Tomographic Alcock-Paczynski Test for CSST

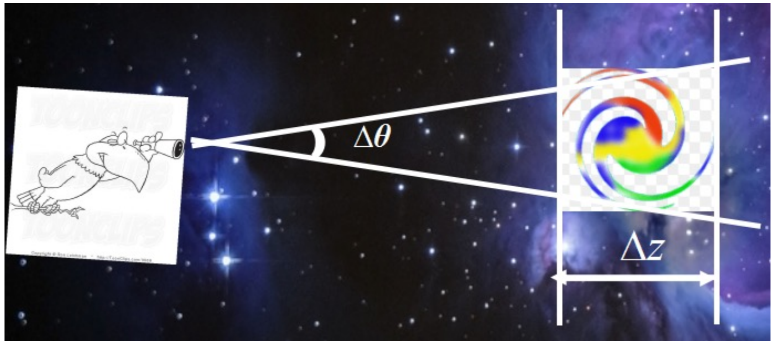
Xiao-Dong Li (with many collaborators)

Sun Yat-Sen University (SYSU)

Nov 2023 @ SJTU

The Alcock-Paczynski test

Alcock & Paczynski, Nature, 1979



$$\Delta r_{\parallel} = \frac{c}{H(z)} \Delta z$$

$$\Delta r_{\perp} = (1+z) D_A(z) \Delta\theta$$

$$H(z) = H_0 \sqrt{\Omega_m a^{-3} + (1-\Omega_m) a^{-3(1+w)}}$$

$$D_A(z) = \frac{c}{1+z} r(z) = \frac{c}{1+z} \int_0^z \frac{dz'}{H(z')}$$

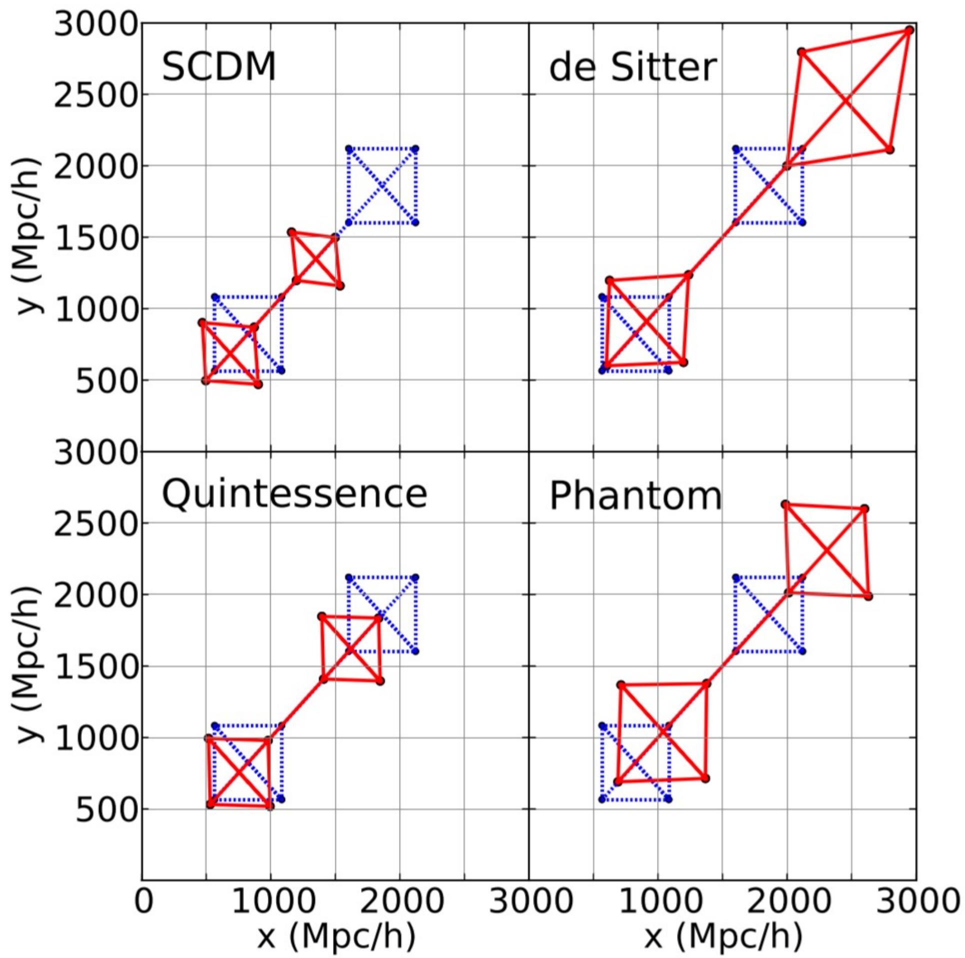
In case of using wrong cosmology....

Shape distortion due to wrong H, D_A :

Tomographic AP test

Focus on the **redshift evolution** of the distortion

Li, Park, Forero-Romero et al. 2015, APJ



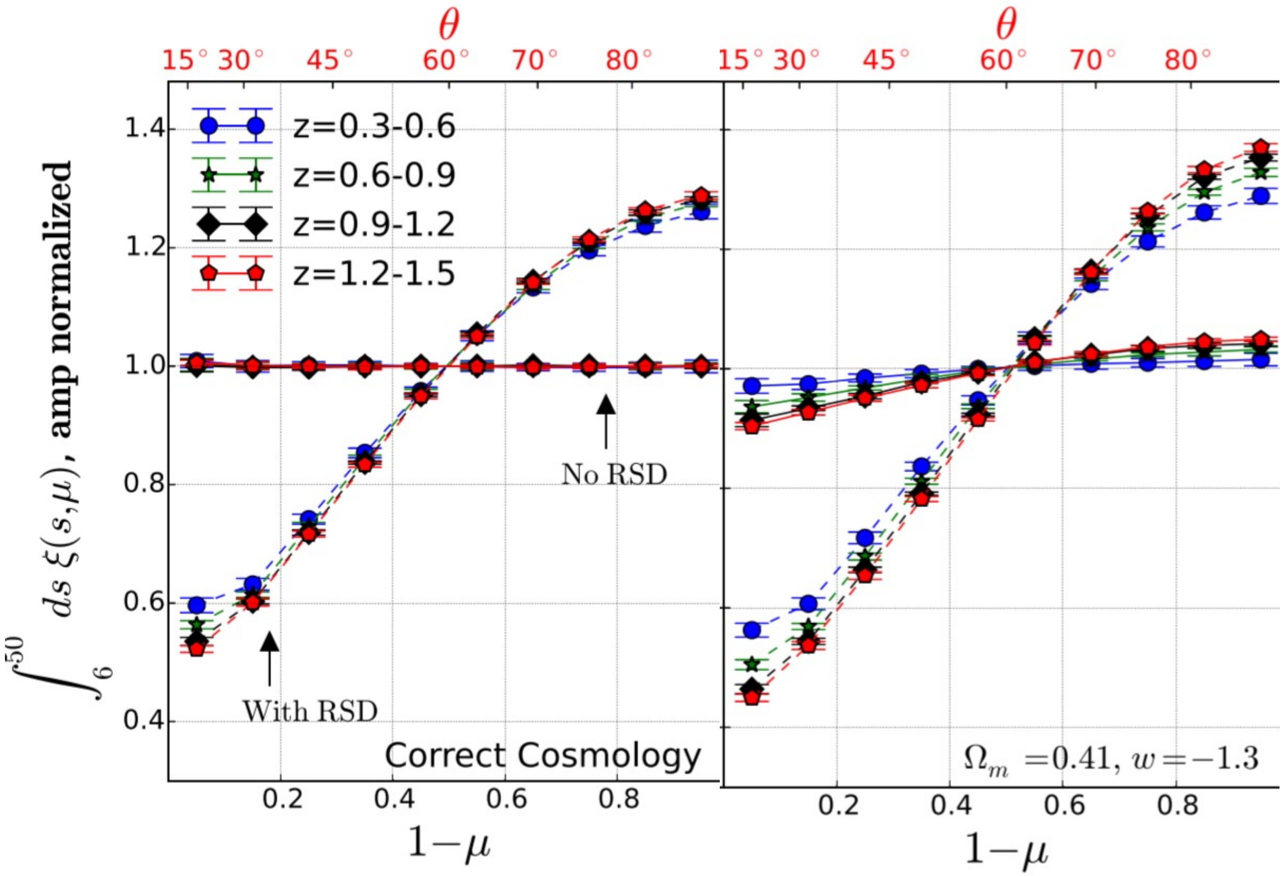
Overcoming RSD via Tomographic Analysis

Xiao-Dong Li, Changbom Park, et al. 2014, 2015, 2016, ApJ

Using redshift evolution to beat RSD!

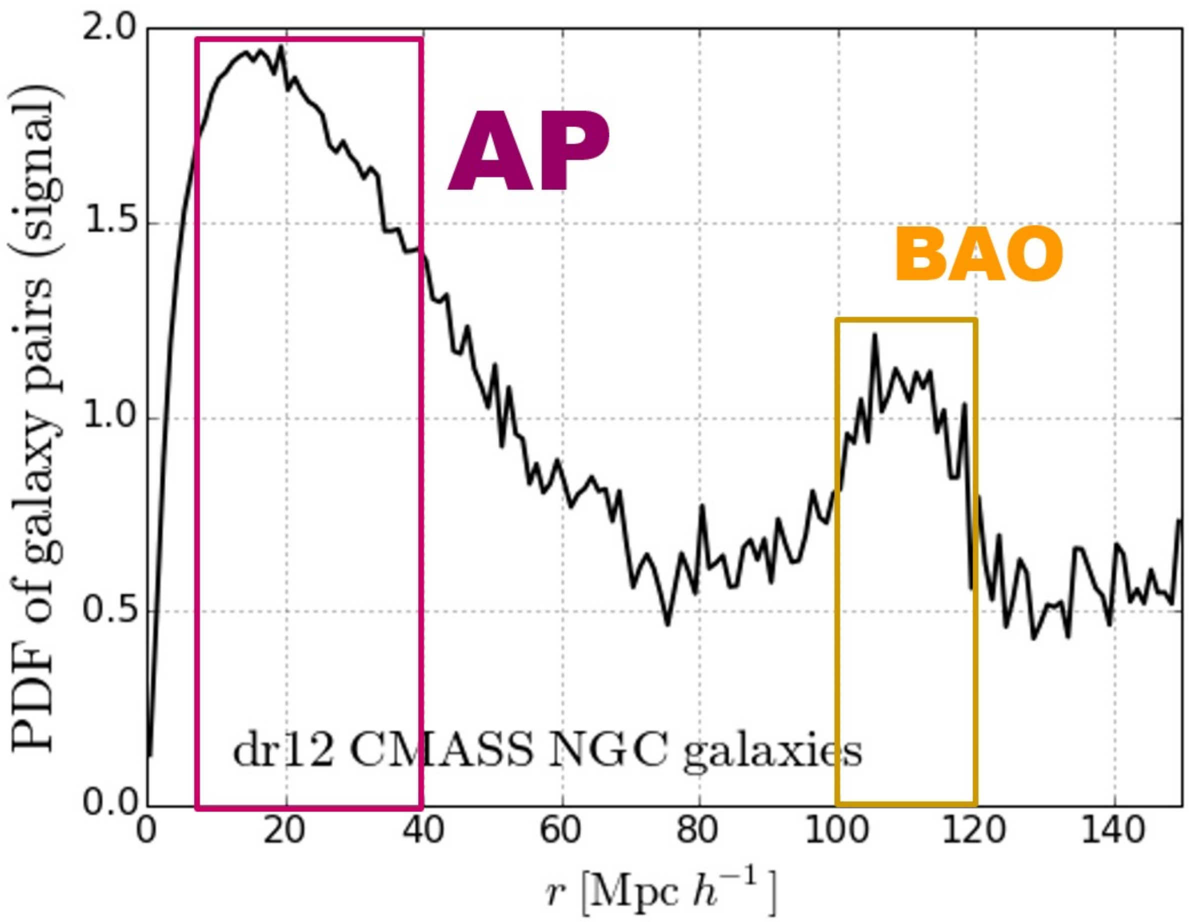
$$\xi_{\Delta s}(\mu) \equiv \int_{s_{\min}}^{s_{\max}} \xi(s,\mu)\ ds.$$

$$\hat{\xi}_{\Delta s}(\mu) \equiv \frac{\xi_{\Delta s}(\mu)}{\int_0^{\mu_{\max}} \xi_{\Delta s}(\mu)\ d\mu}.$$



A very unique method!

