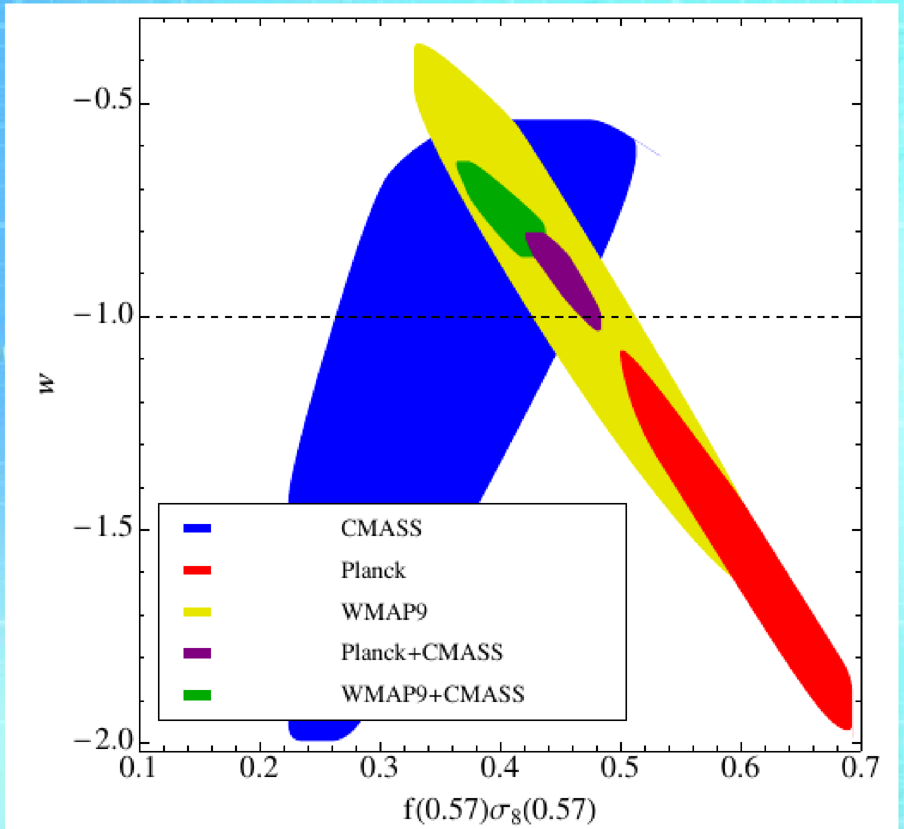
Independent of Dark Energy model

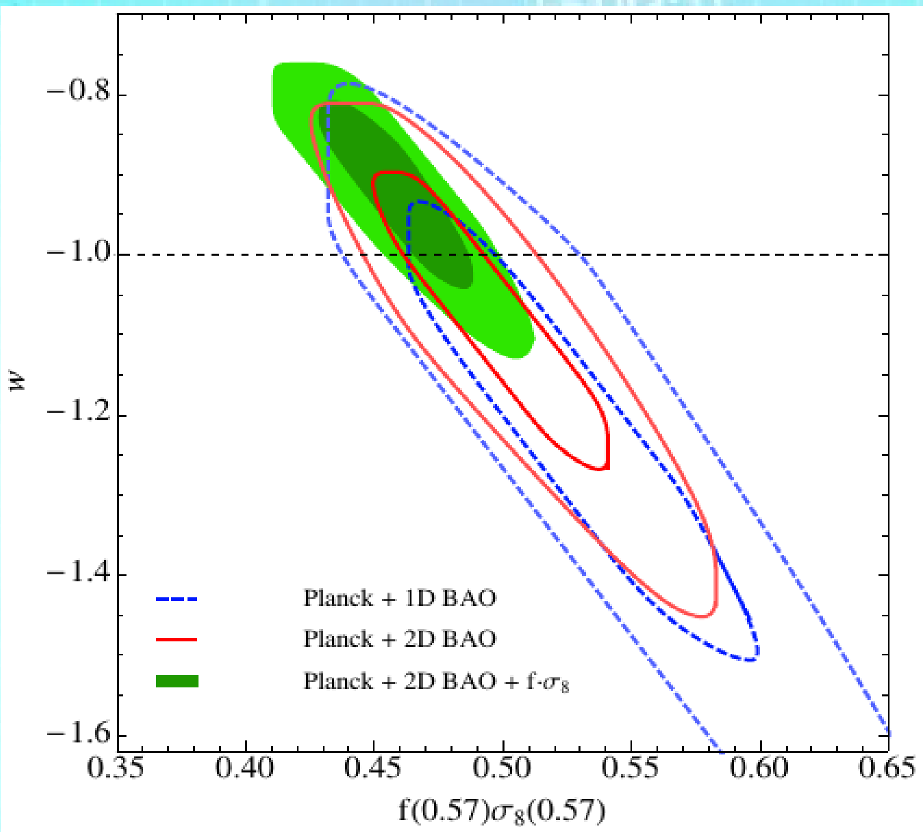
ΛCDM	CMASS-L only	Planck only	Planck+CMASS-L	WMAP9 only	WMAP9+CMASS-L
Ω_m	0.336 ± 0.077	0.315 ± 0.016	0.309 ± 0.011	0.280 ± 0.026	0.295 ± 0.013
h	69.3 ± 4.1	67.3 ± 1.2	67.72 ± 0.83	70.0 ± 2.2	68.5 ± 1.0
$f(0.57)\sigma_8(0.57)$	0.348 ± 0.071	0.480 ± 0.010	0.4756 ± 0.0082	0.466 ± 0.019	0.471 ± 0.012
$\Omega_m h^2$	0.165 ± 0.052	0.1426 ± 0.0025	0.1416 ± 0.0018	0.1364 ± 0.0045	0.1381 ± 0.0026
σ_8	0.60 ± 0.16	0.828 ± 0.013	0.822 ± 0.011	0.821 ± 0.023	0.821 ± 0.017
$f(0.57)$	0.788 ± 0.061	0.782 ± 0.012	0.7780 ± 0.0082	0.754 ± 0.021	0.767 ± 0.010
$H(0.57)$	97 ± 11	92.87 ± 0.50	93.01 ± 0.38	93.9 ± 1.1	93.01 ± 0.66
$D_A(0.57)$	1351 ± 118	1393 ± 16	1387 ± 11	1359 ± 29	1380 ± 15
$D_V(0.57)$	2001 ± 194	2065 ± 19	2058 ± 14	2023 ± 37	2051 ± 19

wCDM	CMASS-L only	Planck only	Planck+CMASS-L	WMAP9 only	WMAP9+CMASS-L
Ω_m	0.331 ± 0.084	0.210 ± 0.059	0.327 ± 0.021	0.30 ± 0.11	0.333 ± 0.021
h	71 ± 13	84 ± 10	65.7 ± 2.2	71 ± 14	63.4 ± 2.1
