LSS Survey Cosmology

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David H. Weinberg (OSU), Donald P. Schneider (Penn State),

Yuting Wang, Gong-bo Zhao (NAOC), …

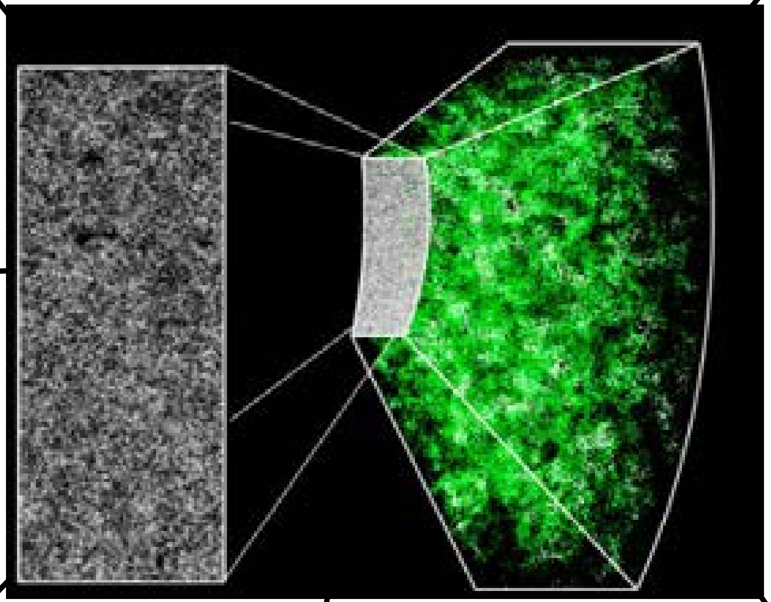
April 28, 2019 @ CCNU, WuHan

Large-scale Structure (LSS)

Baryon acoustic oscillation

Redshift space distortion

Topology

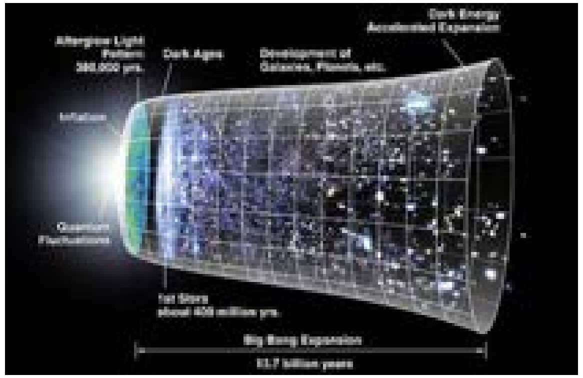


Weak lensing

Cluster abundance

Alcock-Paczynski test

Expansion history



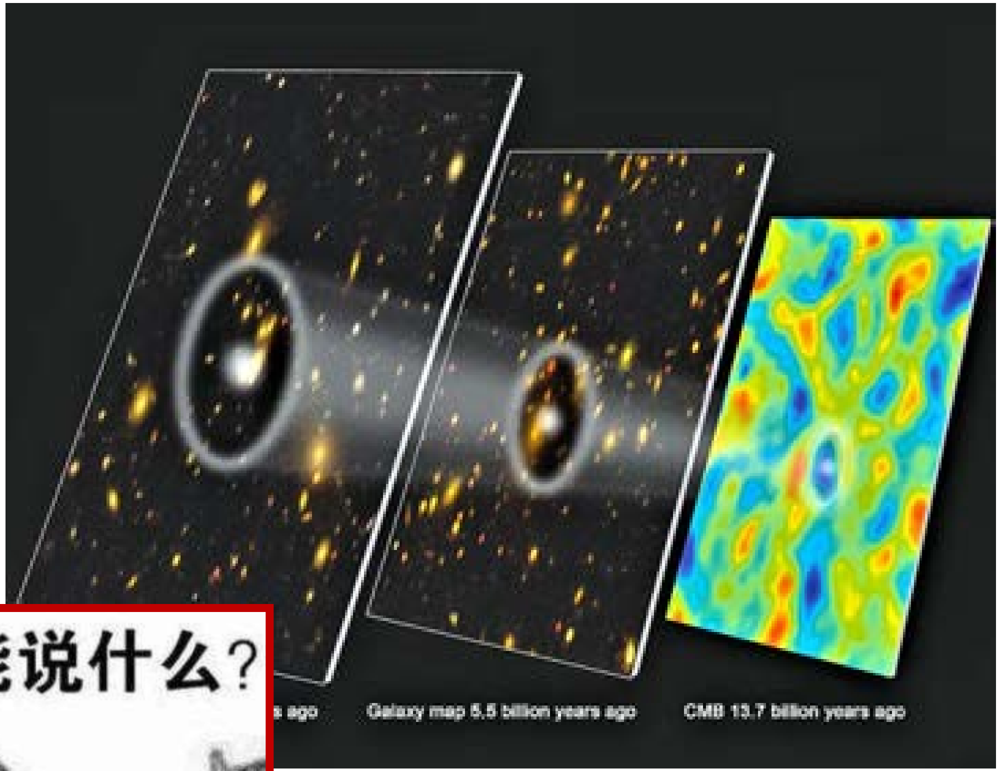
Growth of structure

Why new methods?

80% LSS people mainly working on BAO

80% cosmology people ONLY use BAO

Far from exploring everything!

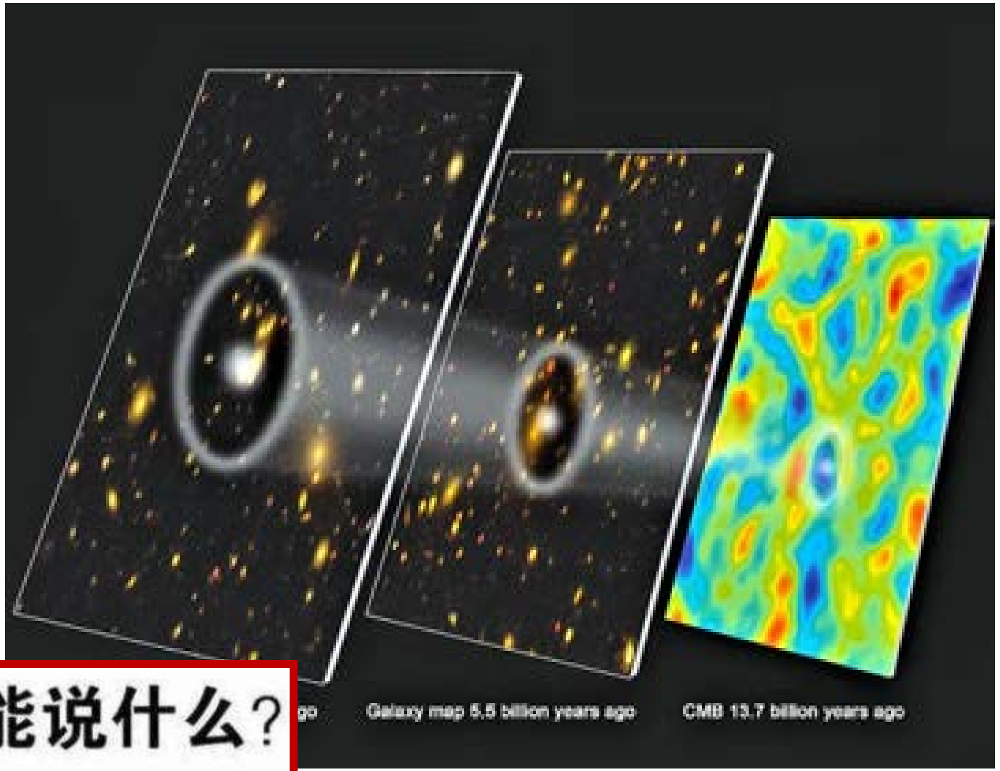


My work: designing new methods

BAO only probes ~100Mpc/h

A lot of information on non-linear scales

But still 80% people only using BAO...



Far from exploring everything!

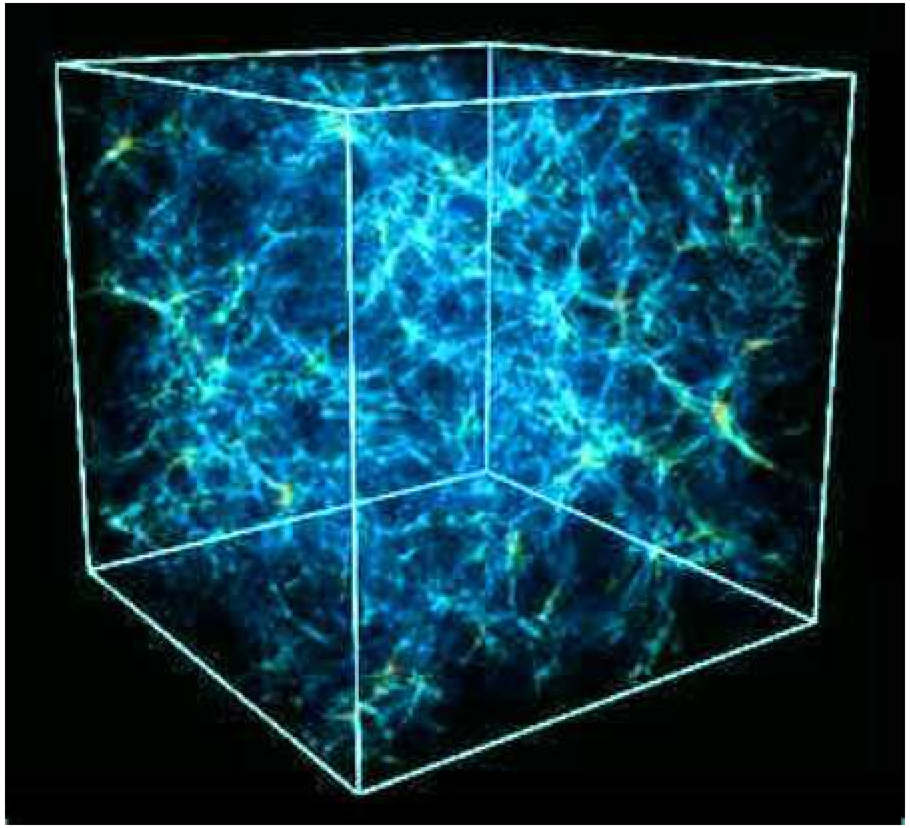
Outline

AP Test

Volume Effect

β-skeleton

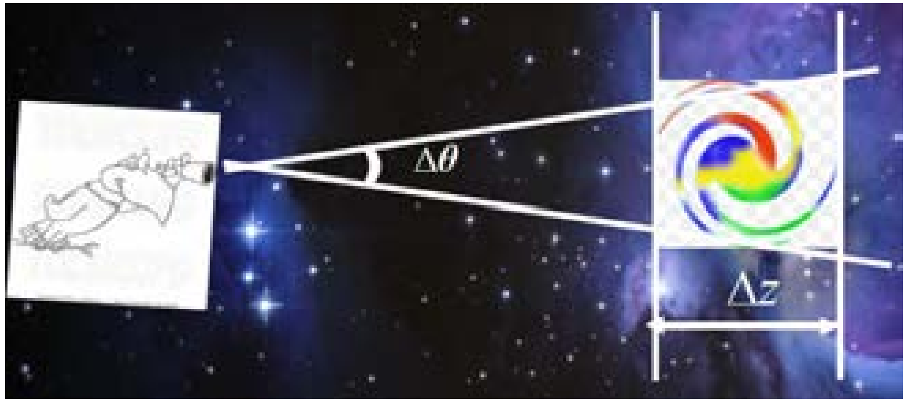
Machine learning



I. Tomographic AP Test

The Alcock-Paczynski test

Alcock & Paczynski, Nature, 1979



We need cosmology to calculate 3d shape

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

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

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

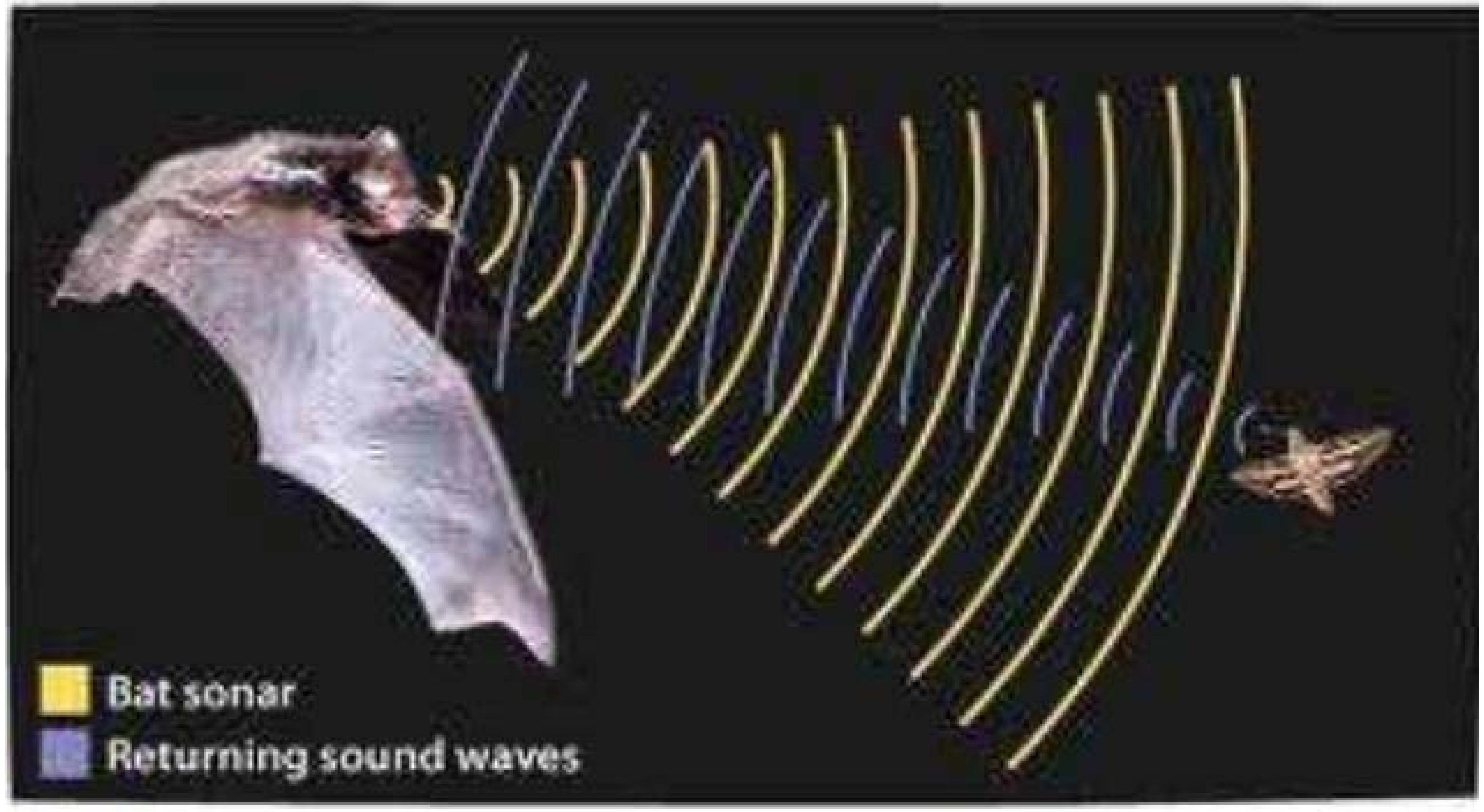
$$D_A(z) = \frac{c}{1+z} r(z) = \frac{c}{1+z}\int_0^z \frac{dz'}{H(z')}$$

In case of using wrong cosmology....