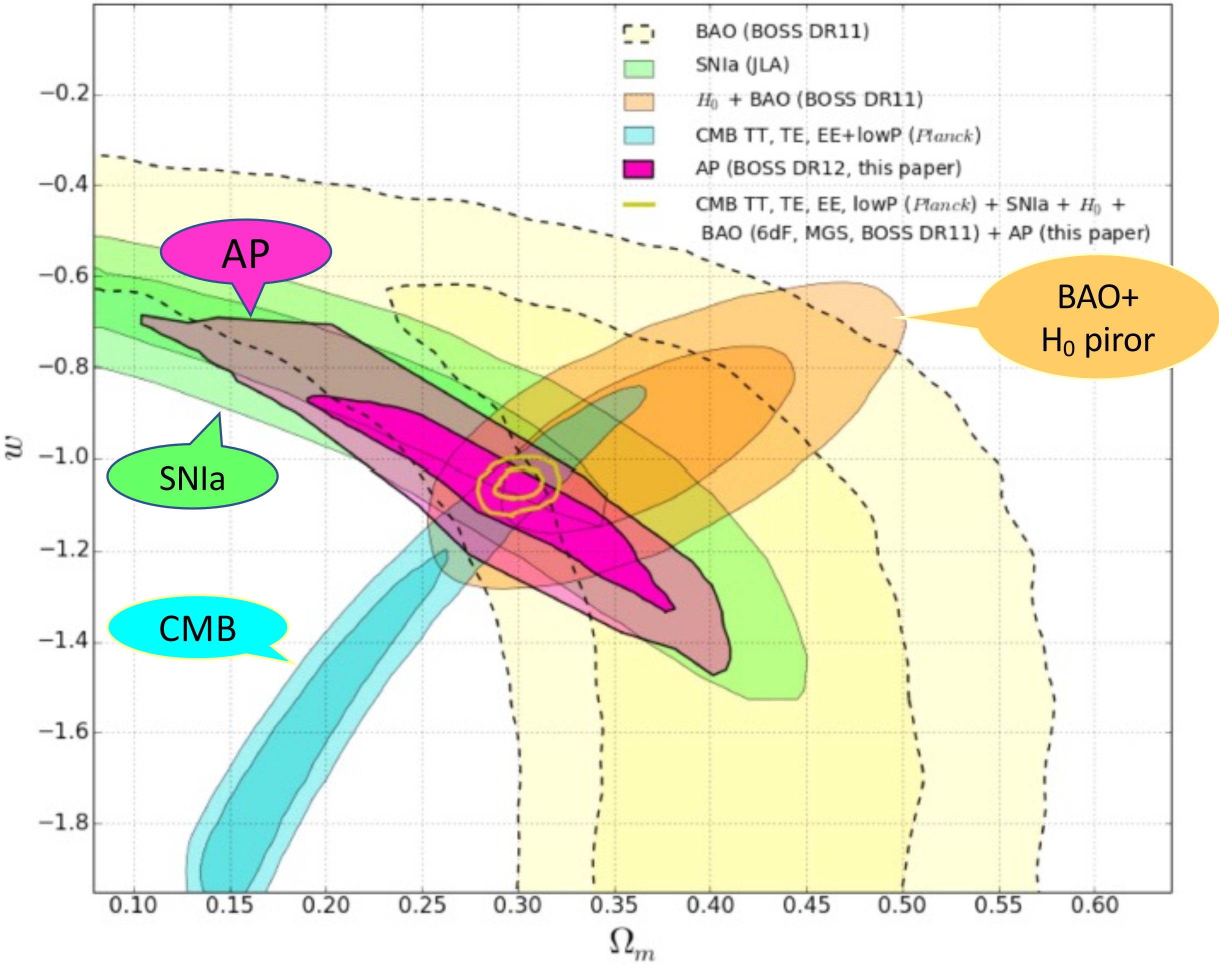
non-linear clustering analysis (6-40 Mpc/h)



Zhang, Huang, Li et al. 2019, MNRAS

Applied to SDSS DR12

Xiao-Dong Li, Changbom Park, et al. 2016, ApJ



Combining all:

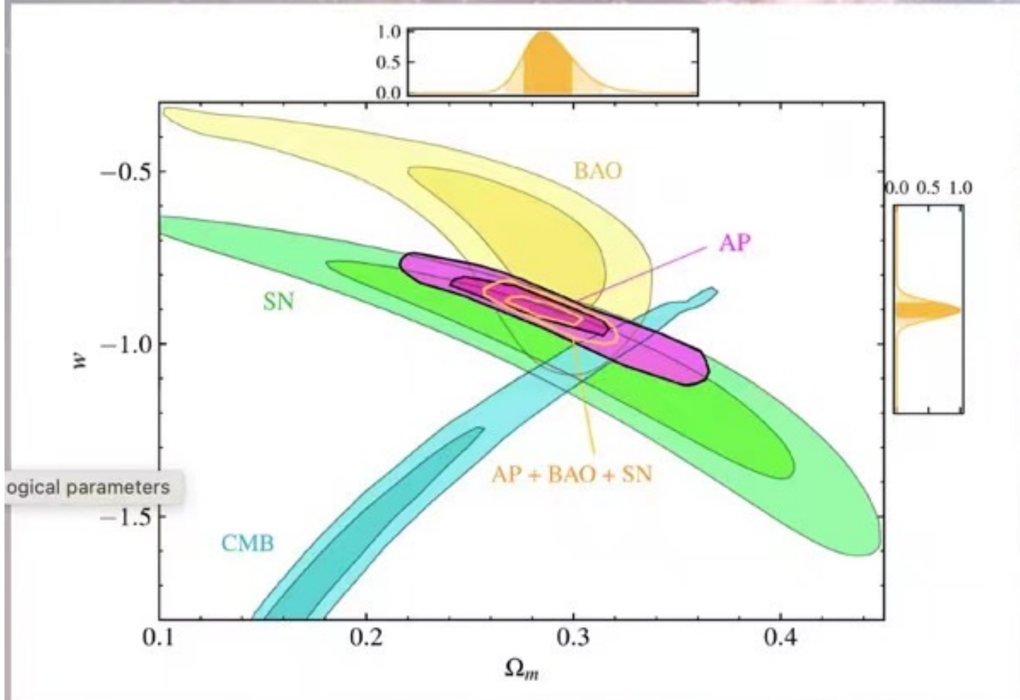
$\Omega_m = 0.301 \pm 0.006$

$w = -1.054 \pm 0.025$

AP reduces the error of Planck+BAO+SNIa+H0 by **30-40% !**

(From Fuxu Dong's PPT)

5. Result from Observation

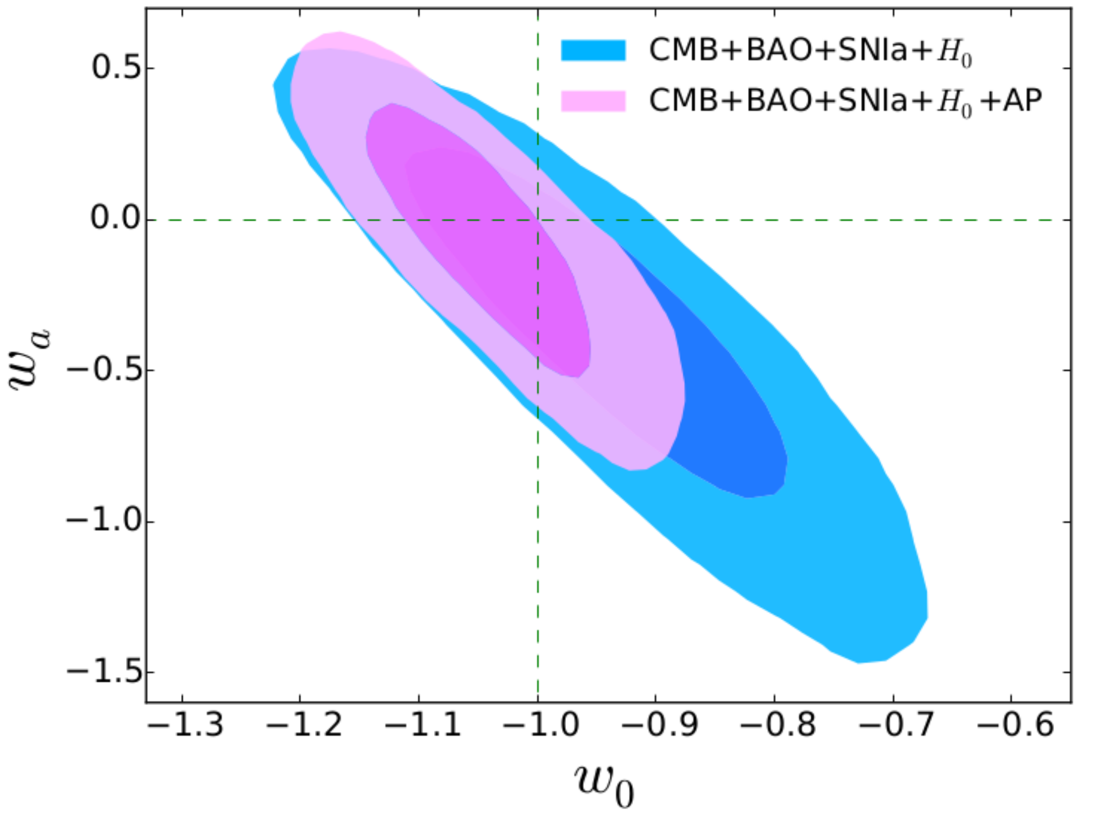


galaxies	probes	Ω_m,	$\langle\Omega_m\rangle$,	$\sigma(\Omega_m)$	w,	$\langle w\rangle$,	$\sigma(w)$
	BAO	$0.285^{+0.025}_{-0.030}$,	0.271,	0.036	$-0.686^{+0.144}_{-0.149}$,	-0.689,	0.147
	SN	$0.333^{+0.063}_{-0.080}$,	0.309,	0.076	$-1.0024^{+0.2}_{-0.22}$,	-1.066,	0.216
	CMB	$0.154^{+0.067}_{-0.011}$,	0.199,	0.049	$-1.836^{+0.419}_{-0.092}$,	-1.575,	0.269
baseline	AP	$0.282^{+0.024}_{-0.023}$,	0.286,	0.025	$-0.892^{+0.045}_{-0.050}$,	-0.9,	0.05
baseline	BAO+AP	$0.287^{+0.012}_{-0.011}$,	0.289,	0.013	$-0.897^{+0.020}_{-0.025}$,	-0.905,	0.025
baseline	SN+AP	$0.282^{+0.026}_{-0.020}$,	0.289,	0.024	$-0.897^{+0.040}_{-0.045}$,	-0.911,	0.049
baseline	CMB+AP	$0.317^{+0.008}_{-0.005}$,	0.32,	0.007	$-0.982^{+0.020}_{-0.025}$,	-0.989,	0.026
baseline	AP(joint)	$0.276^{+0.024}_{-0.021}$,	0.280,	0.024	$-0.892^{+0.04}_{-0.045}$,	-0.899,	0.047
all	AP	$0.255^{+0.023}_{-0.023}$,	0.255,	0.023	$-0.842^{+0.05}_{-0.05}$,	-0.844,	0.054

1. Big improvement on constraining DE model with the addition of AP test.
2. The constraint from AP test is in tension with CMB.