$f(0.57)\sigma_8(0.57)$	0.36 ± 0.11	0.592 ± 0.068	0.456 ± 0.021	0.47 ± 0.10	0.406 ± 0.027
$\Omega_m h^2$	0.182 ± 0.088	0.1425 ± 0.0024	0.1405 ± 0.0021	0.1364 ± 0.0048	0.1335 ± 0.0033
σ_8	0.65 ± 0.30	0.974 ± 0.086	0.795 ± 0.029	0.82 ± 0.15	0.734 ± 0.038
$f(0.57)$	0.78 ± 0.13	0.804 ± 0.020	0.771 ± 0.010	0.764 ± 0.027	0.739 ± 0.014
$H(0.57)$	99 ± 14	90.9 ± 1.5	93.21 ± 0.42	92.6 ± 1.9	94.02 ± 0.75
$D_A(0.57)$	1346 ± 194	1300 ± 53	1403 ± 19	1384 ± 115	1415 ± 21
$D_V(0.57)$	1988 ± 289	1985 ± 48	2073 ± 20	2057 ± 119	2078 ± 23
w	-1.10 ± 0.45	-1.52 ± 0.30	-0.917 ± 0.081	-1.01 ± 0.43	-0.767 ± 0.088

Chuang et. al. 2013

MCMC analysis (CMB combination)





Conclusions

- We are developing robust methodology extracting cosmological constraints from galaxy distribution.
- We minimize systematics from: observation, covariance matrix, theoretical model and MCMC analysis.
- We are applying the method to BOSS dr12.

THANK YOU

Theoretical model

- Assumptions:
  - Adiabatic initial conditions
  - Cold Dark Matter
  - No early type Dark Energy
  - Smooth Dark Energy i.e. no structure of Dark Energy.