Shape distortion from the wrong H, D_A :

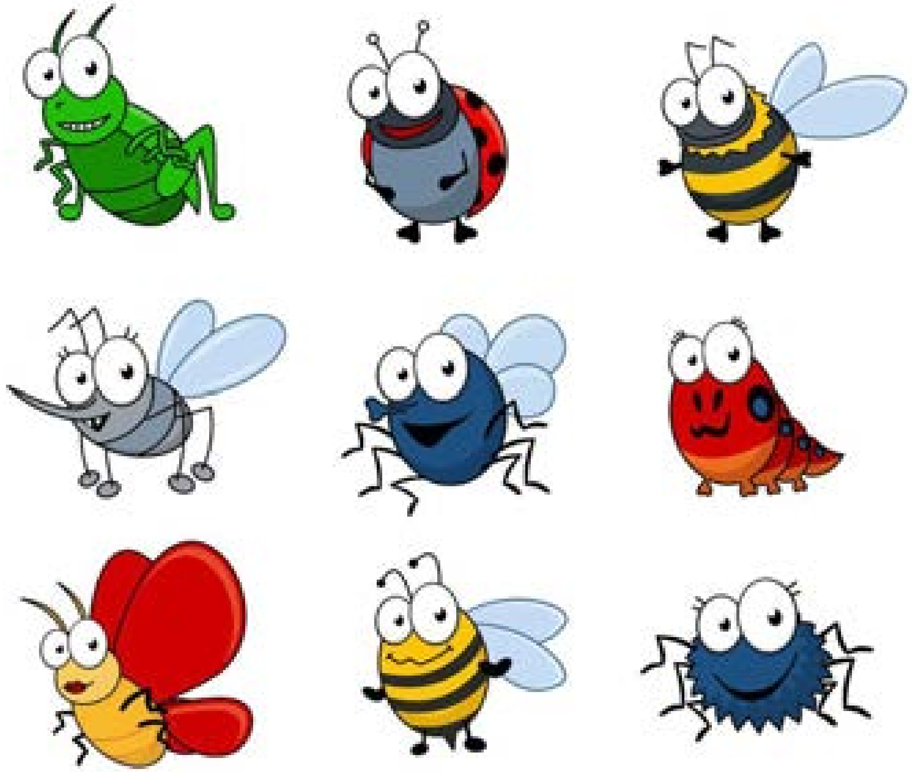
......


Q: How can we find isotropic objects in the Universe?
A: Galaxy distribution statistics!
Credit: Sloan Digital Sky Survey.



- The bat can identify an object by the sound of the echo.

The bat receives the sound, and its brain convert it into 3d positions.



What if something wrong in brain? A: Wrong distribution of bugs!

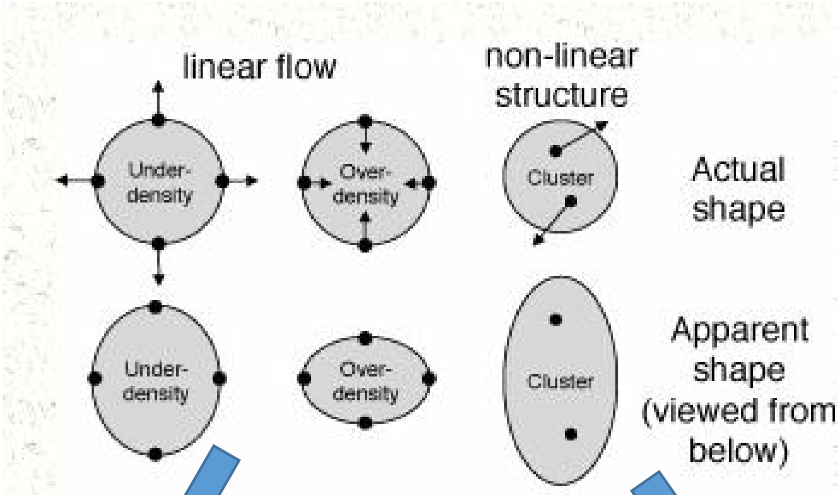
There is no problem with observables. The interpretation is wrong.

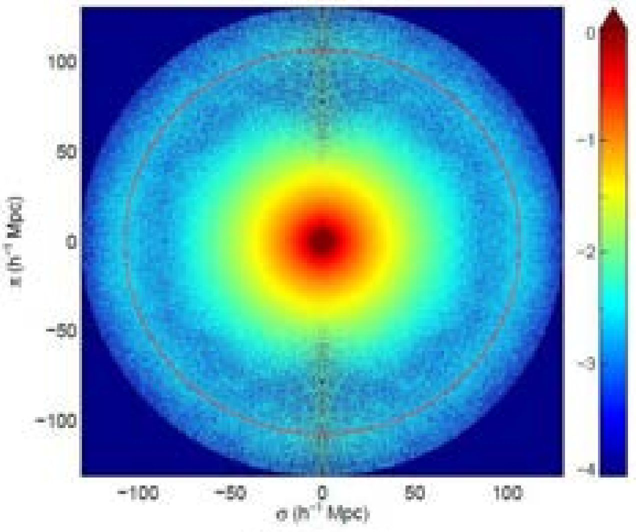
Through statistics we can find our interpretation is wrong.

Difficulty: Contamination from RSD

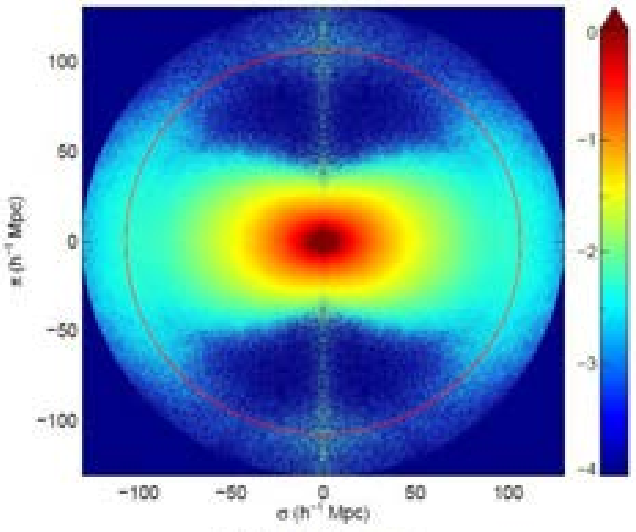
Galaxy peculiar motion produces strong anisotropy

(no good solution for many years)

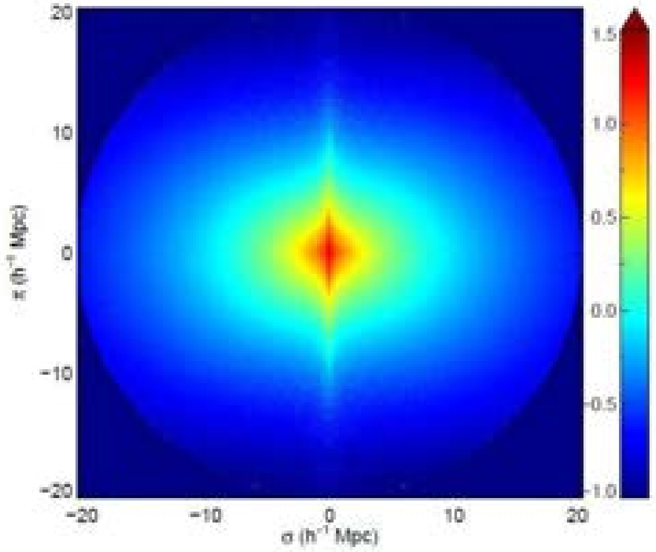




(a) real space



(b) redshift space



Redshift space distortion (RSD)

RSD produces very strong anisotropy.

RSD is usually 5-10 times larger than AP distortion.

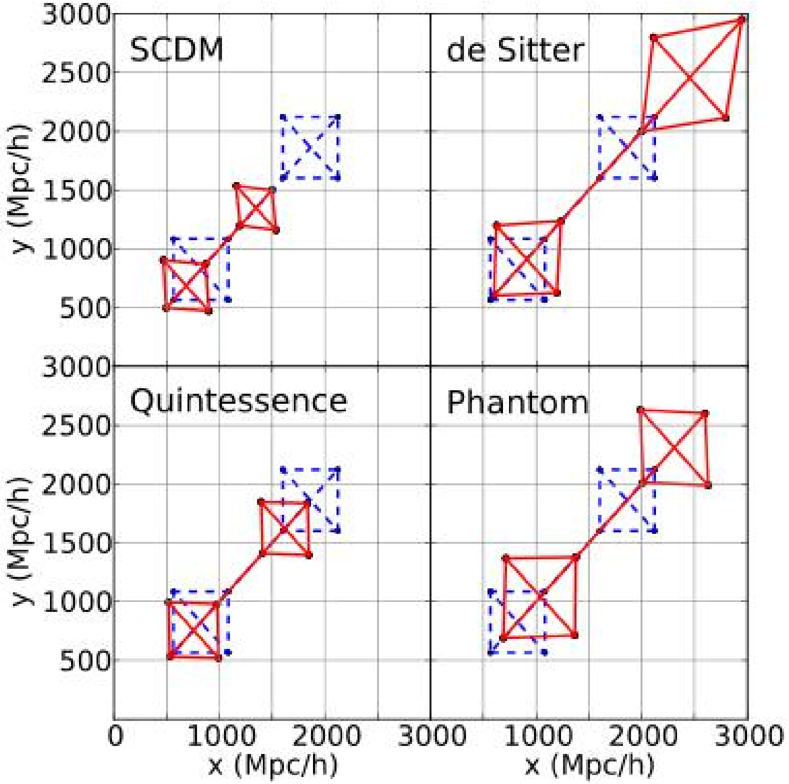
RSD is non-linear, very difficult to be modelled.

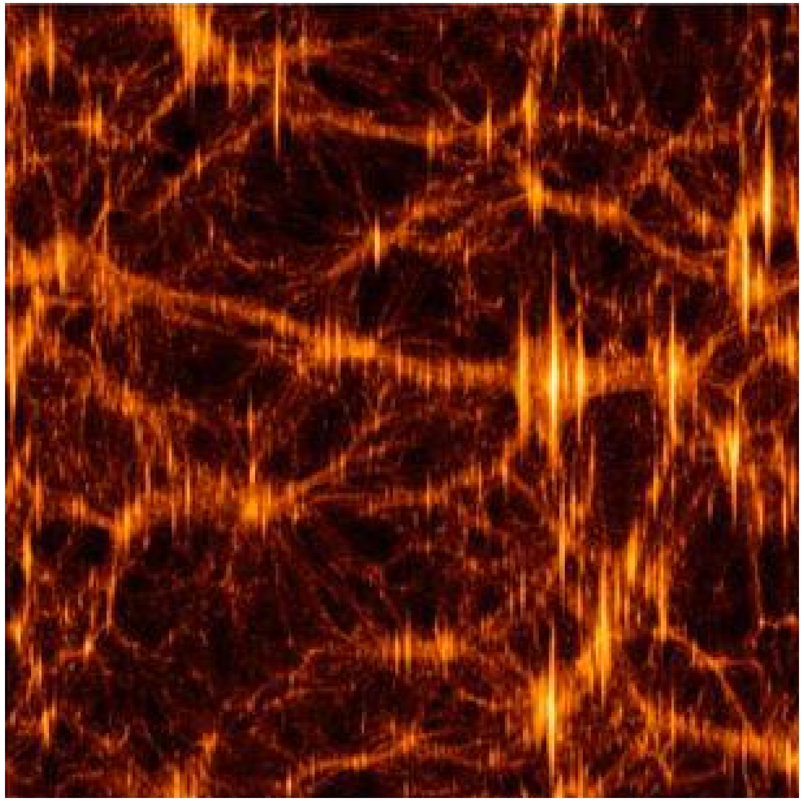
To constrain cosmology, we need to overcome the RSDs.

How to distinguish AP from RSD?

Li et al, 2014, ApJ, work with Prof. Changbom Park @ KIAS

AP observed in Ω_m=0.26 ΛCDM
Observer located at (0,0)



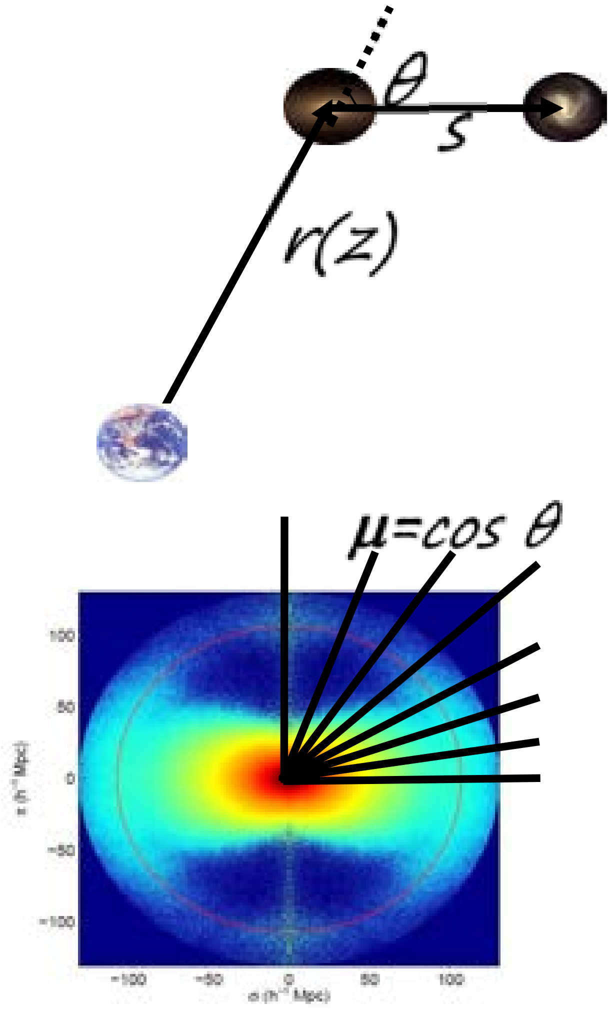


AP: significant redshift evolution

RSD: pattern ~ independent of redshift

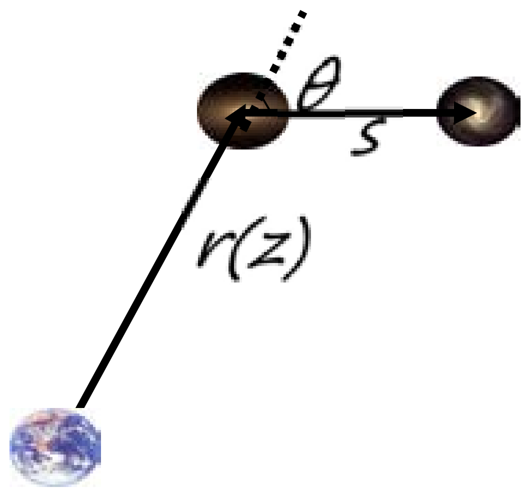
Distinguishing AP & RSD in 2pCF statistics