Dynamical dark energy

Li, Sabiu, Park, et al. 2018, ApJ

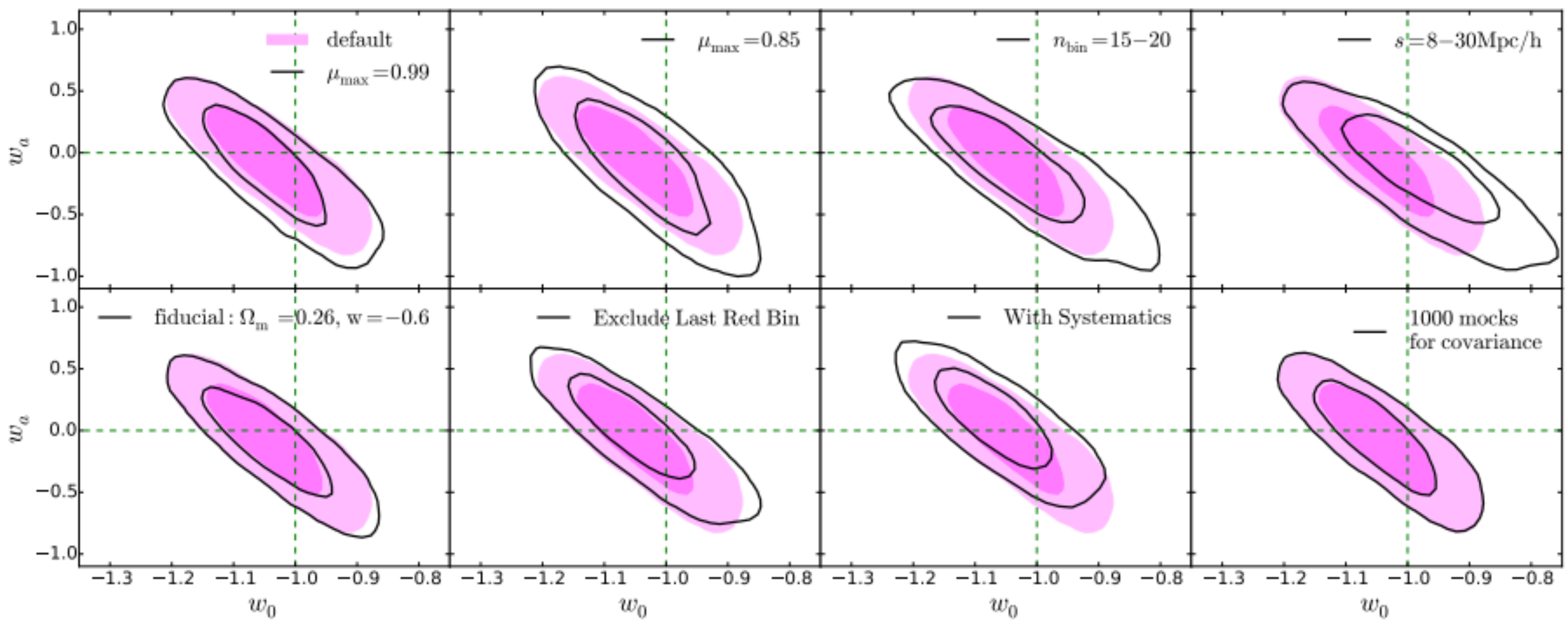


$$w = w_0 + w_a\ z / (1+z)$$

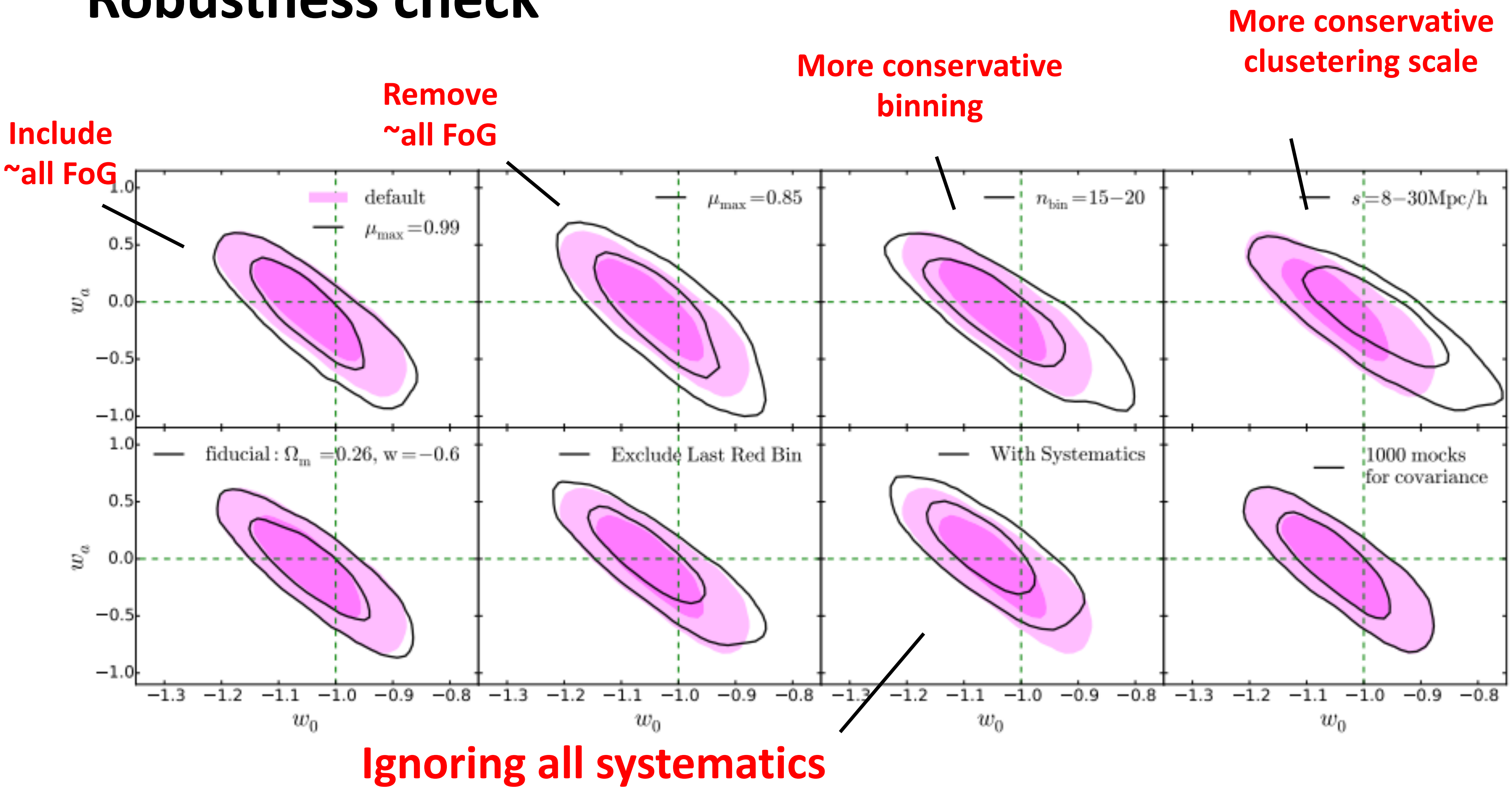
AP reduces the contour area

by 100%!

Robustness check



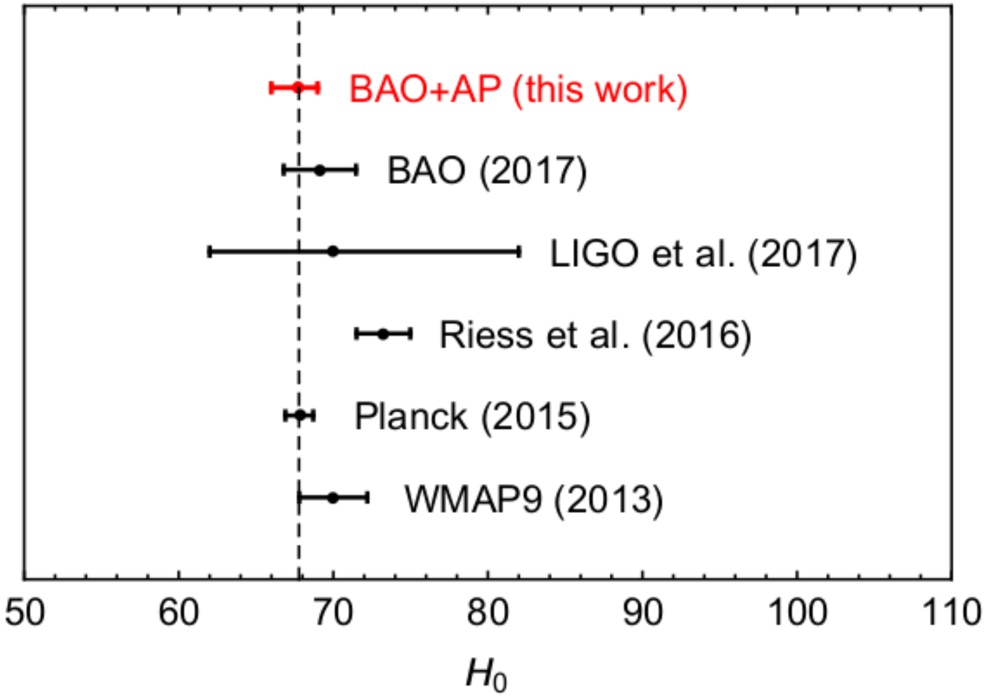
Robustness check



More Cosmological Constraints...

Dr. Xue Zhang

H_0 constraints (1801.07403)

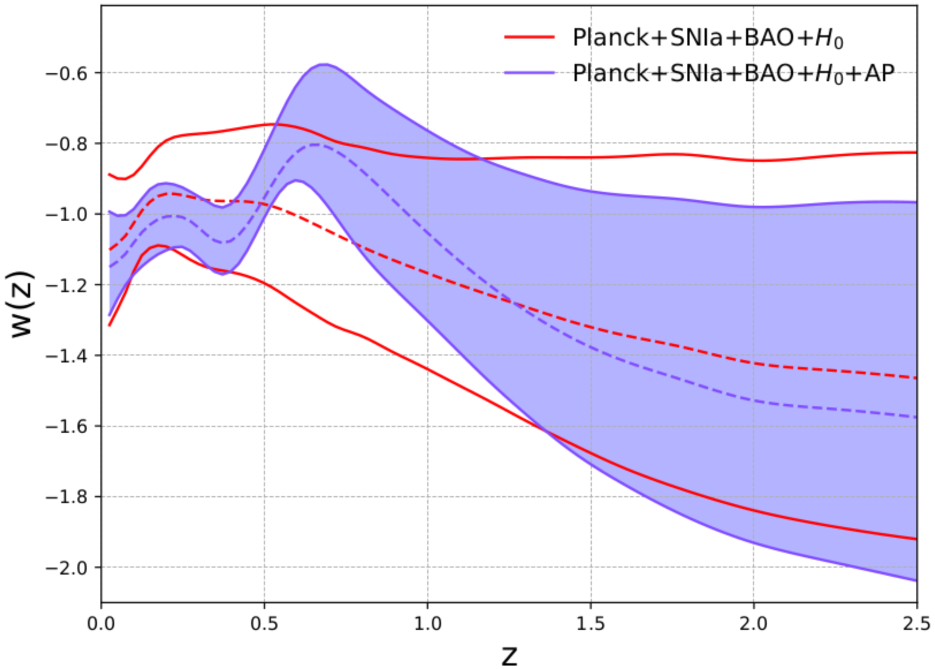


32% improvement by adding AP

More Cosmological Constraints...

H_0 constraints (1801.07403)

Non-parametric DE constraint (1902.09794)



Yunhe Li
(Northeastern Univ.)

Zhenyu Zhang
(Peking Univ.)

100% improvement by adding AP!

More Cosmological Constraints...