Li, Park, Sabiu, et al. 2015, MNRAS



Statistical Quantification via 2PCF

Li, Park, Sabiu, et al. 2015, MNRAS



μ = cos θ, describing the anisotropy

Statistical Quantification via 2PCF

Li, Park, Sabiu, et al. 2015, MNRAS

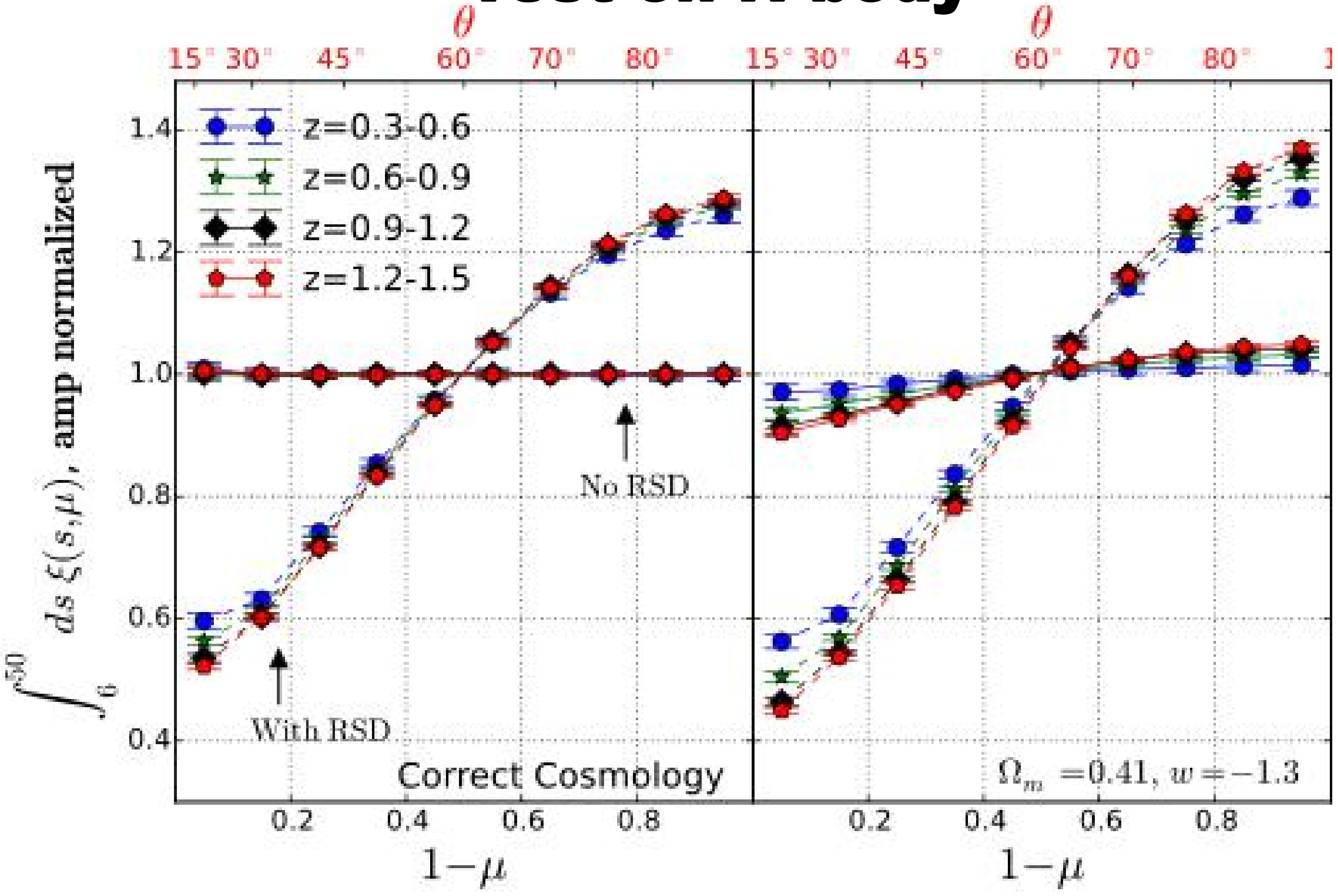
$$\xi_{\Delta s}(\mu) \equiv \int_{s_{\min}}^{s_{\max}} \xi(s,\mu)\ ds.$$

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

We choose the integration scale

6-40 Mpc/h

Test on N-body

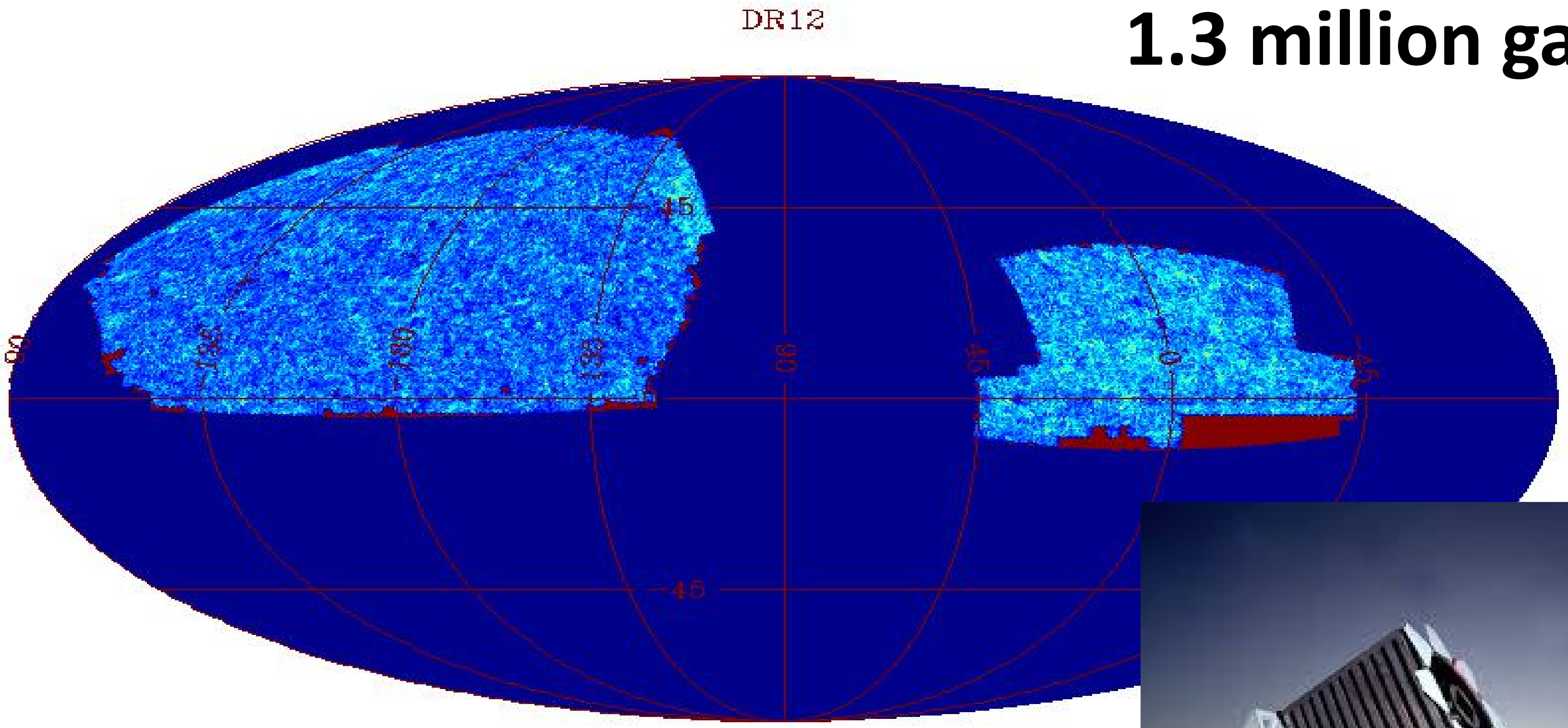


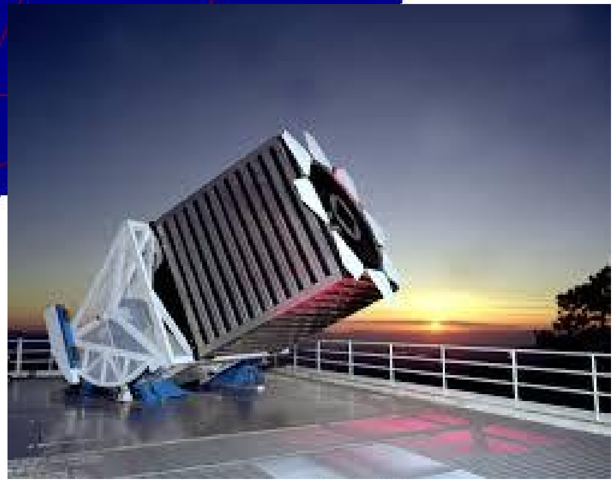
RSD is larger than AP, BUT
***redshift evolution* of RSD is smaller!**

Application to SDSS DR12

Li, Park, Sabiu, et al. 2016, ApJ

1/4 sky, z = 0.15-0.7,
1.3 million galaxies



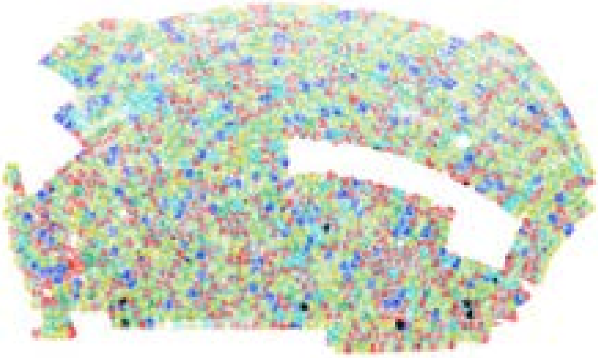


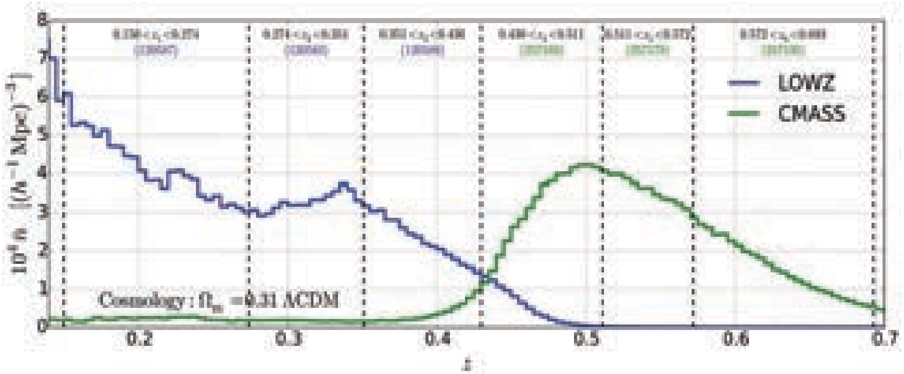
有种的咱就来真的！

Systematics

1. RSD

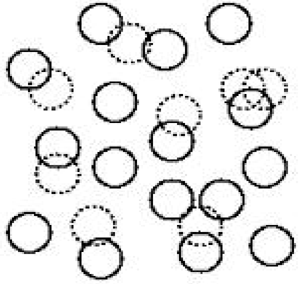
2. Galaxy bias
(affect clustering)





3. Angular variation

4. Radial variation
(incomplete LF coverage)

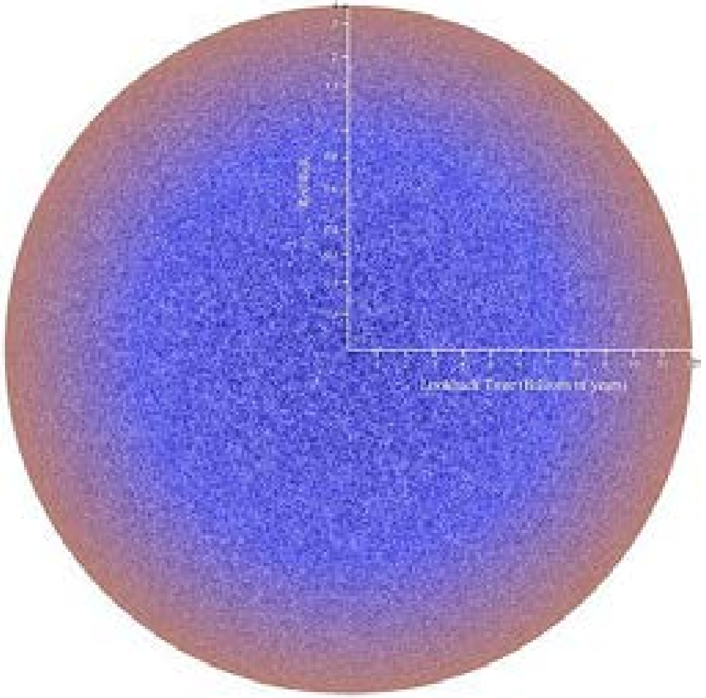


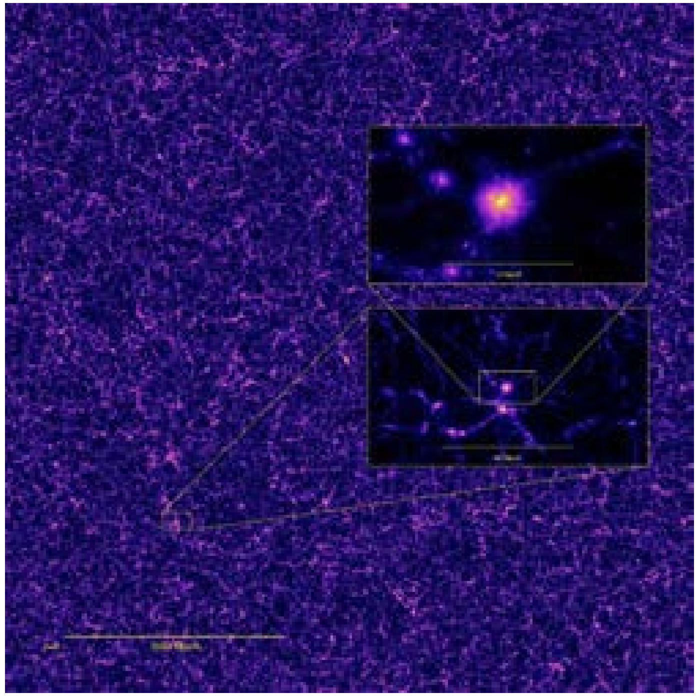
5. Fiber collision
(high-density regions under-sampled)

But, we solved them, easily:
Just create mocks to simulate everything.