Dr. Xue Zhang

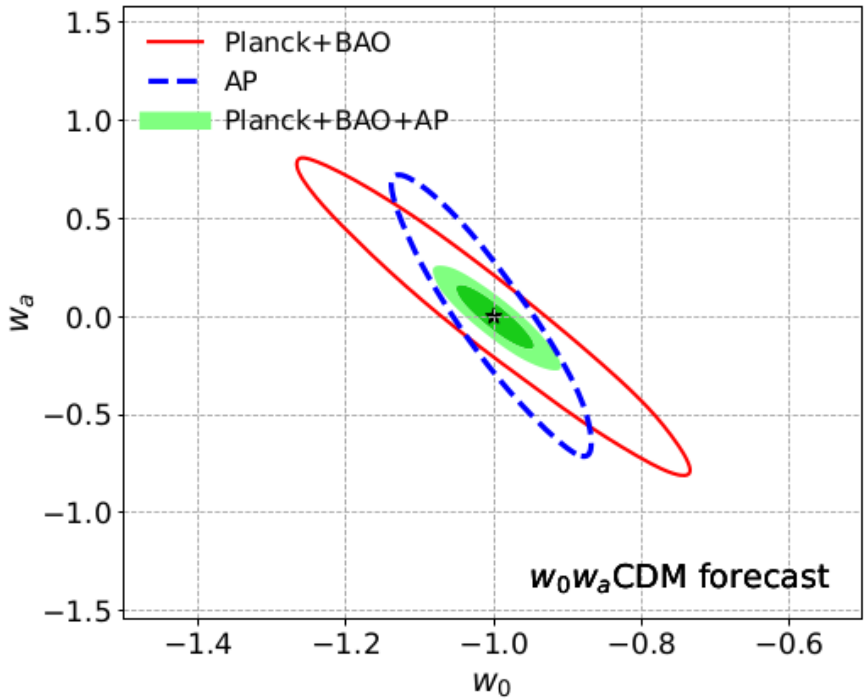
H_0 constraints (1801.07403)

Non-parametric DE constraint (1902.09794)

Neutrinos, Curvature (1903.04757)

Parameter	ΛCDM extension		*w*CDM extension	
	Planck+BAO	+AP	Planck+BAO	+AP
Ω_k	$-0.0002^{+0.0041}_{-0.0040}$	$0.0004^{+0.0042}_{-0.0039}$	$-0.0010^{+0.0066}_{-0.0061}$	$-0.0015^{+0.0042}_{-0.0044}$
$\sum m_\nu$ [eV]	< 0.181	< 0.141	< 0.295	< 0.243
$N_{\rm eff}$	$2.97^{+0.34}_{-0.34}$	$3.07^{+0.33}_{-0.33}$	$2.95^{+0.38}_{-0.37}$	$2.96^{+0.37}_{-0.35}$
$dn_s/d\ln k$	$-0.0023^{+0.0132}_{-0.0138}$	$-0.0025^{+0.0133}_{-0.0136}$	$-0.0024^{+0.0134}_{-0.0136}$	$-0.0025^{+0.0132}_{-0.0139}$
r	< 0.115	< 0.121	< 0.113	< 0.111

20-30% improvement on Ω_k m_υ $N_{\rm eff}$



We expect the method play an

import role in Stage-IV surveys!

Planck+DESI BAO/AP can be 10 times

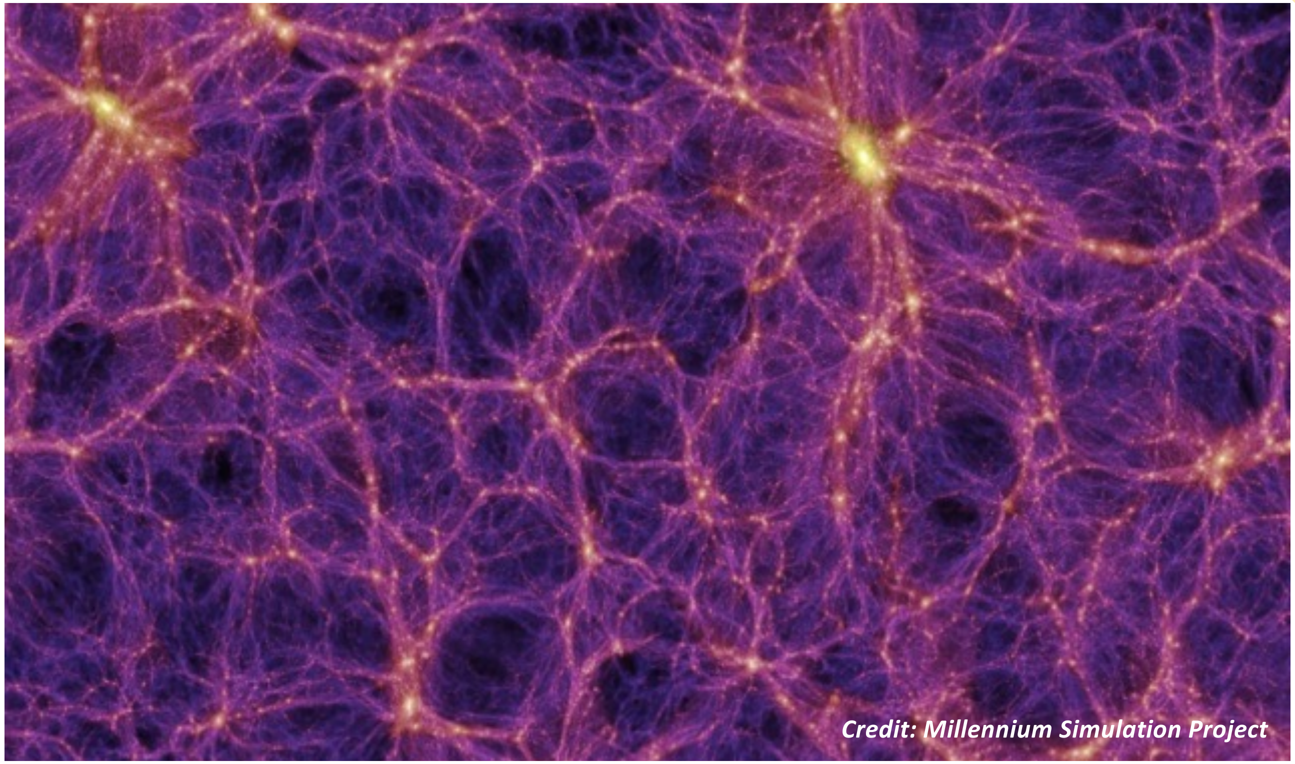
better than **Planck+ DESI BAO** (1903.04757)

(ideal, no systematics)

Current work: Preparing for Stage-IV Surveys

Challenges:

- Deep Surveys -> Non-linear clustering analysis (go beyond 2pCF!)
- Covariance
- Systematics (e.g. redshift errors of slitless survey)



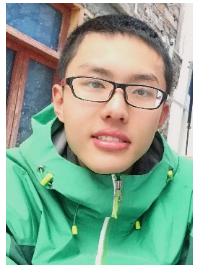
Outline

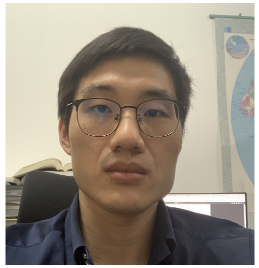
Liang Xiao

Sun Yat-Sen Univ.

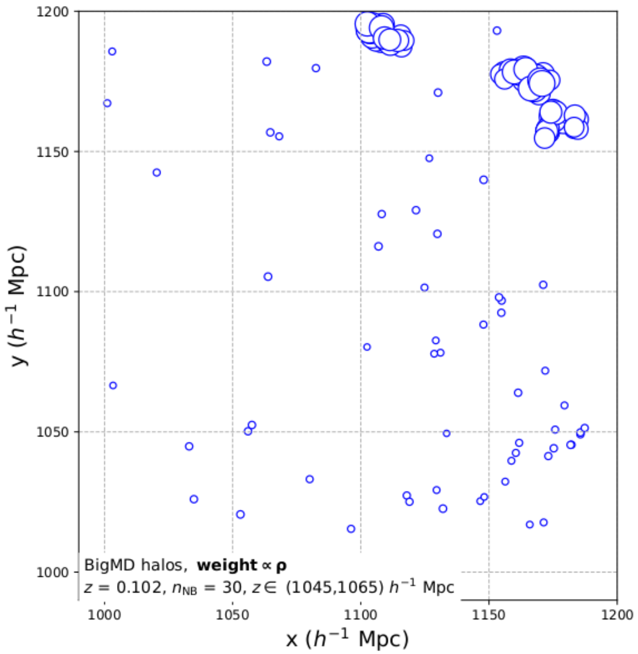
1. Beyond 2-point statistics
2. Covariance estimation
3. Systematics from Redshift Errors

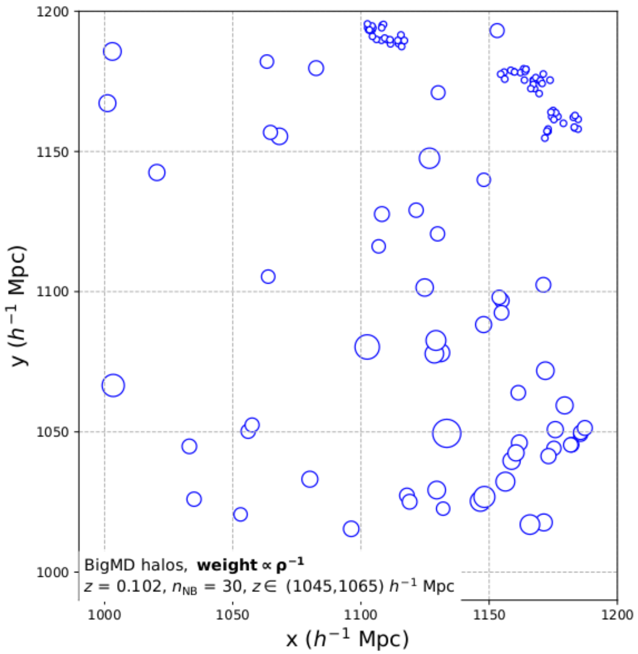
Beyond 2-point CF: Marked Statistics


Yizhao Yang
SJTU


Haitao Miao
NAOC


Limin Lai
SJTU





α=1: focus on clusters/filaments **α= -1**: voids

Weight = ρ^{α},

$$W(\boldsymbol{r}) = \langle \delta(\boldsymbol{x})\rho(\boldsymbol{x})^{\alpha}\delta(\boldsymbol{x}+\boldsymbol{r})\rho(\boldsymbol{x}+\boldsymbol{r})^{\alpha}\rangle$$

From: Yizhao Yang et al., 2020, ApJ

Our Advantages

*** Avoid analytical modeling**

*** Can use any statistics**

*** Easier than emulation method**

*** only emulate systematics not everything;**

*** fast mock will work fine (Qinglin Ma et al., ApJ, 2020, arXiv1908.10595)**

Best-fit = minimal redshift evolution after systematics correction

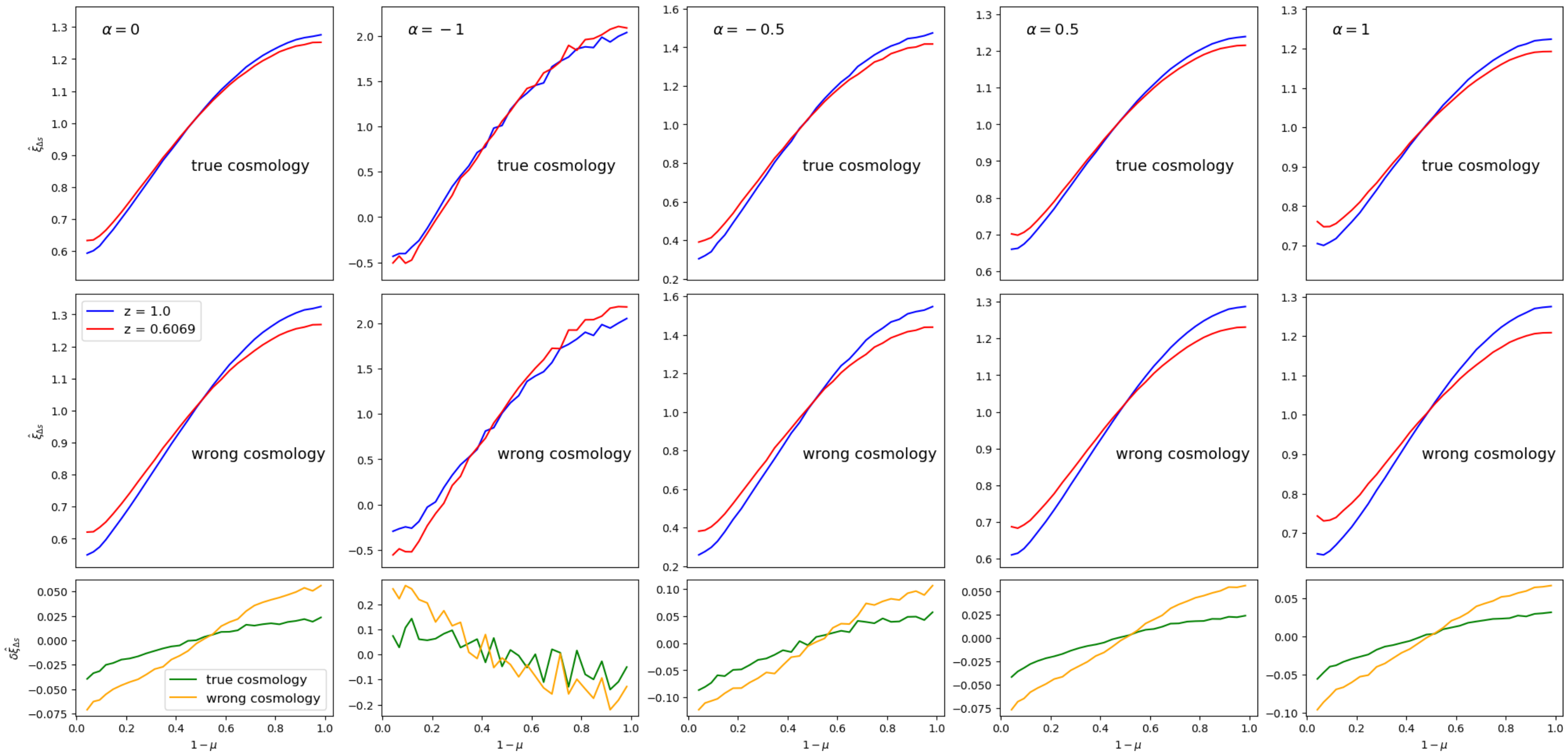
Qinglin Ma
(TSU)

Beyond 2-point CF: Marked Statistics

CF, true cosmology

CF, wrong cosmology

z-evolv of CF



As a proof of concept, we use z=1/0.61 snaps @ BigMD

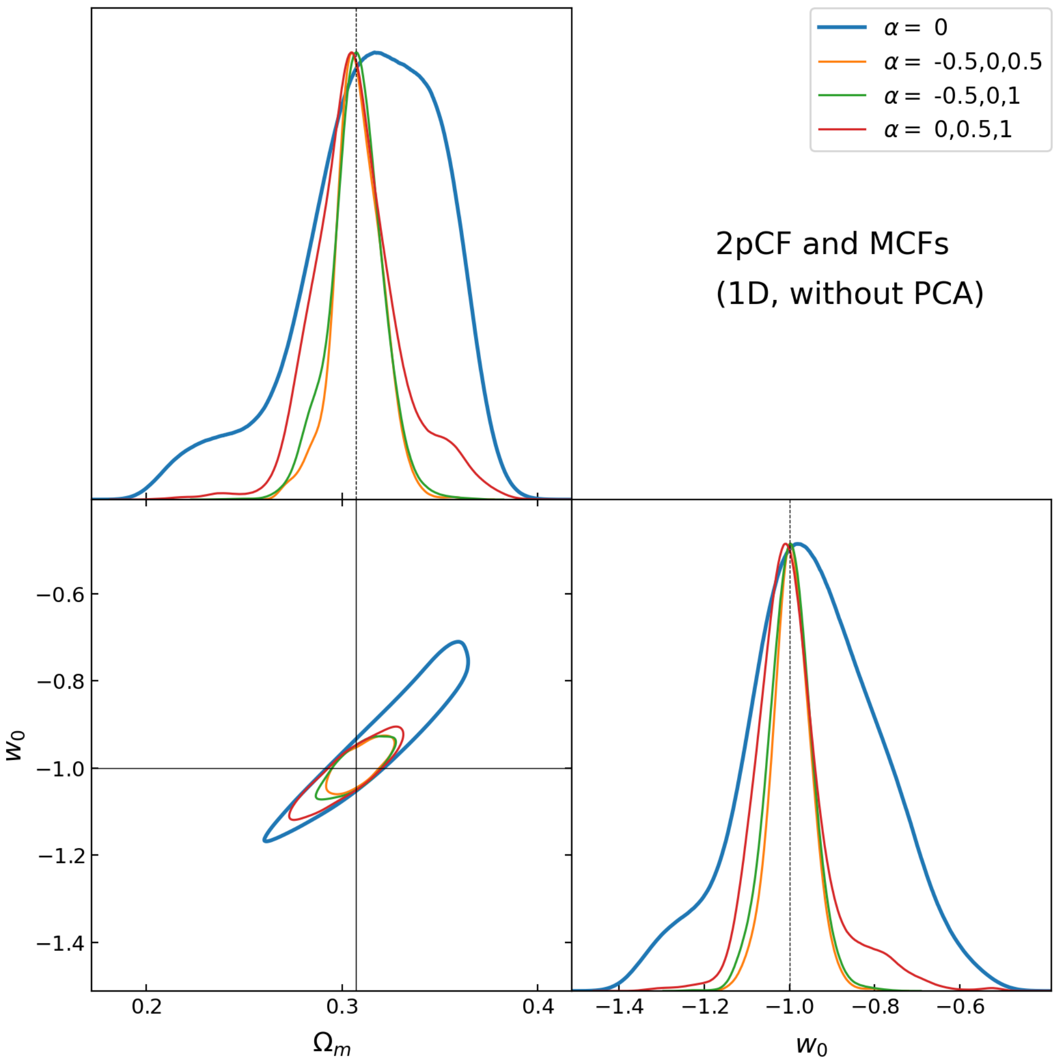
true cosmology: om/w = 0.3071/-1

wrong cosmology: om/w = 0.4071/-1.5

Test based on BigMDPL simulation

Name	Box(Mpc/h)	Particles	$m_p(M_\odot)$	ε（kpc/h）	Ω_m
BigMDPL	2500	3840^3	2.4×10^{10}	10.0	0.3071
Ω_B	Ω_Λ	σ_8	n_s	H_0(km/s/Mpc)	Code
0.048	0.693	0.829	0.96	67.8	GADGET-2

Klypin, Yepes et al. 2016, MNRAS



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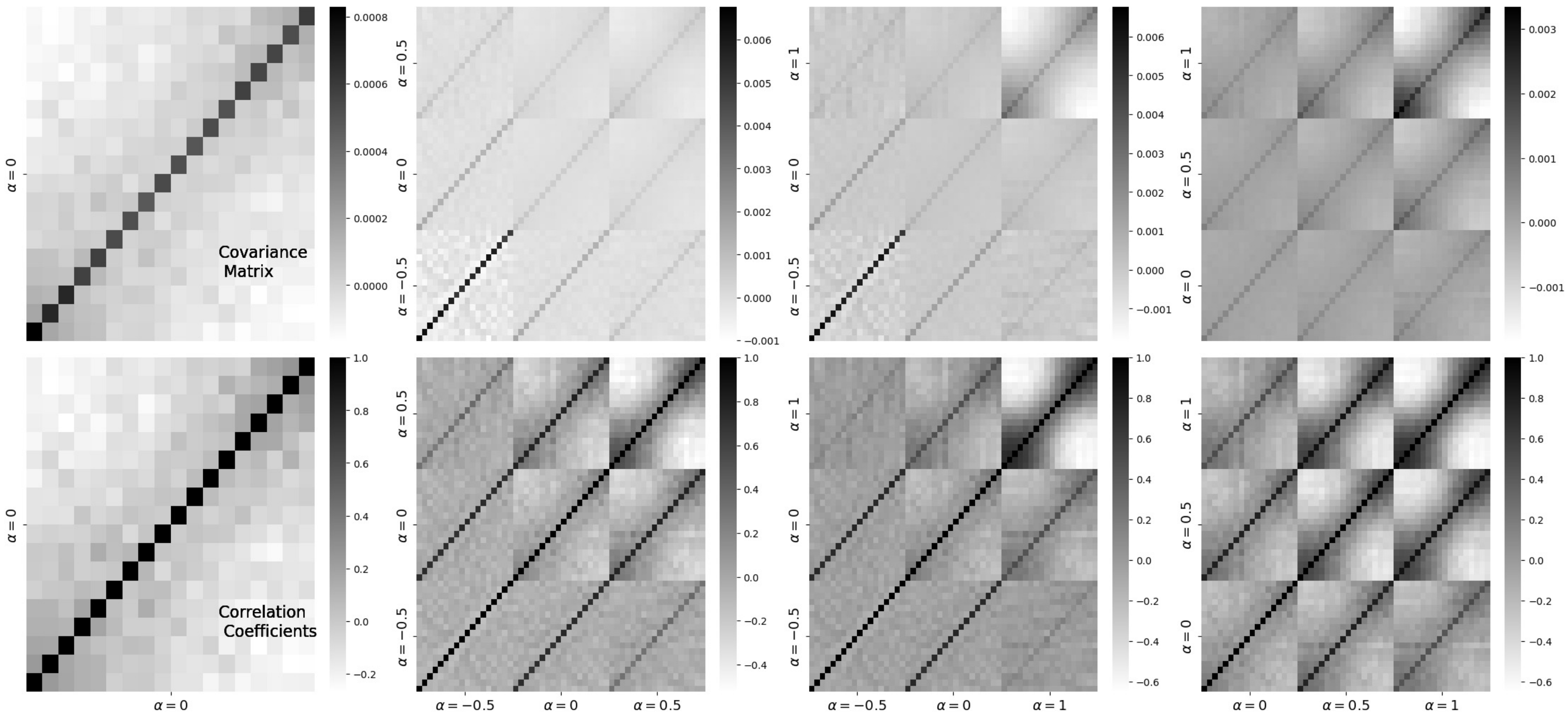
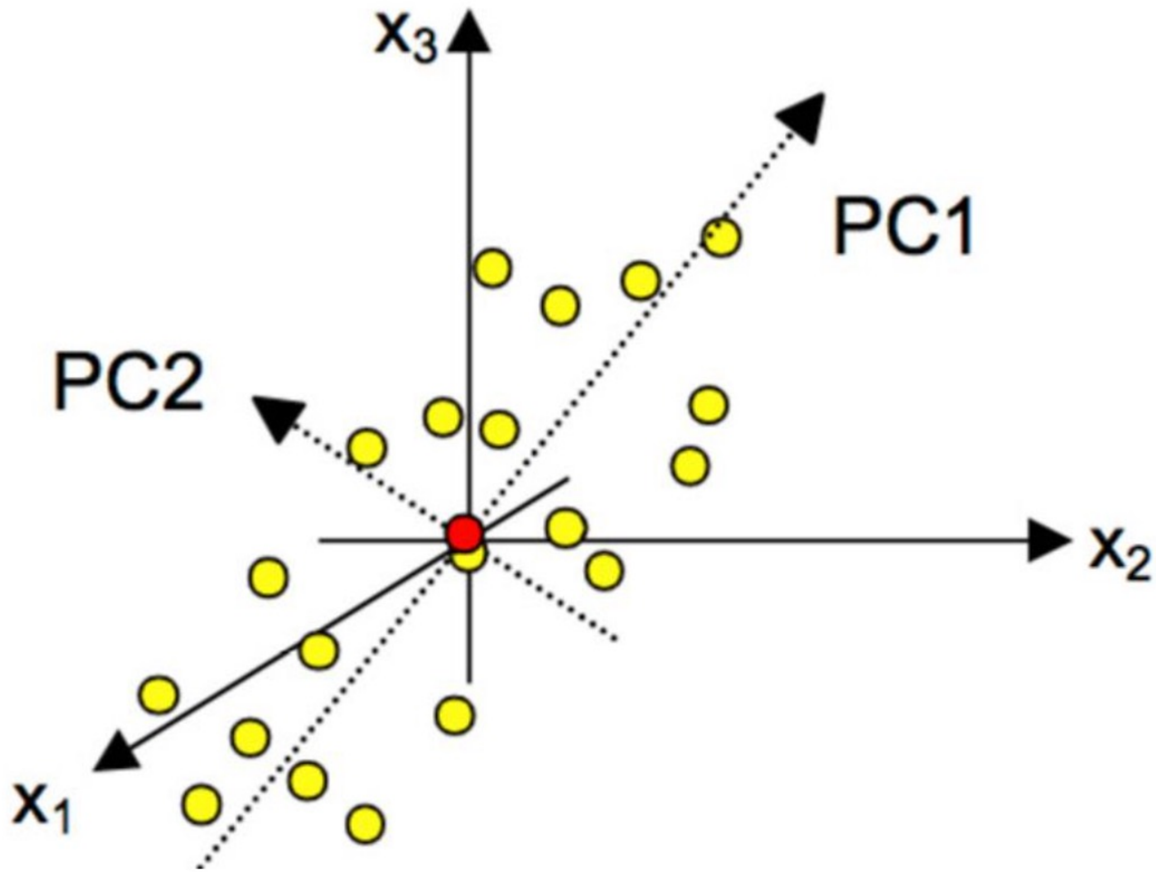
Marked CFs are much more powerful!