同志，麻烦你共产主义一点

Correcting systematics (Horizon run N-body)





HR3 (Kim et al. 2012)

$(10.815\ h^{-1}\ \mathrm{Gpc})^3$

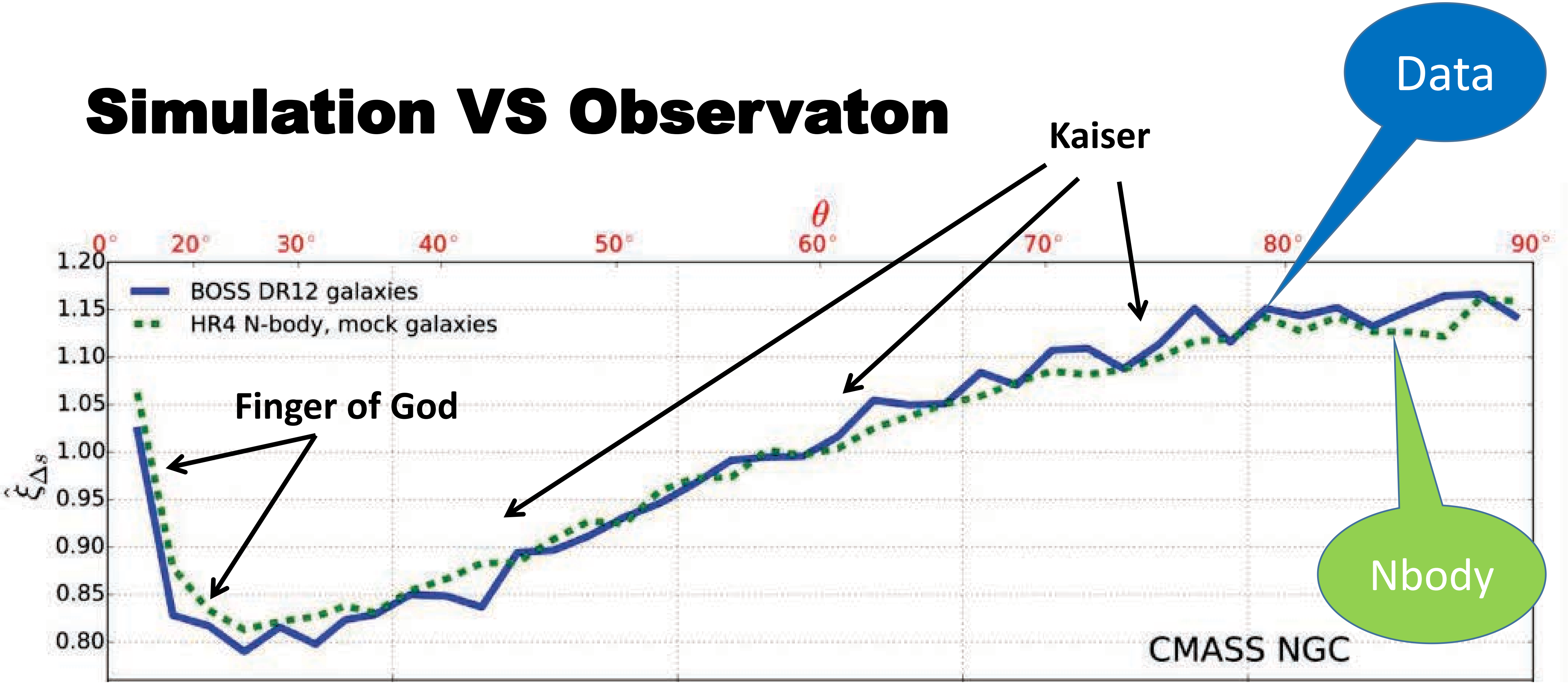
7120^3 particles

HR4 (Kim et al. 2015)

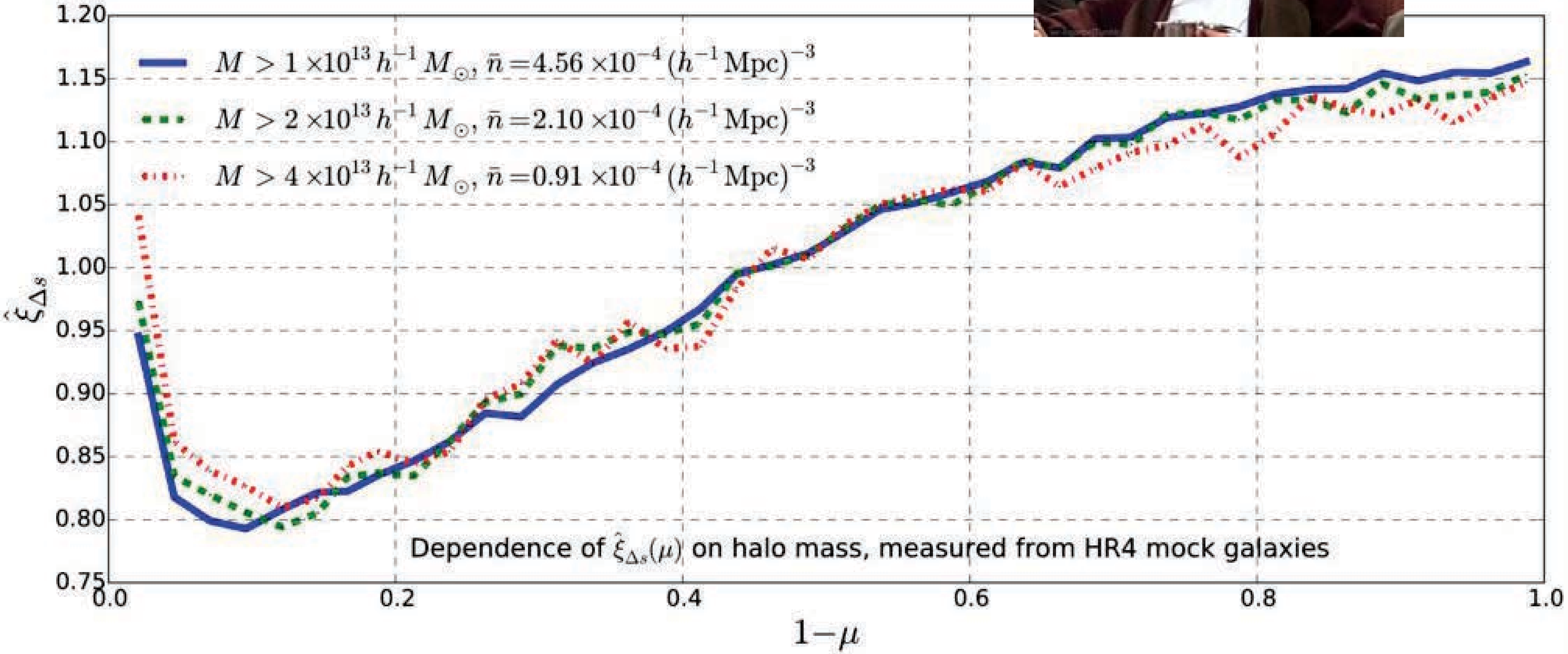
$(3.15h^{-1}\ \mathrm{Gpc})^3$

6300^3 particles

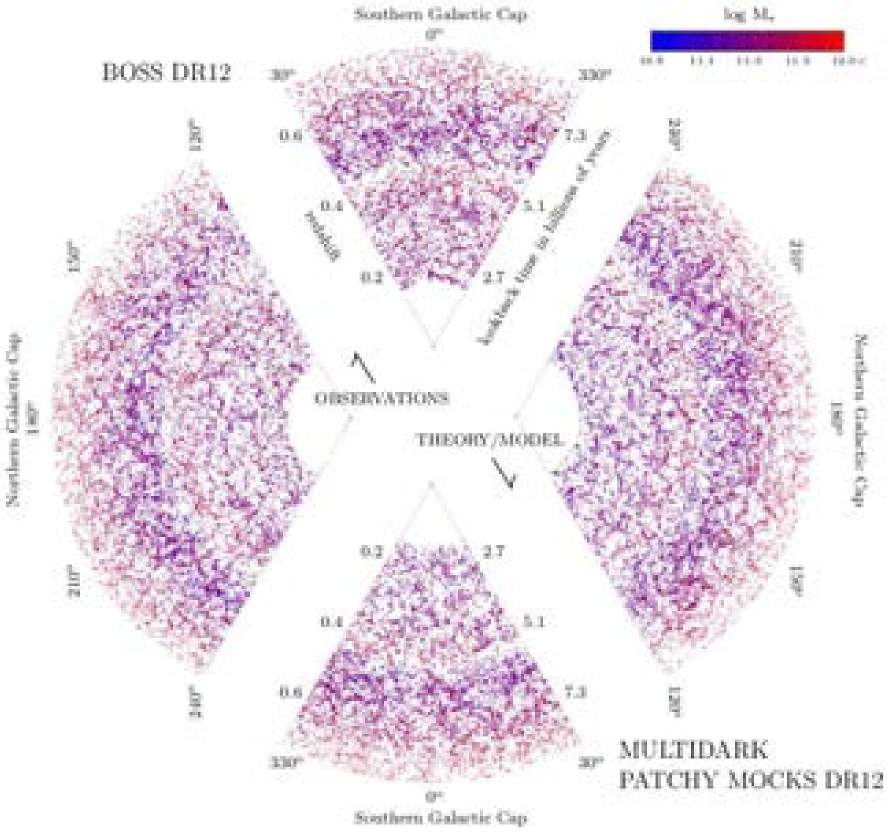
Simulation VS Observaton



Insensitive to Galaxy Bias



Covariance: MultiDark-PATCHY Mocks



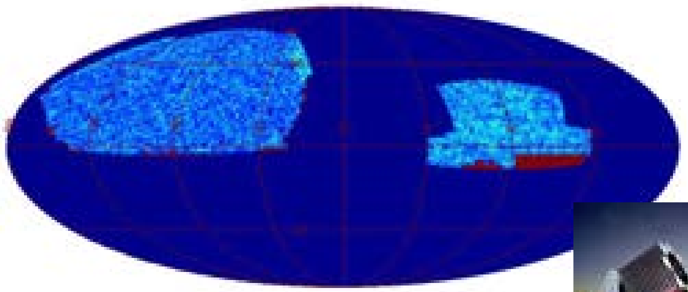
Not real N-body.

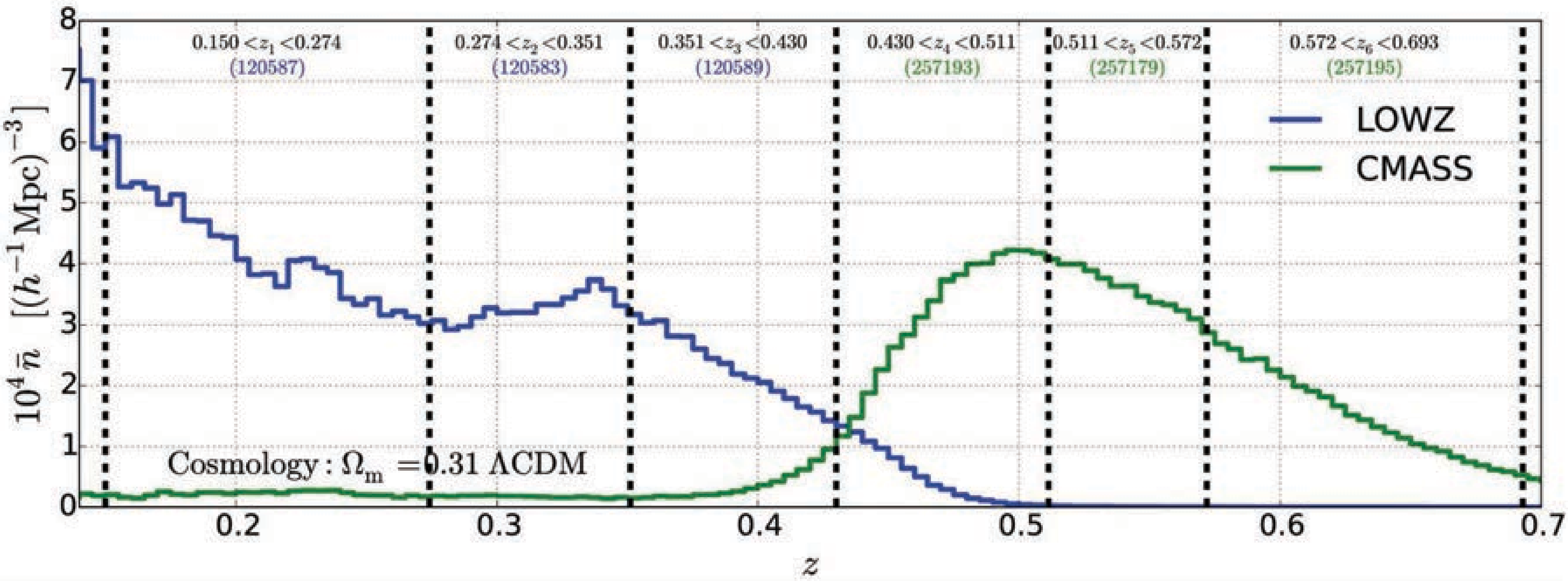
Cheap, fast.