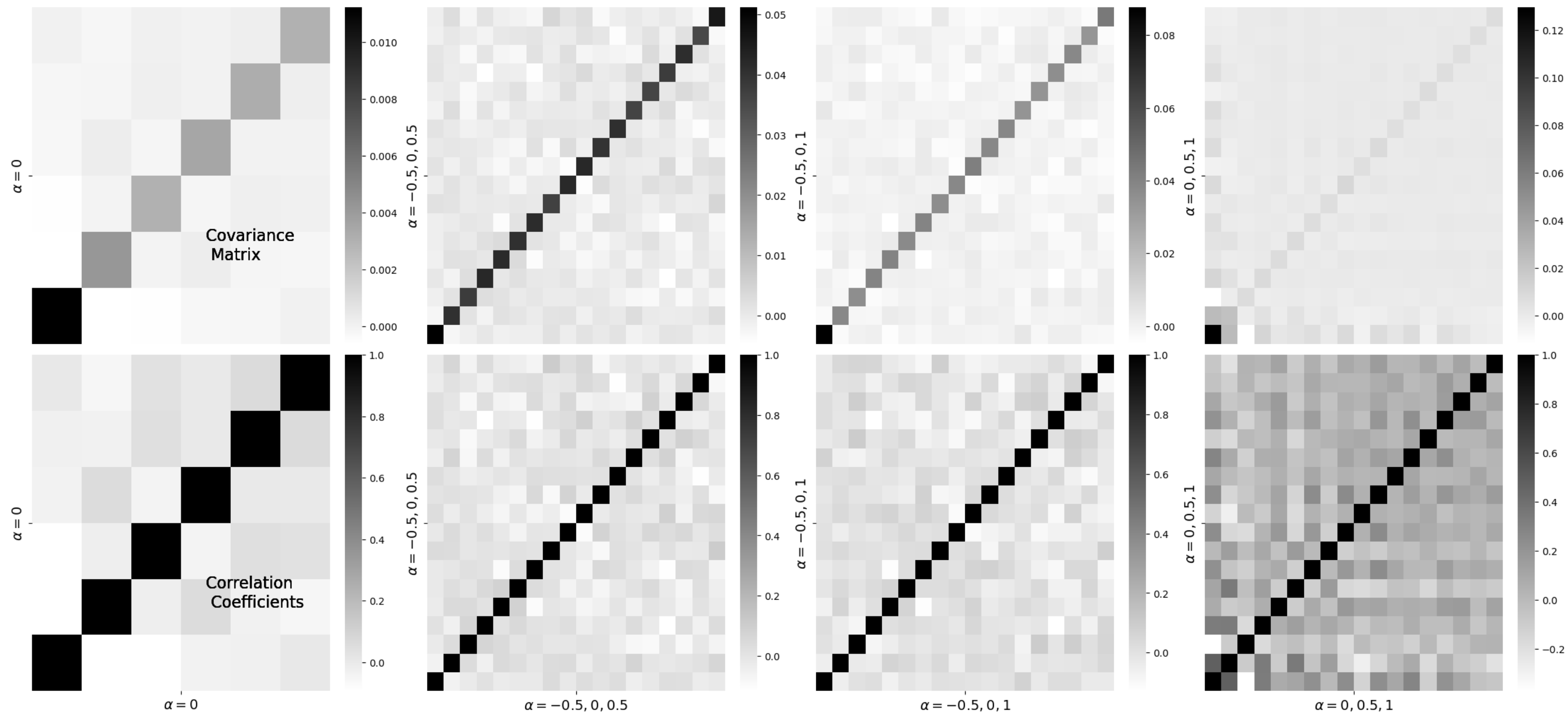
Problem: Too Large Covariance Matrix



Solution: Using PCA Compression!



Covariance after PCA



Cosmological Constraints

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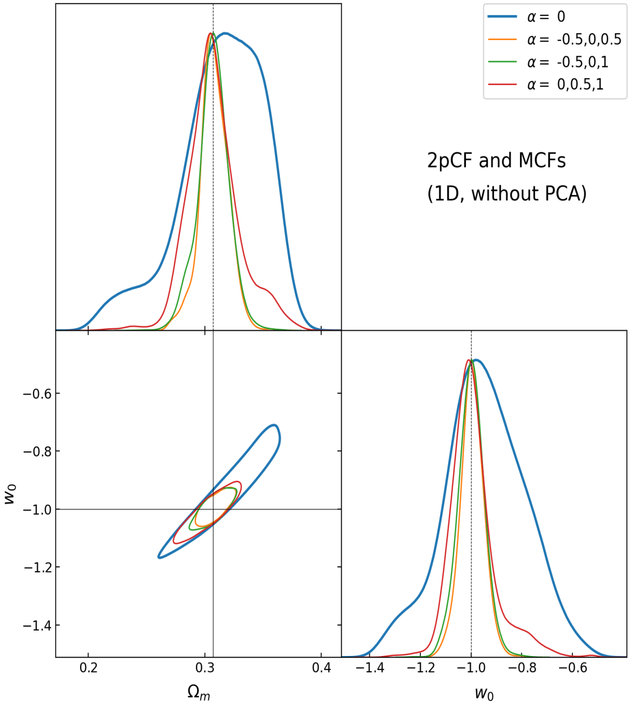

1D, w.o. PCA:

MCFs much better than 2pCF

Cosmological Constraints

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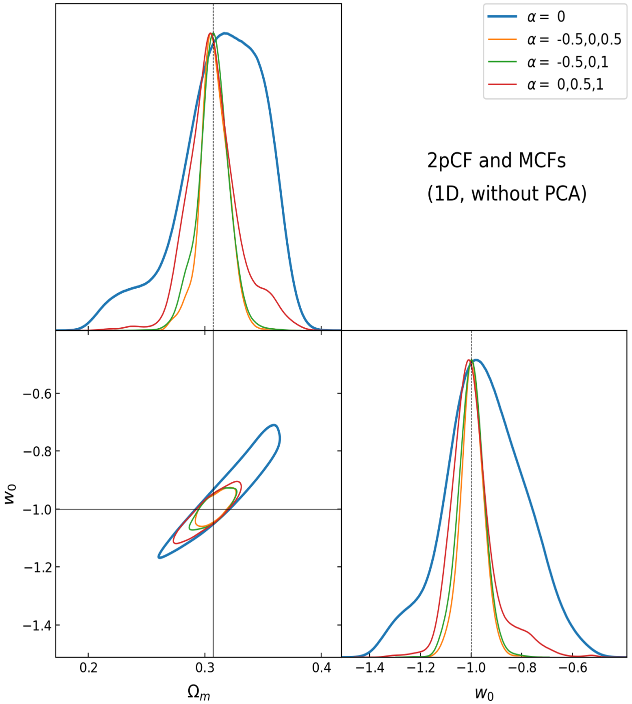
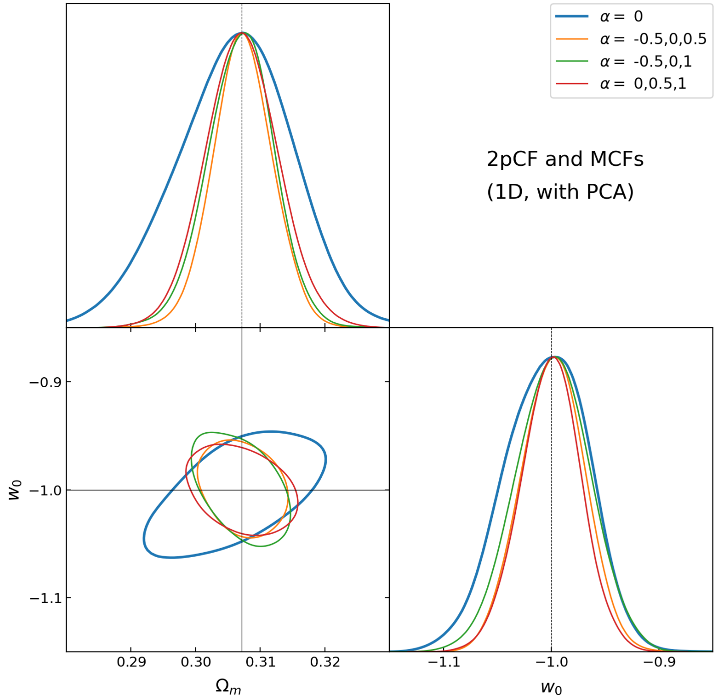




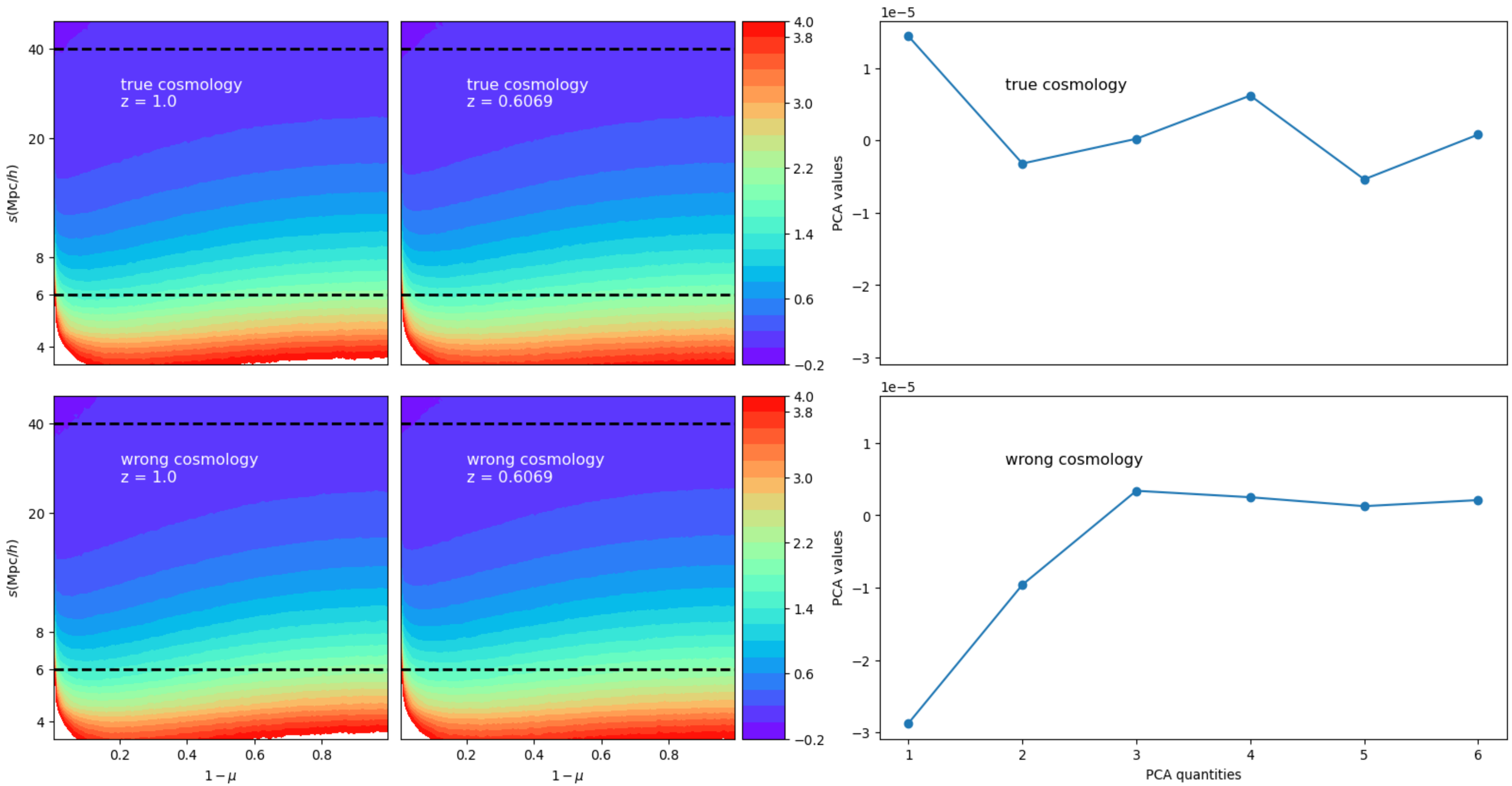
1D, w.o. PCA:

MCFs much better than 2pCF

1D, with PCA:

not only easier but also tighter

Going futher more: PCA of 2-D ξ(s,μ)



Cosmological Constraints

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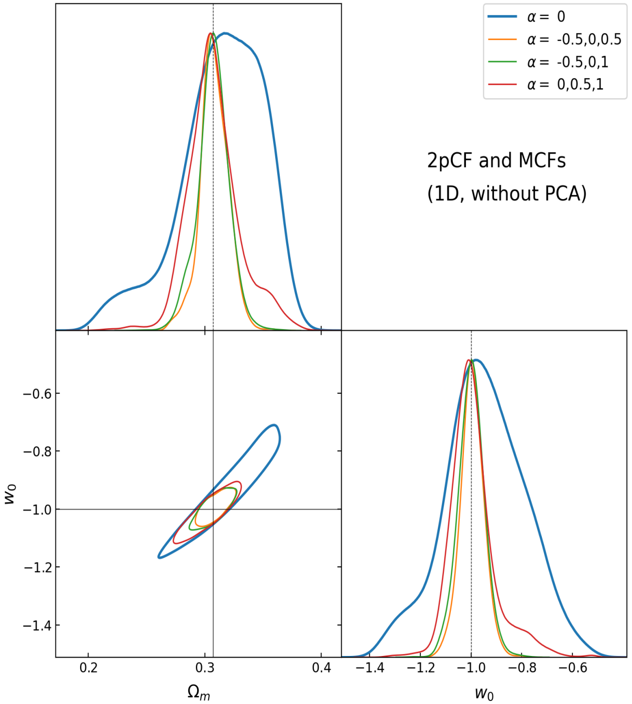
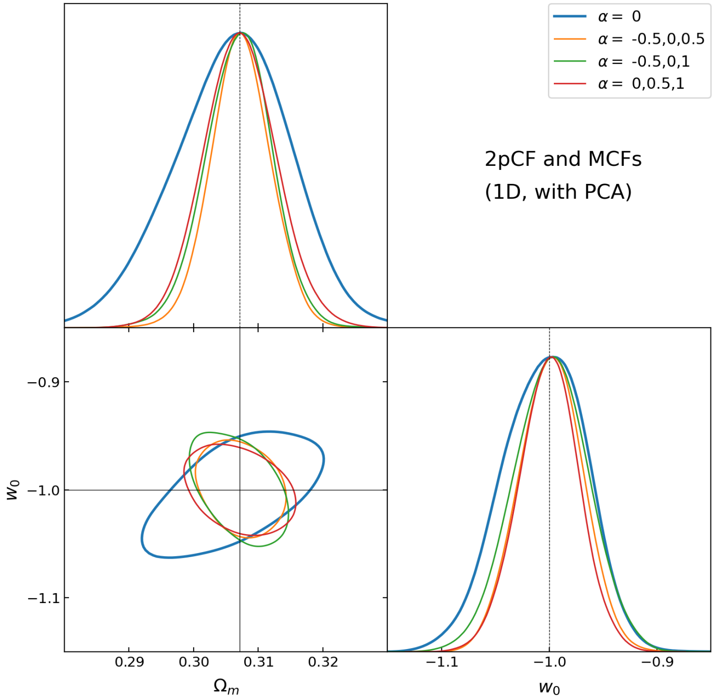
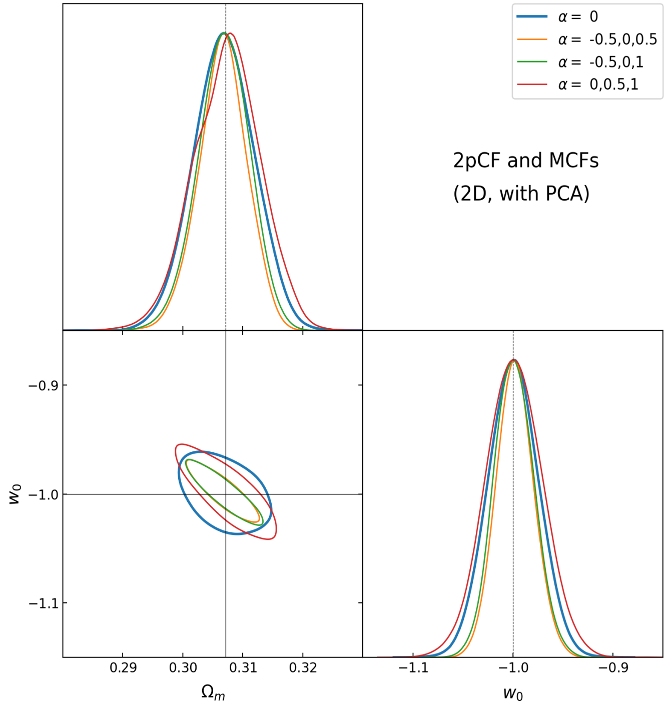






1D, w.o. PCA:

MCFs much better than 2pCF

1D, with PCA:

not only easier but also tighter

2D xi(s,mu):

even more tighter constraints!

Outline

Liang Xiao

Sun Yat-Sen Univ.