2048 mocks → covariance matrix

Methodology: 6-bin evolution

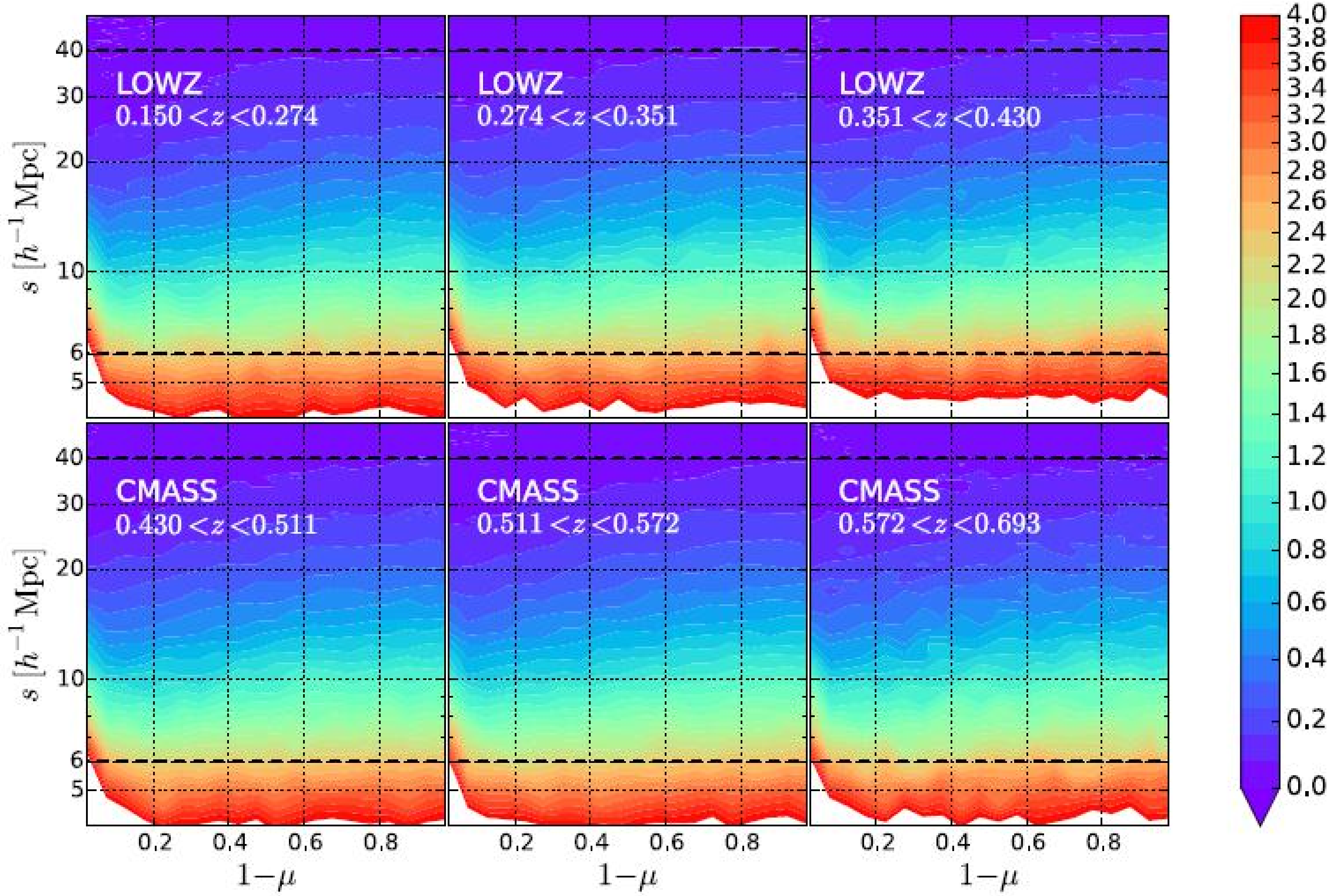
Li, Park, Sabiu, et al. 2016, ApJ

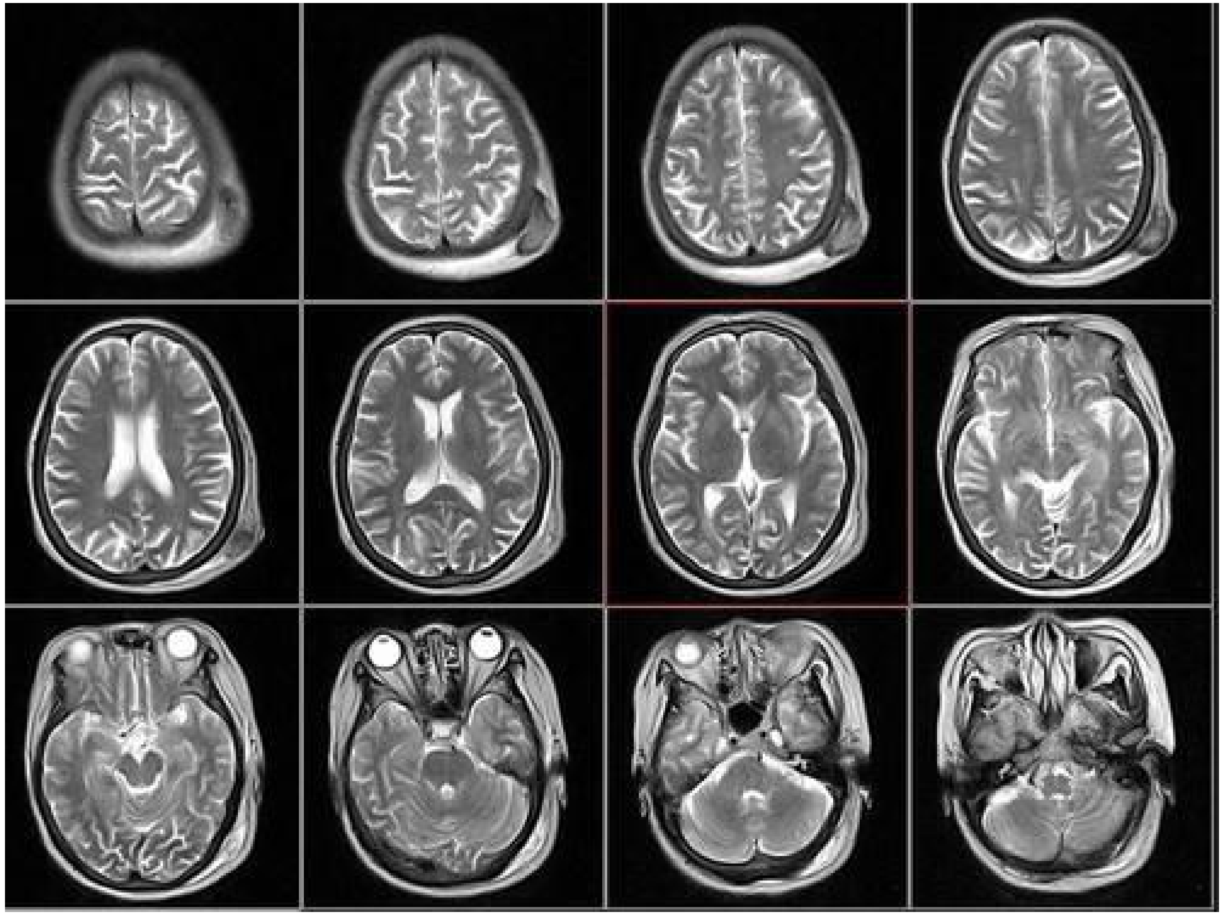




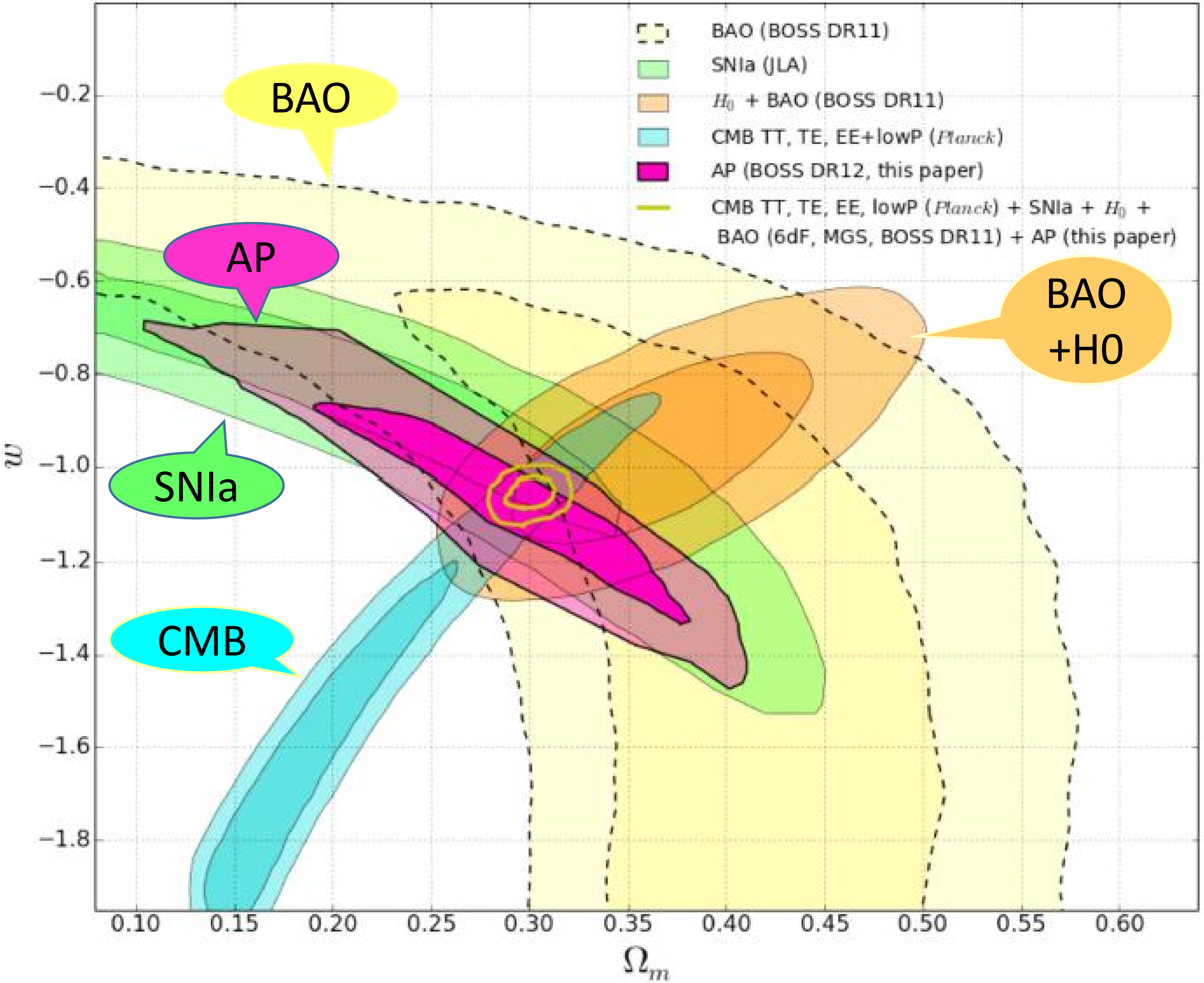
True cosmology: the one has minimal redshift evolution after systematics correction

Tomographic Analysis





Cosmological constraints from SDSS DR12



Tighter than SNIa

Consistent with everything.

Combining all:

$$\Omega_m = 0.301 \pm 0.006$$

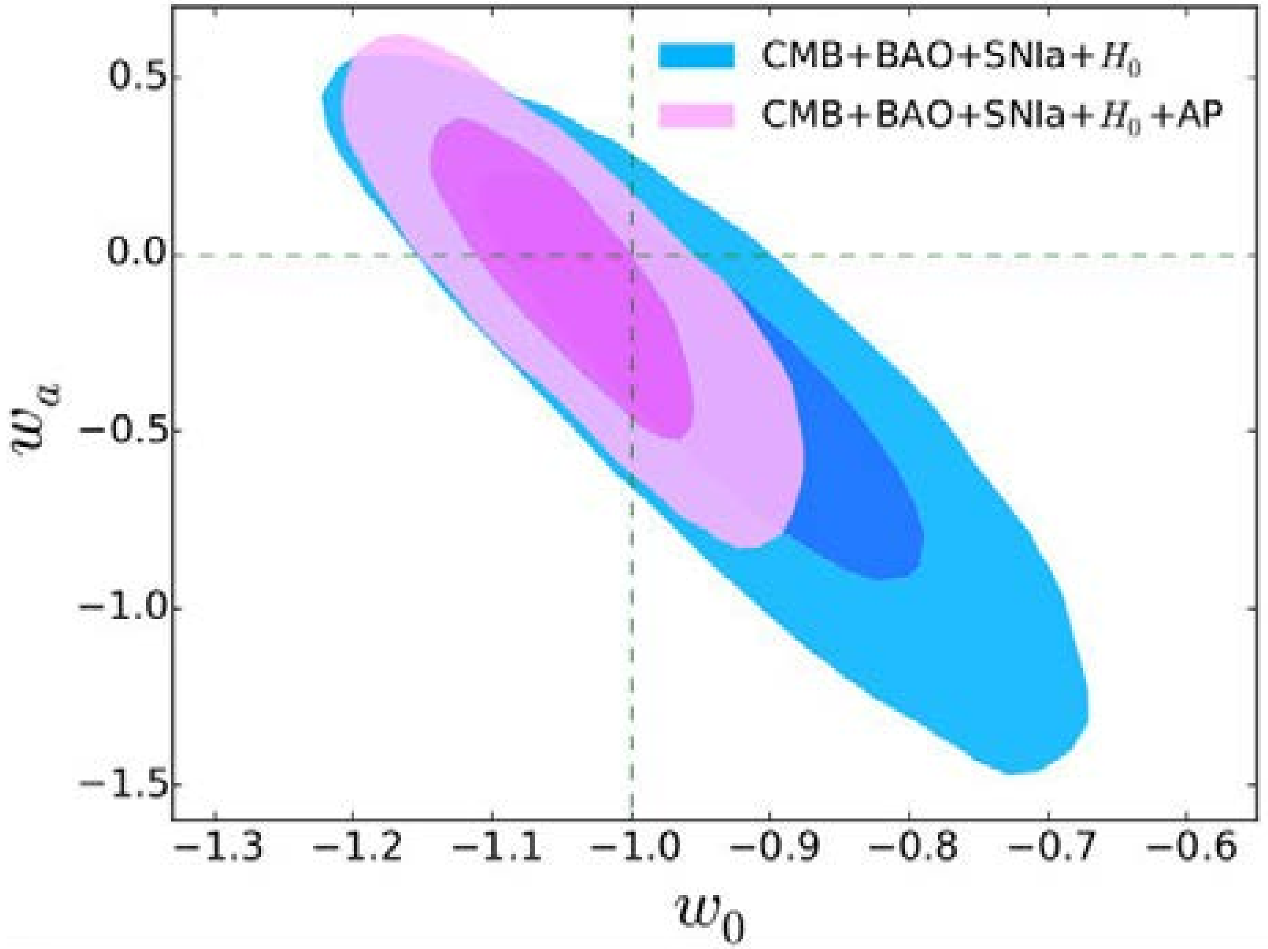
$$w = -1.054 \pm 0.025$$

AP reduces the error by

30-40% !

Dynamical dark energy

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



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

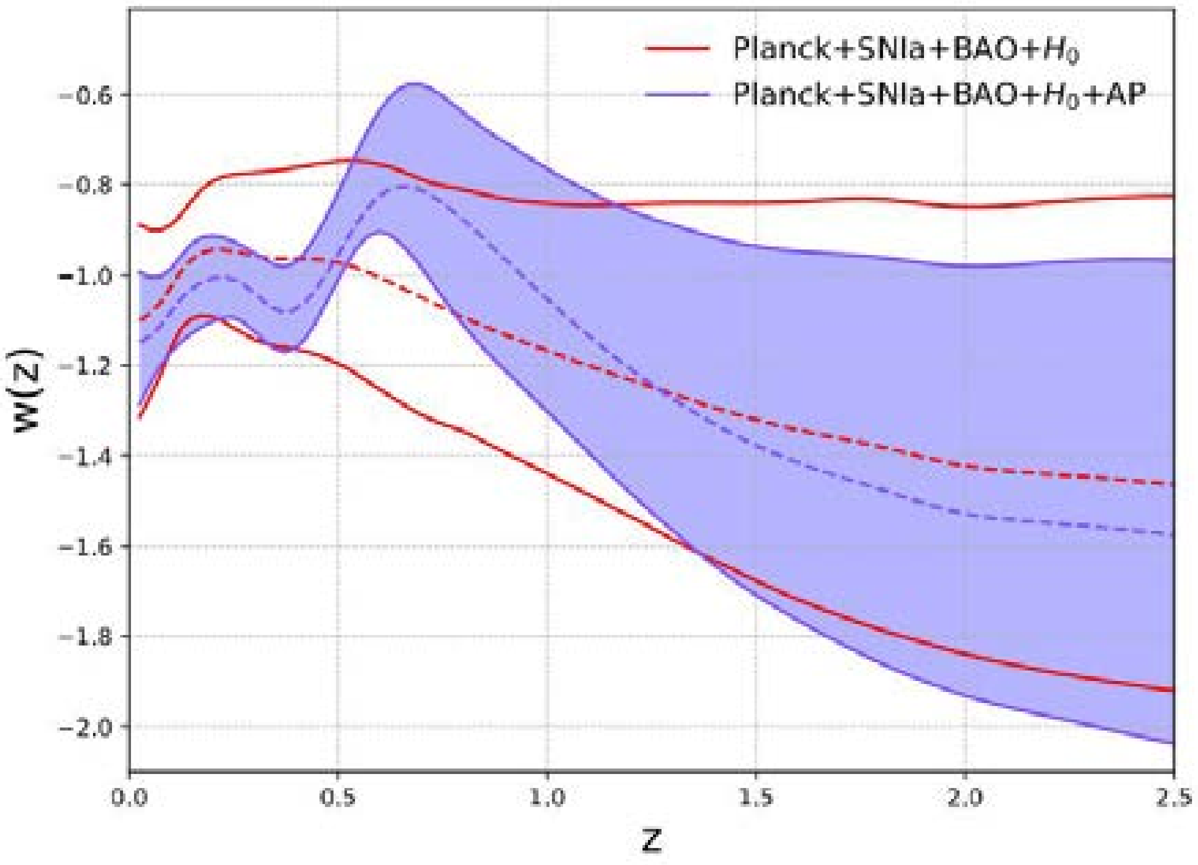
Result consistent with cc

AP reduces the contour area by

100%!

Nonparametric dark energy reconstruction

Zhang, Gu, Wang, et al. 2019, ApJ submitted



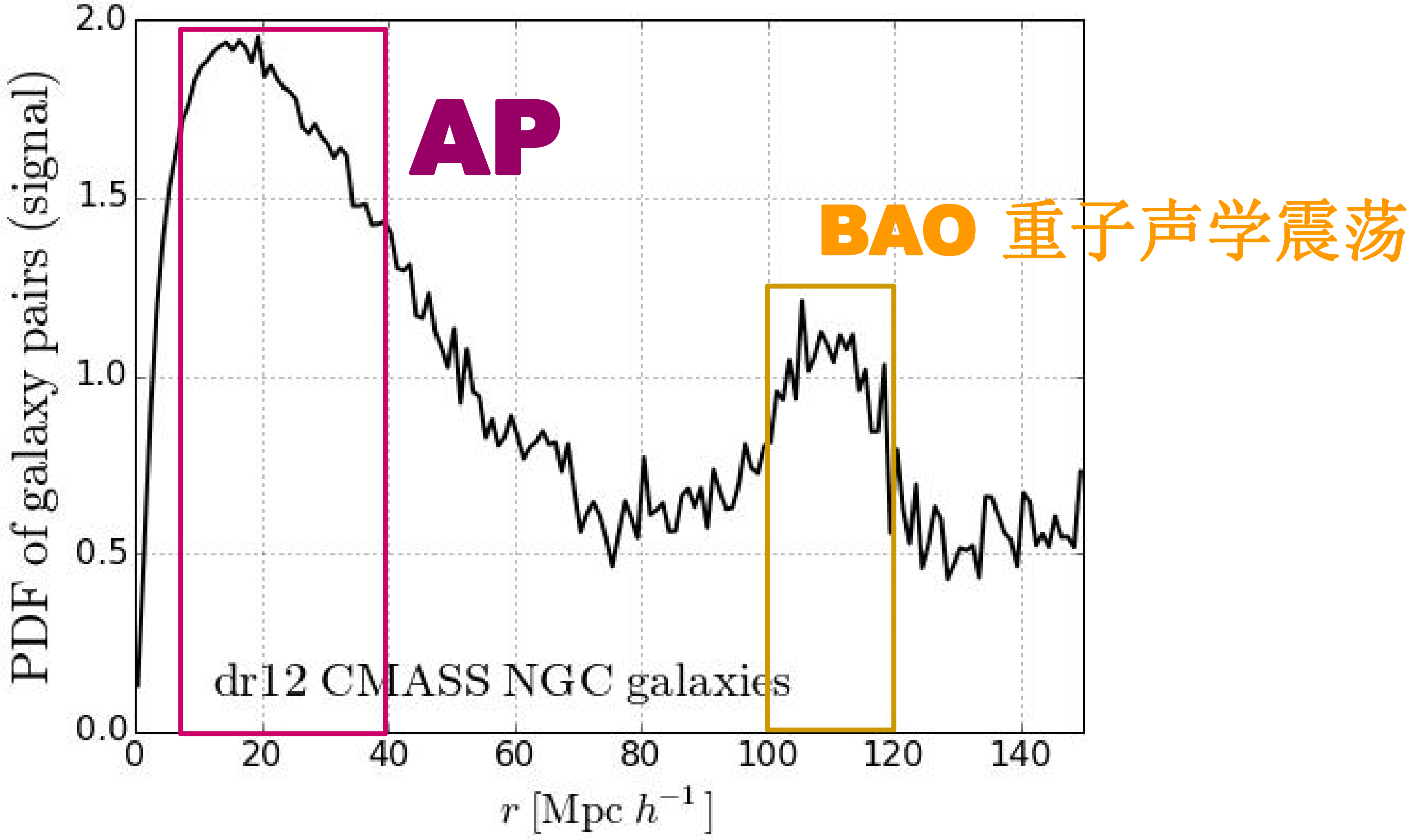
At z<0.8, AP reduces the error by ~

100%

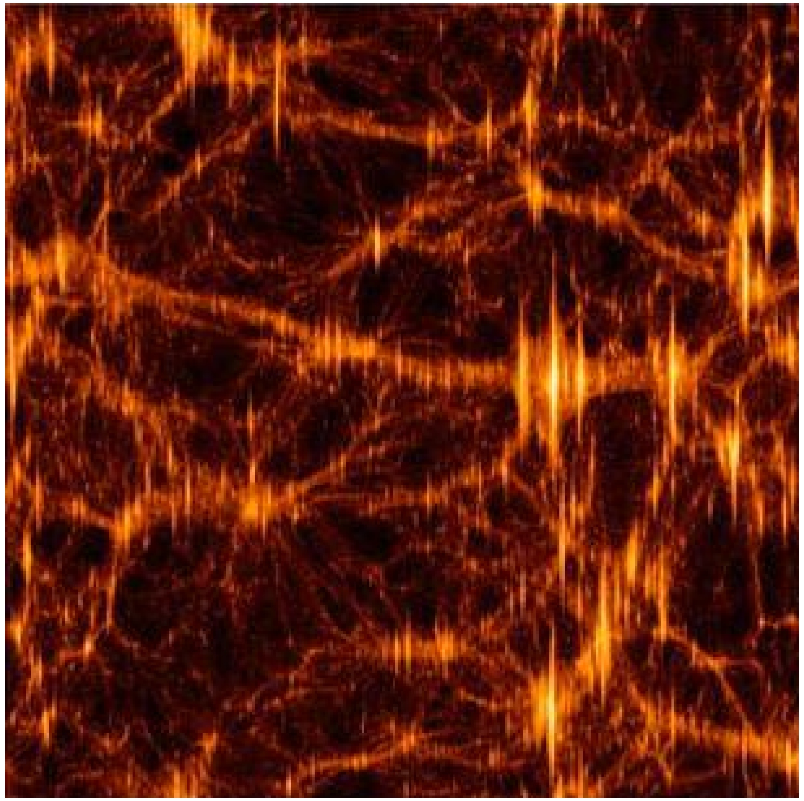
Low redshift result as tight as with Zhao et al. 2017, Nat. Astron., 1, 627 (they combine 16 datasets)

Q1: Why so powerful !?

A: Information from small-scale clustering.



Q2: Why you are able to use 6-40 Mpc/h?



A1:

We avoid modelling RSD in a smart way.

A2 (guess, in study):

We are <u>making use of the</u> FOG

Check systematics

We have to test the following options

Six redshift bins from 0.15 < z < 0.7

Fiducial: Omegam=0.26 LCDM

20-25 bins @ mu

s = 6 – 40 Mpc/h

mu = 0 - 0.97 (drop FOG & Fiber Collision)

2,000 PATCHY mocks for covariance matrix

Systematic correction from HR4 J08 galaxies

The systematics test

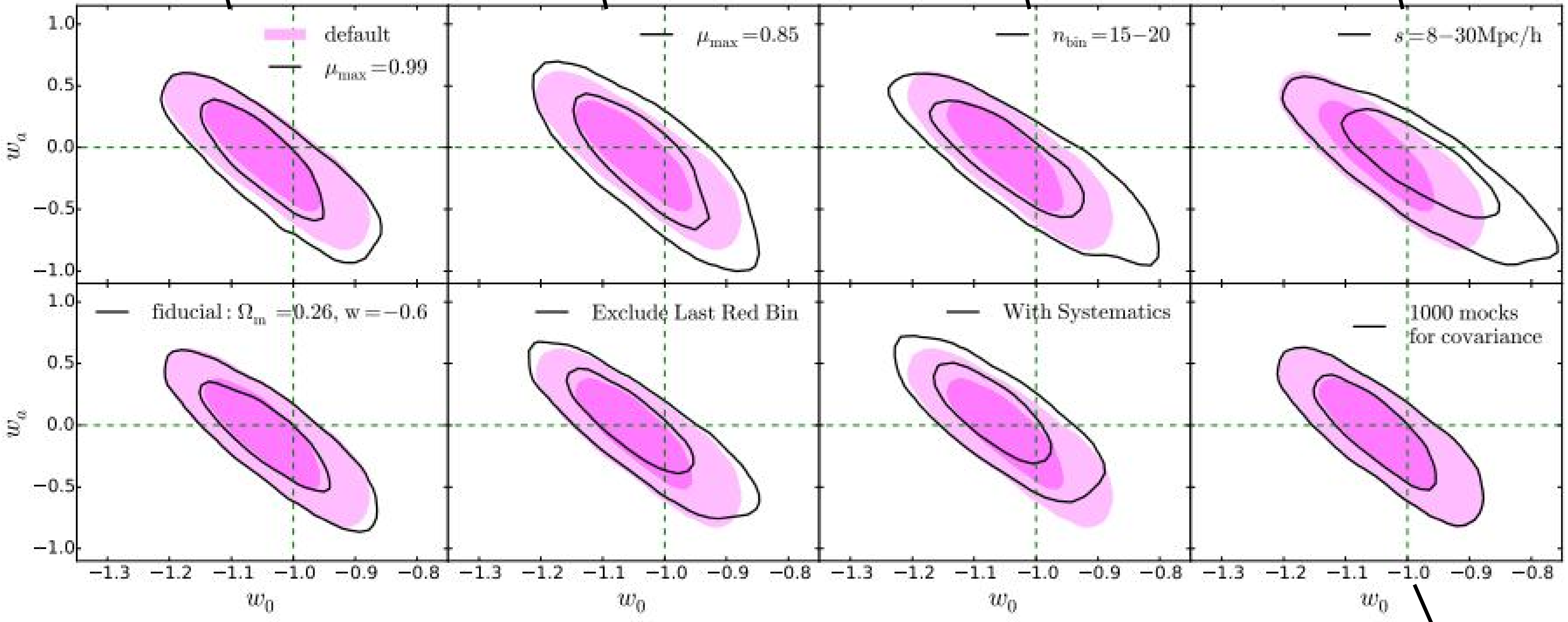
took me half a year.

Include ~all FoG region

Remove the FoG

More conservative binning

More conservative clusetering scale



Number of mocks for covariance

Numerous merits

* **Breakthrough** (Overcoming RSD!)

* **Powerful**

* **Robust** (no serious systematics)

* **Simple** (no complicated modelling)

* **Unique** (using 6-40 Mpc/h)

* **Extra** (independent from BAO, RSD, SNIa)

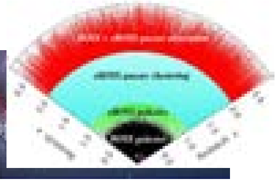
* **Promising** (applicable to future surveys)

Commetns from Prof. Donald Schneider :

"a major advance"

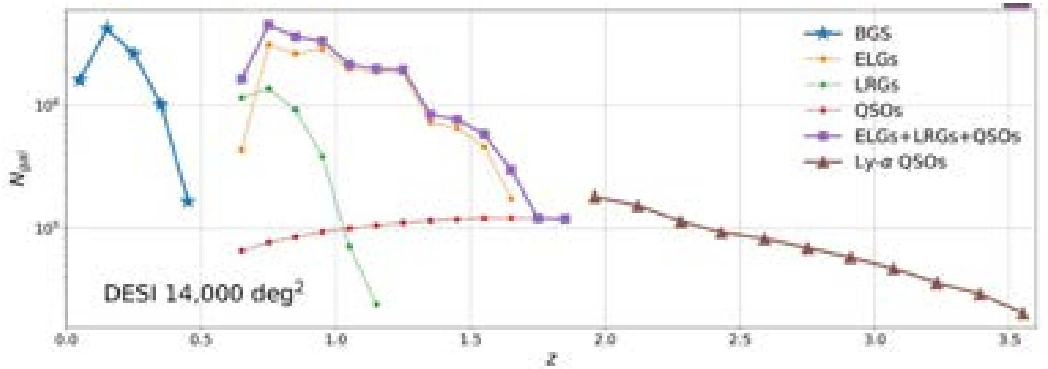
"extremely promising"

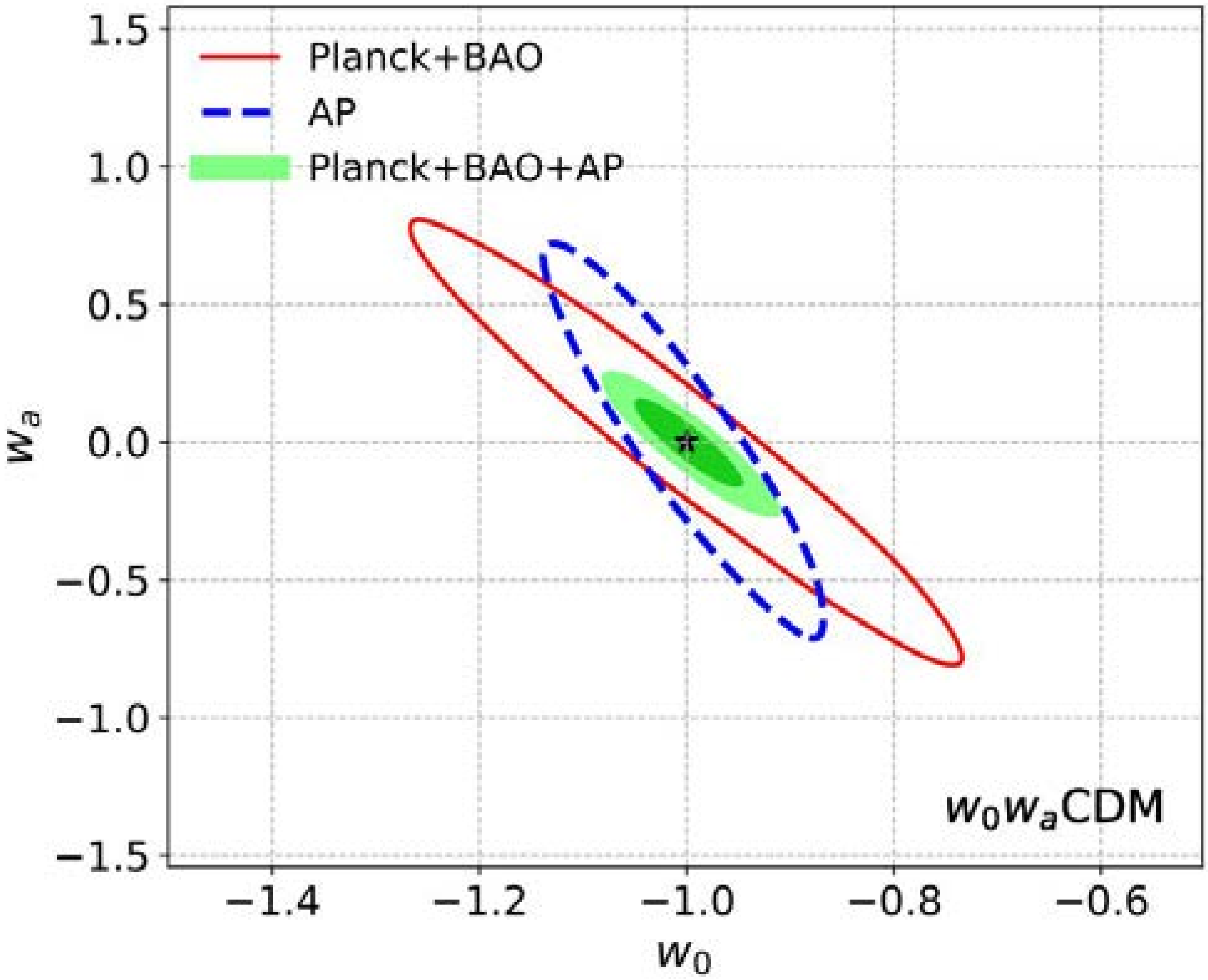
"I believe it will indeed be used in the future"



DESI Forecast

Li et al. 2019, ApJ





For DESI,

Planck+BAO+AP is

10 times

more powerful than

Planck+BAO

More stories ....