1. Beyond 2-point statistics

2. Covariance estimation

3. **Systematics from Redshift Errors**

Distortion from redshift error

$$\sigma_z = \sigma(1+z)^{\alpha}$$

For CSST (Gong et al. 2019),

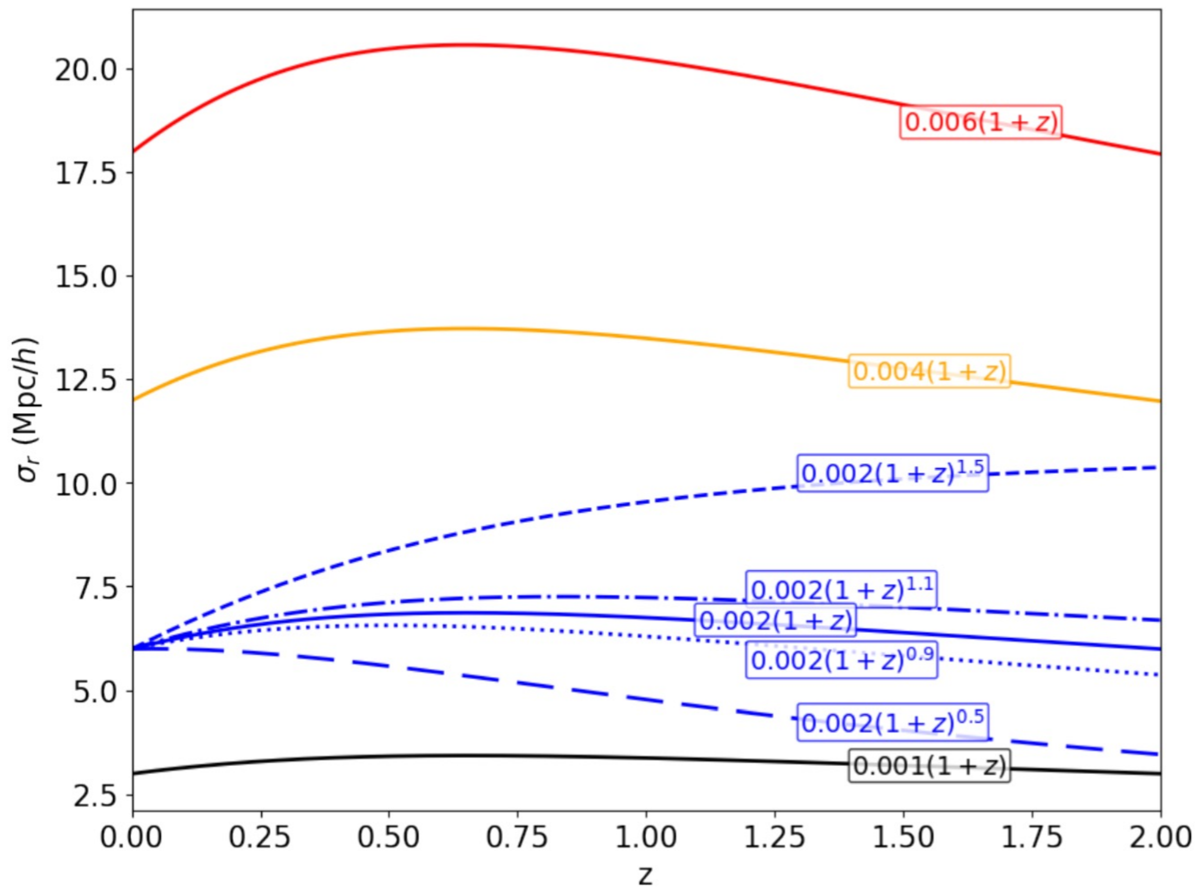
$\sigma_z \sim 0.002(1+z)$

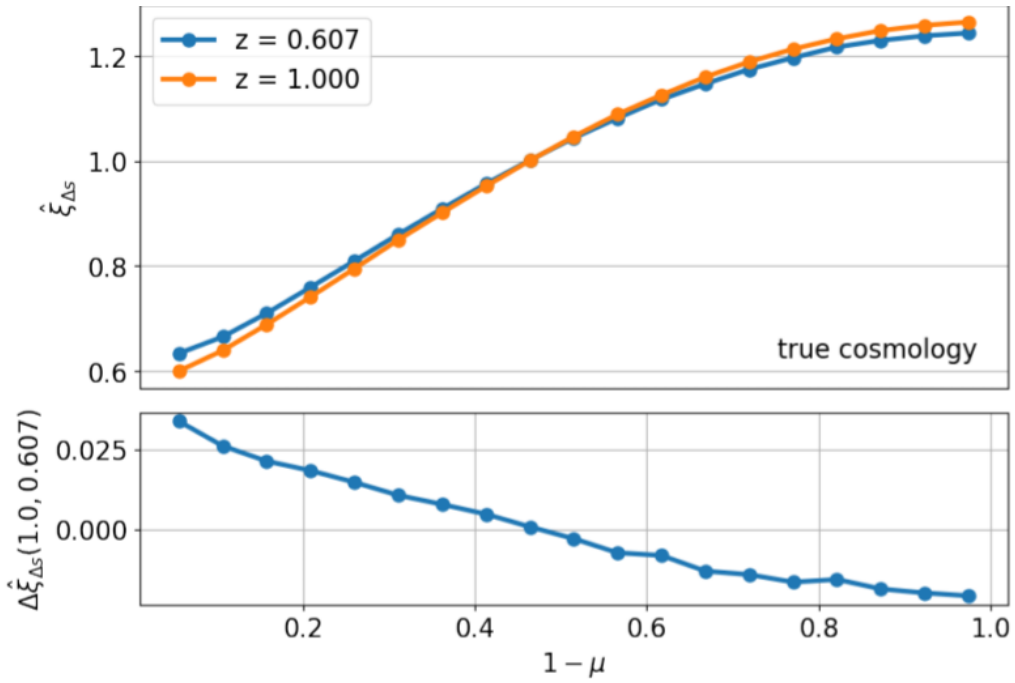
We choose

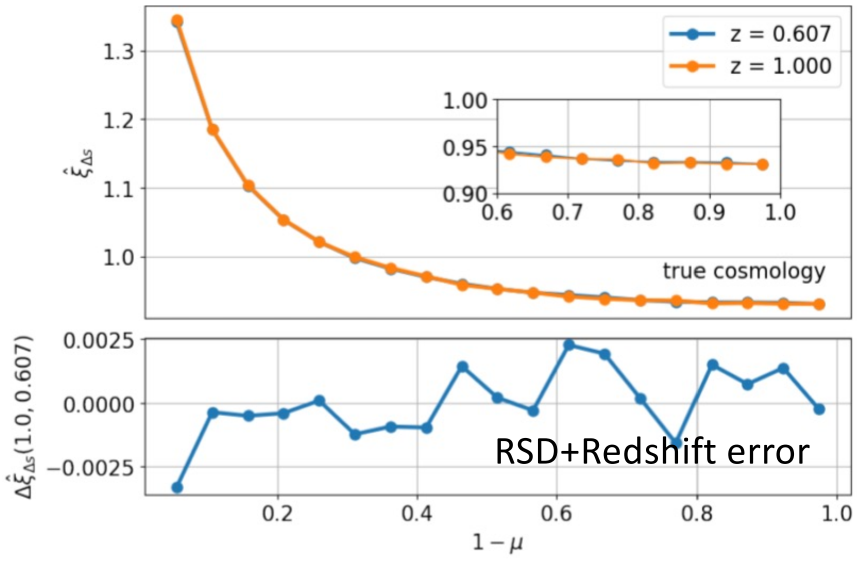
$\sigma = 0.001, 0.002, 0.004, 0.006$

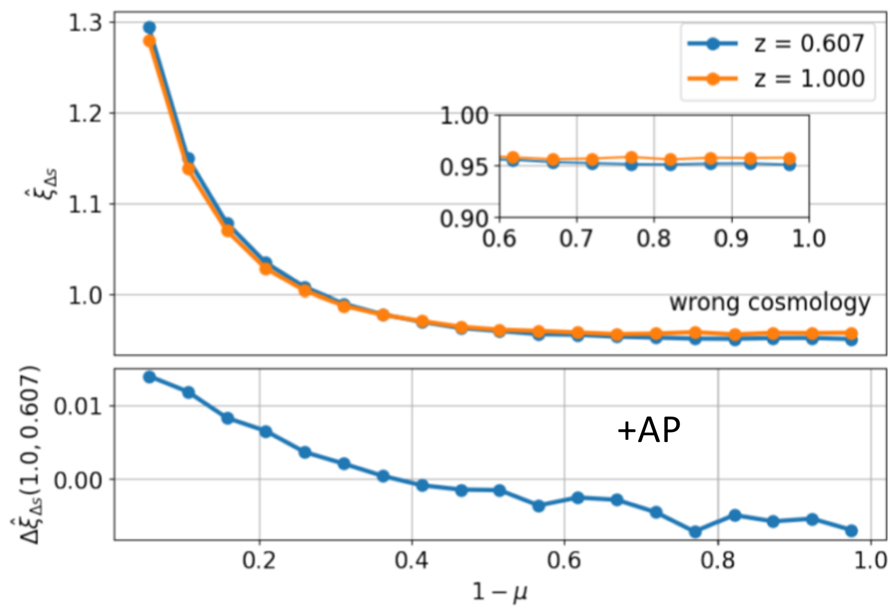
$\alpha = 0.50, 0.90, 1.0, 1.10, 1.50,$

Xiao, Li, et al. 2023, MNRAS



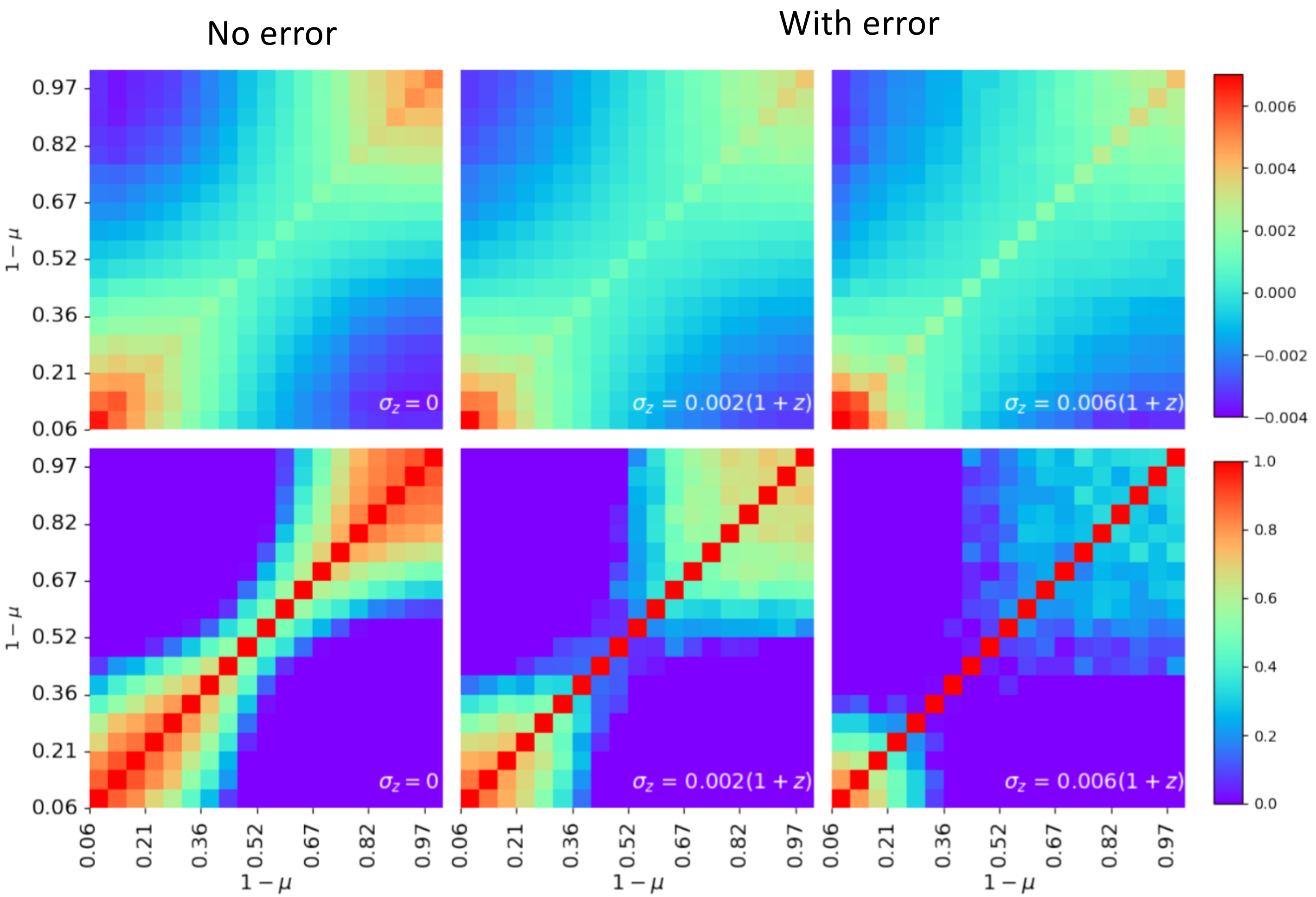






The systematic bias

Effects on covariance matrix

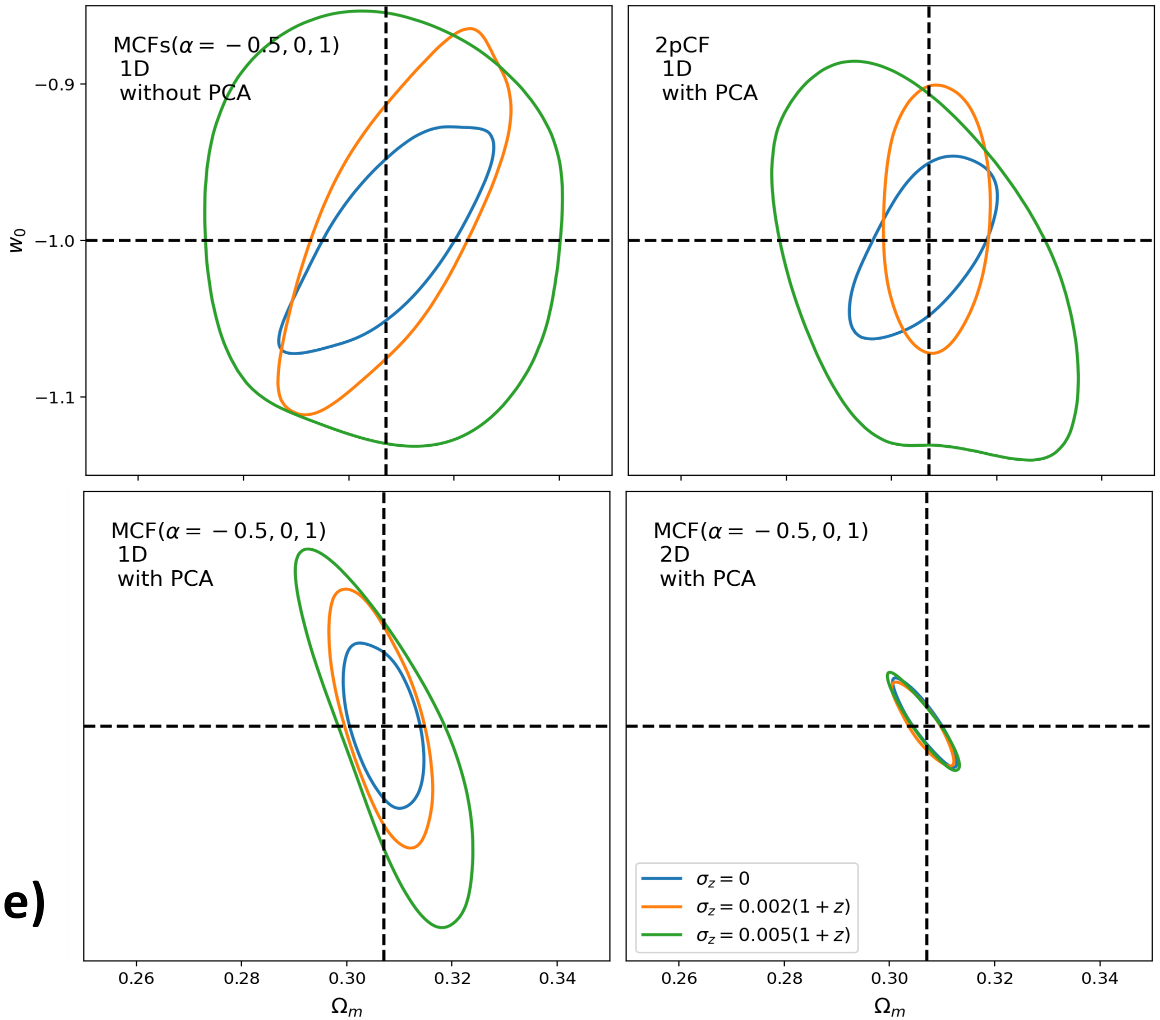


Effects on Results

0.002*(1+z): 30% weaker **(OK)**

0.005*(1+z): ~100% weaker **(possible)**

2D results are less affected
(need check)



Conclusion and Future

Conclusion

- Combining different marked CF can greatly improve constraining power

- PCA is very helpful! (for covariance estimation & improving power & enable 2-D analysis!)

- Robust against simple forms of redshift errors (need more test)
  - More realistic redshift errors; more systematics

- **Cosmological Dependence of RSD (arXiv: 1904.05503, emulator)**

Thank you for listening