* **Volume effect**
* β-skeleton
* **Machine learning**

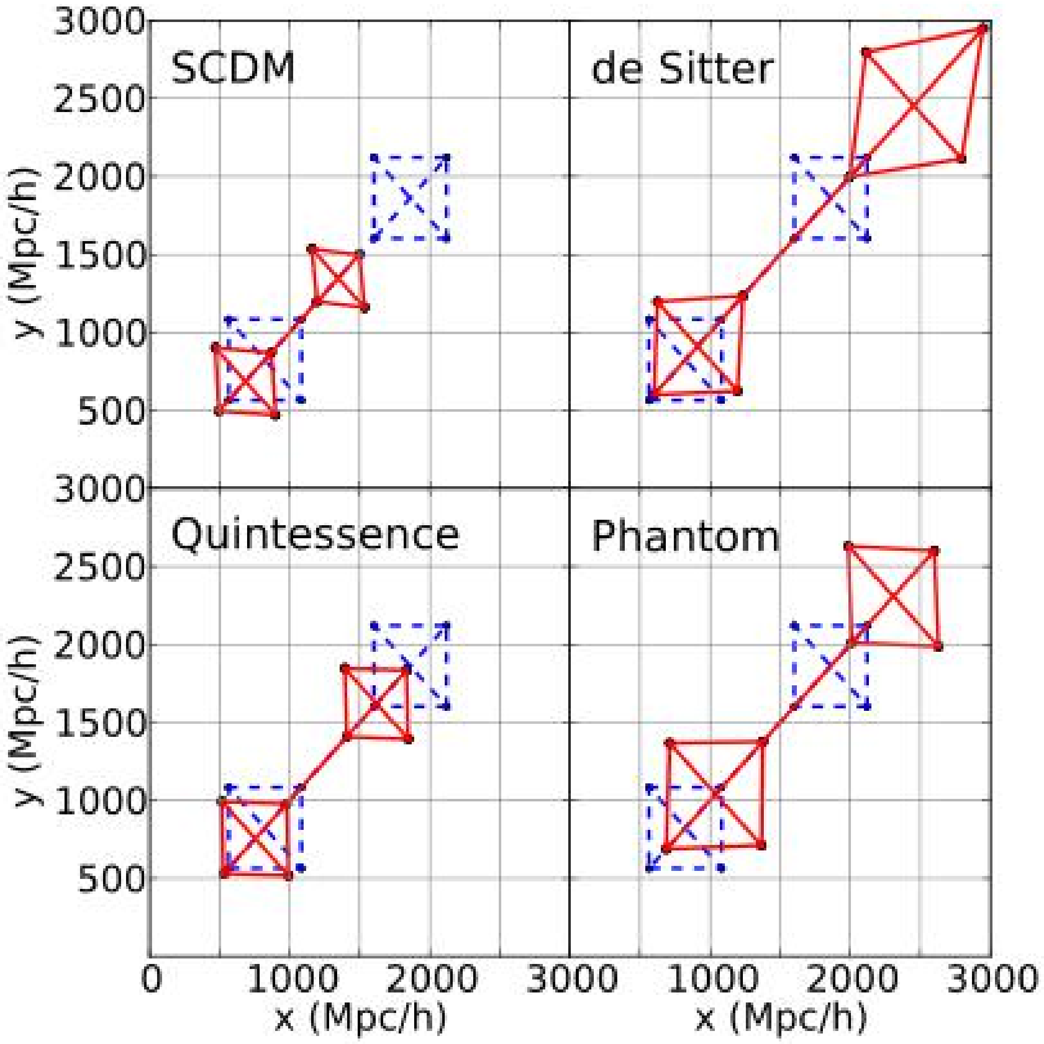
Volume effect

Li, Park, Sabiu, et al. 2017, ApJ

Another consequence of wrongly cosmology:

$$\frac{\text{Volume}_{\text{wrong}}}{\text{Volume}_{\text{true}}} = \frac{[D_A(z)^2/H(z)]_{\text{wrong}}}{[D_A(z)^2/H(z)]_{\text{true}}}$$

Volume change depends on redshift!

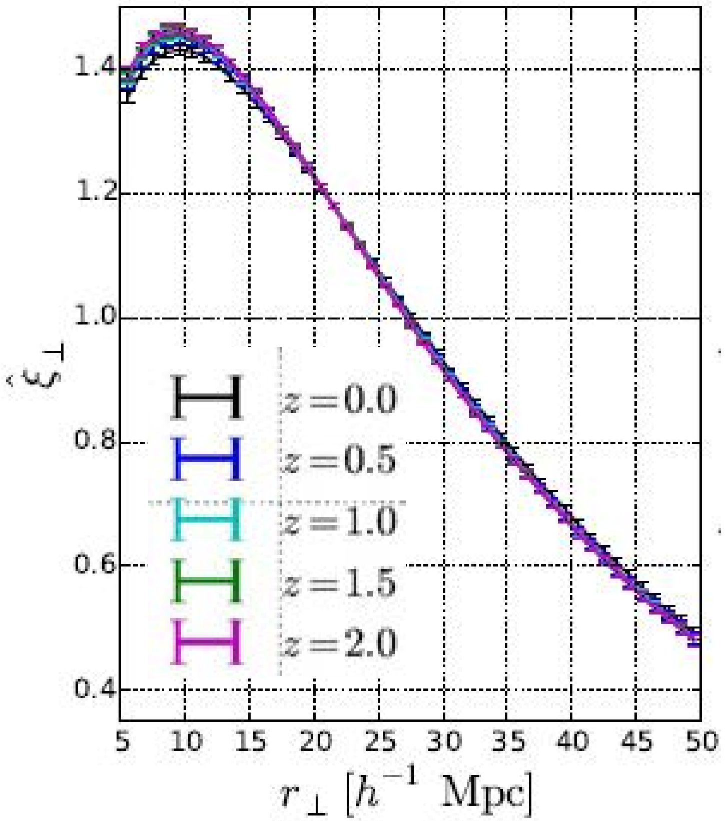


Volume effect

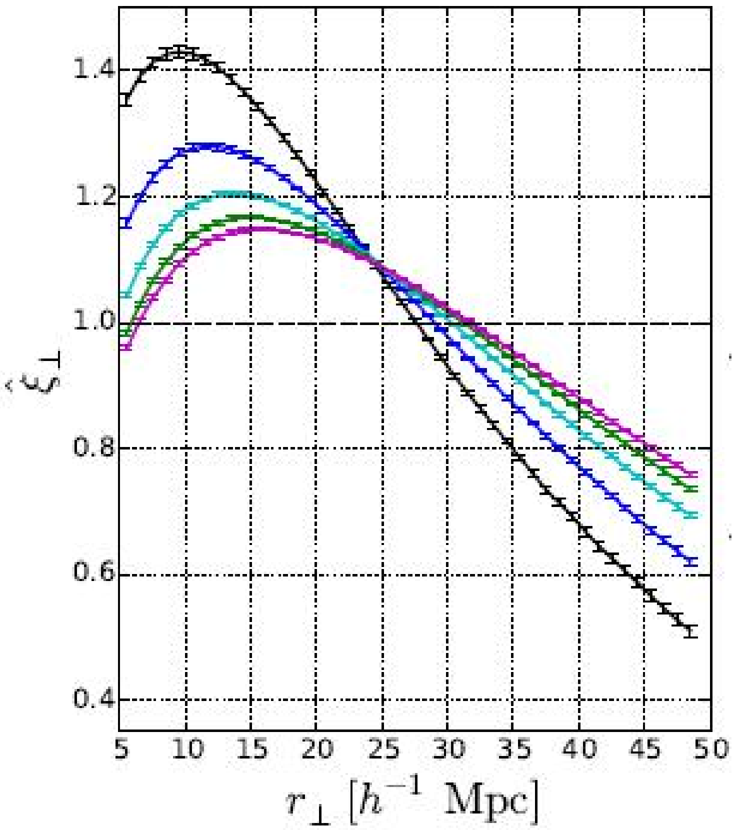
Li, Park, Sabiu, et al. 2017, ApJ

$$\hat{\xi}_{r_\perp} \equiv \frac{r_\perp \xi(r_\perp)}{\int_{r_{\perp,\min}}^{r_{\perp,\max}} r_\perp \xi(r_\perp) dr_\perp / (r_{\perp,\max} - r_{\perp,\min})}$$

Volime effect creates <u>redshift evolution</u> of 2PCF shape!



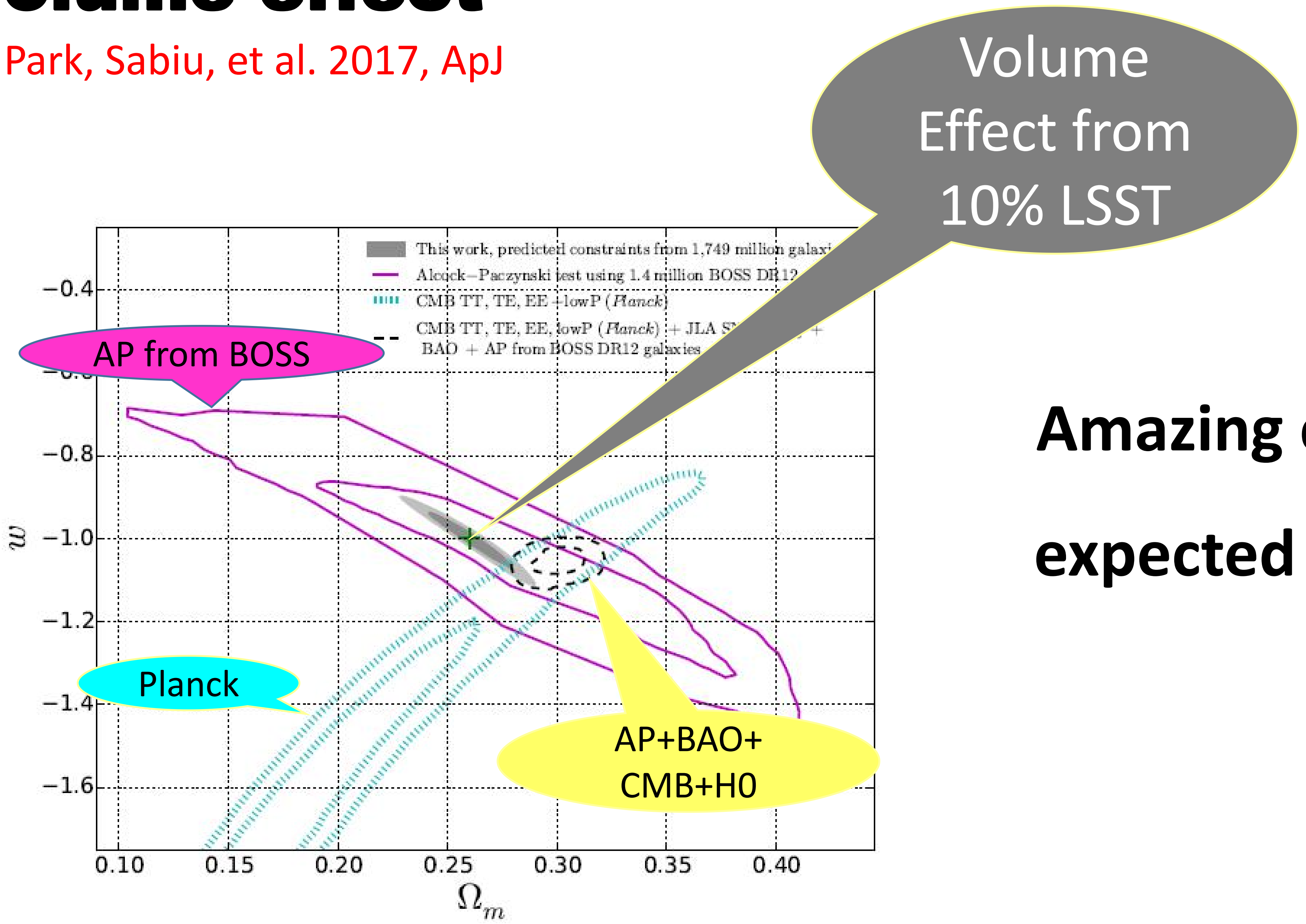
Correct cosmology



$\Omega_m = 0.05,\ w = -1.50$

Volume effect

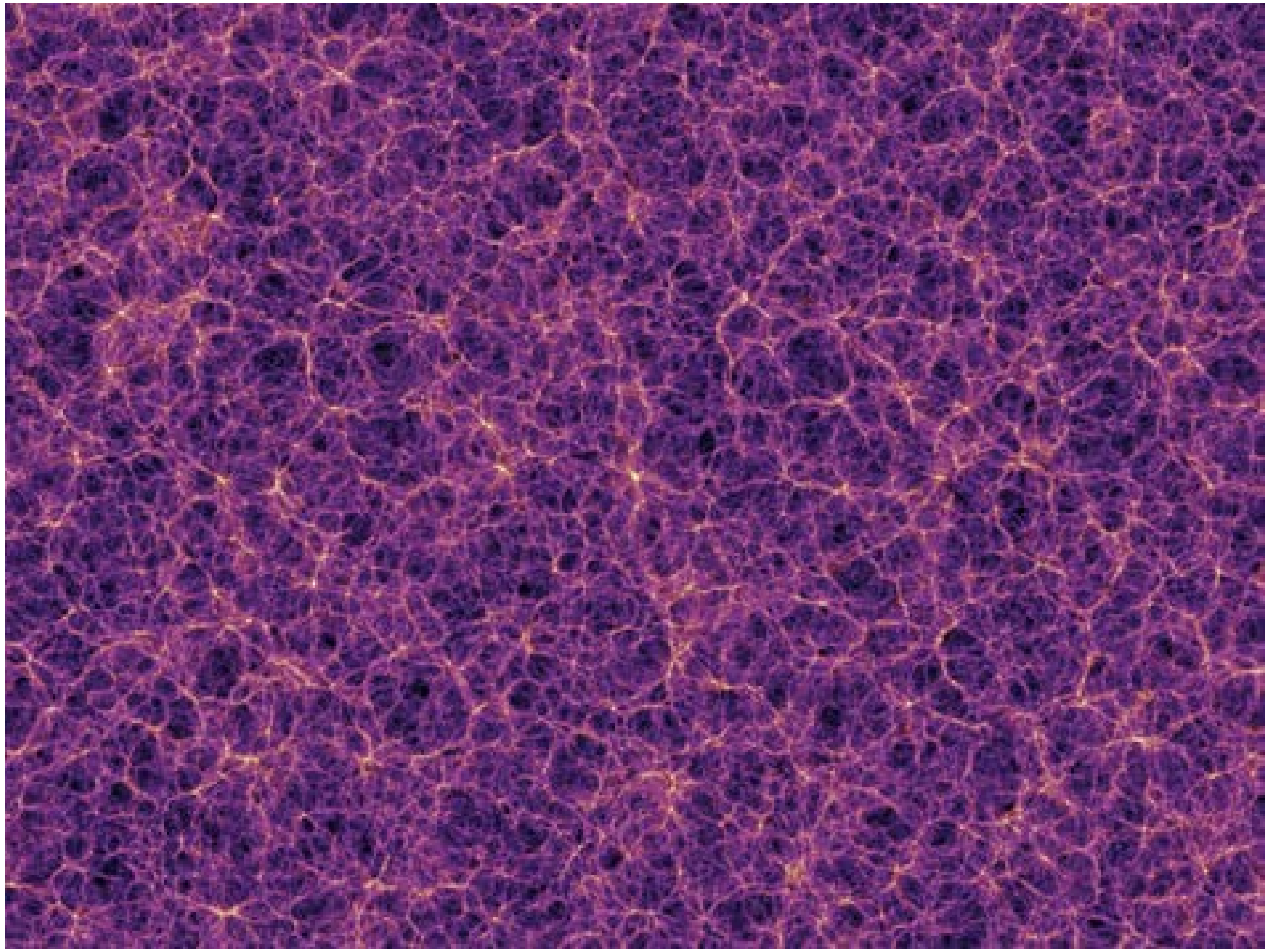
Li, Park, Sabiu, et al. 2017, ApJ



Amazing constraints expected from LSST!

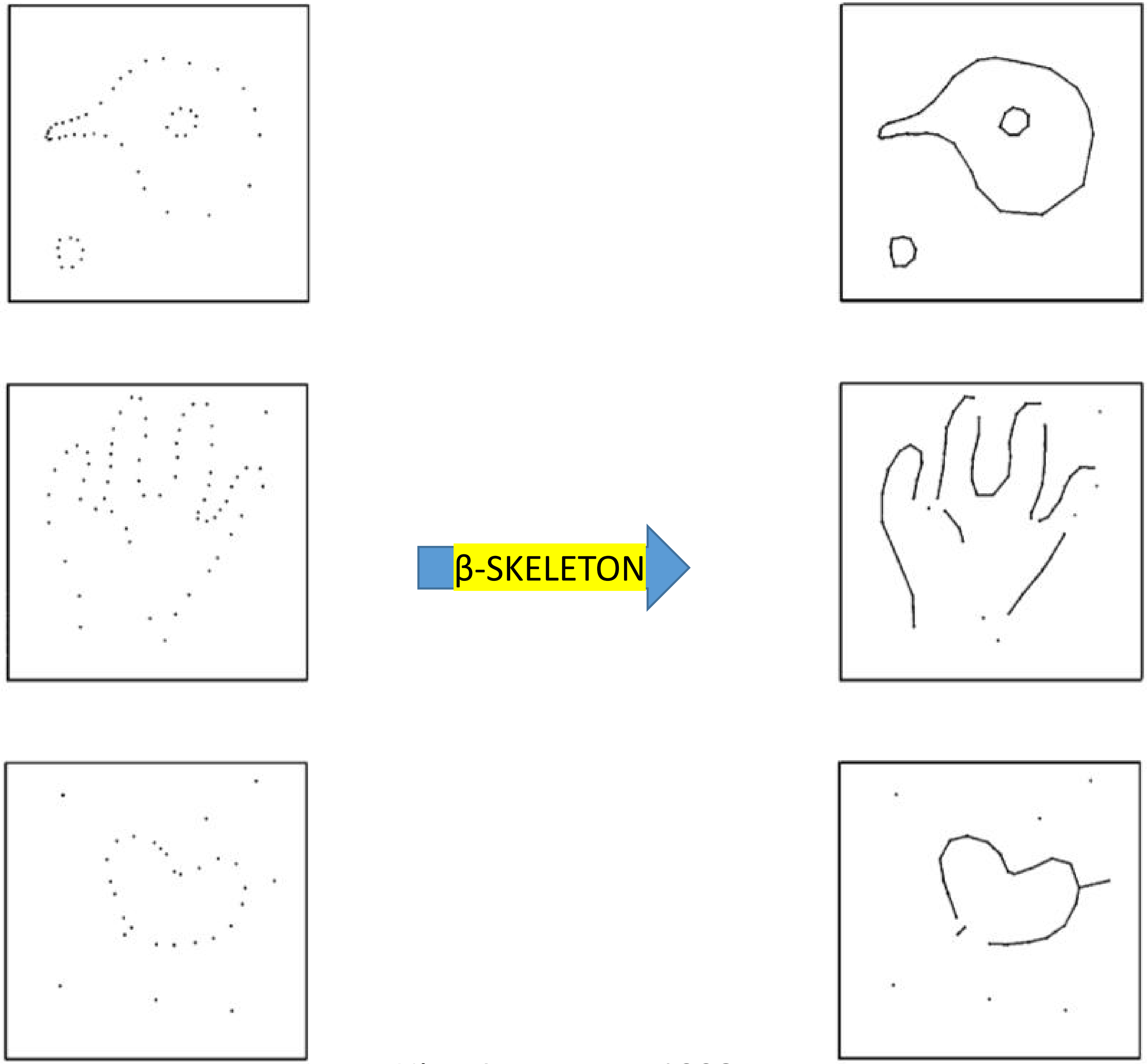
β-skeleton

Feng et al., MNRAS, 2018

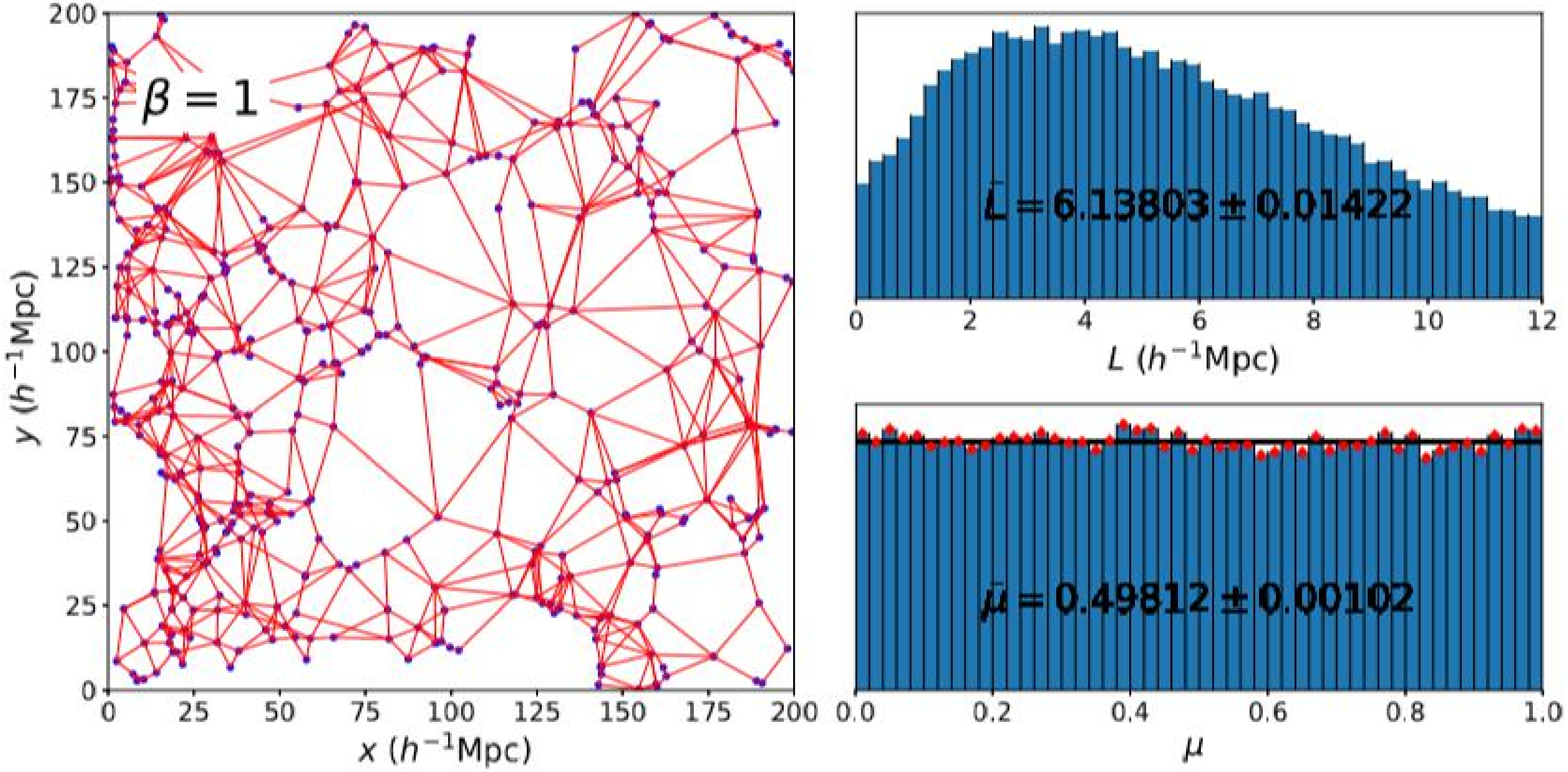


Cosmic Web is far more than a simple Gaussian field.

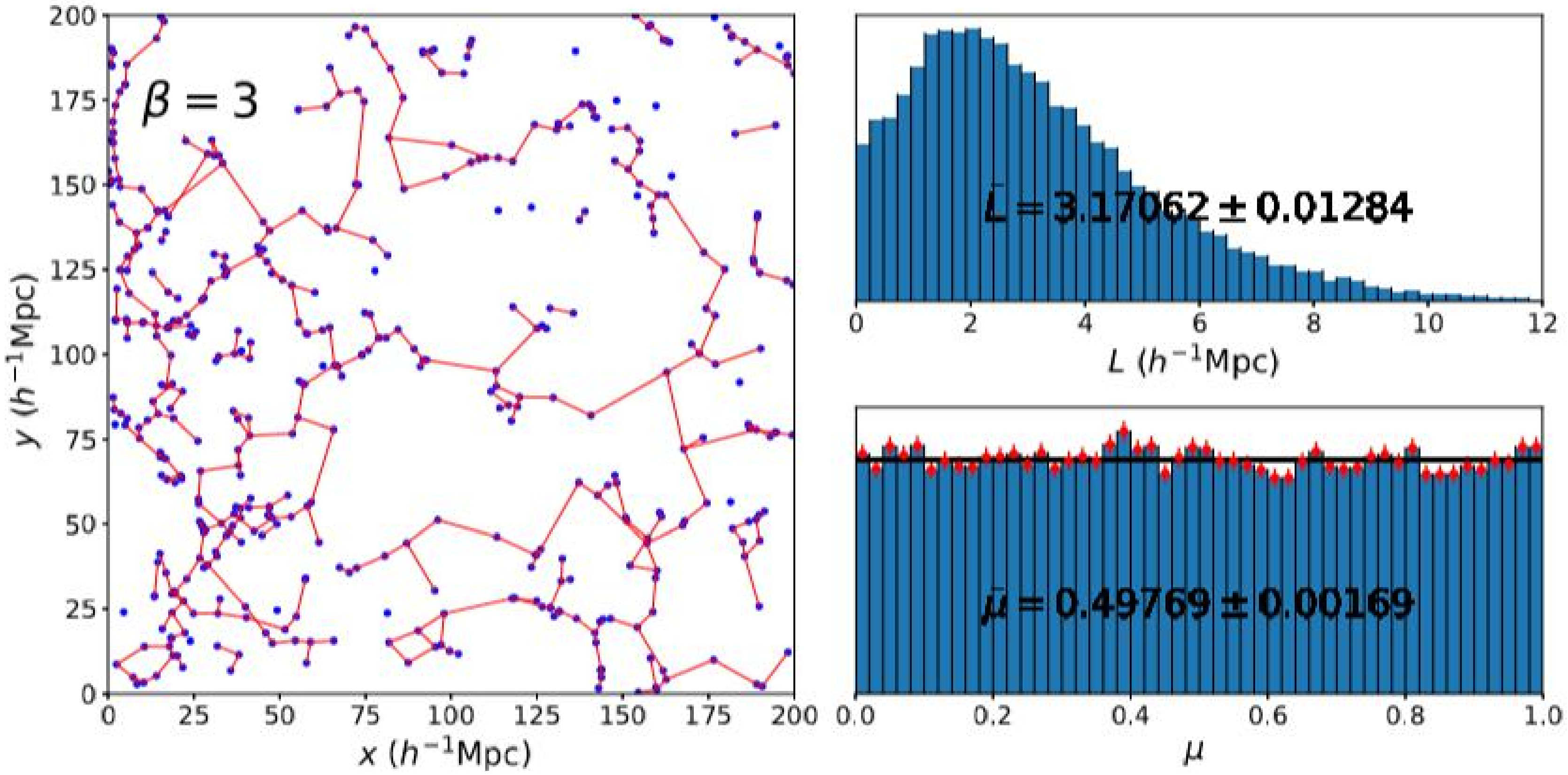
Have to find some methods beyond 2-point.



Nina Amenta et. 1998



- Sample: z=0 halo catalog of the BigMDPL simulation
  - L : length of the connections
  - **μ ≡ |cos θ|**



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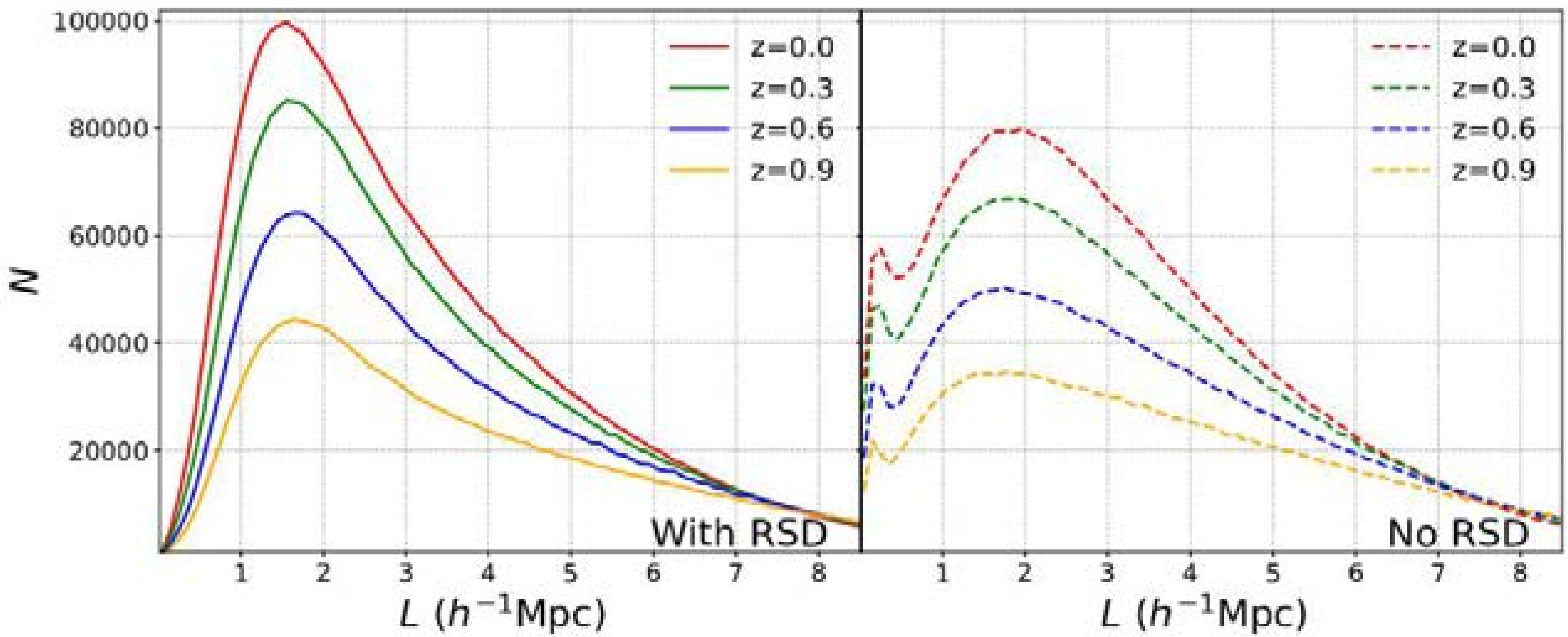
β-skeleton

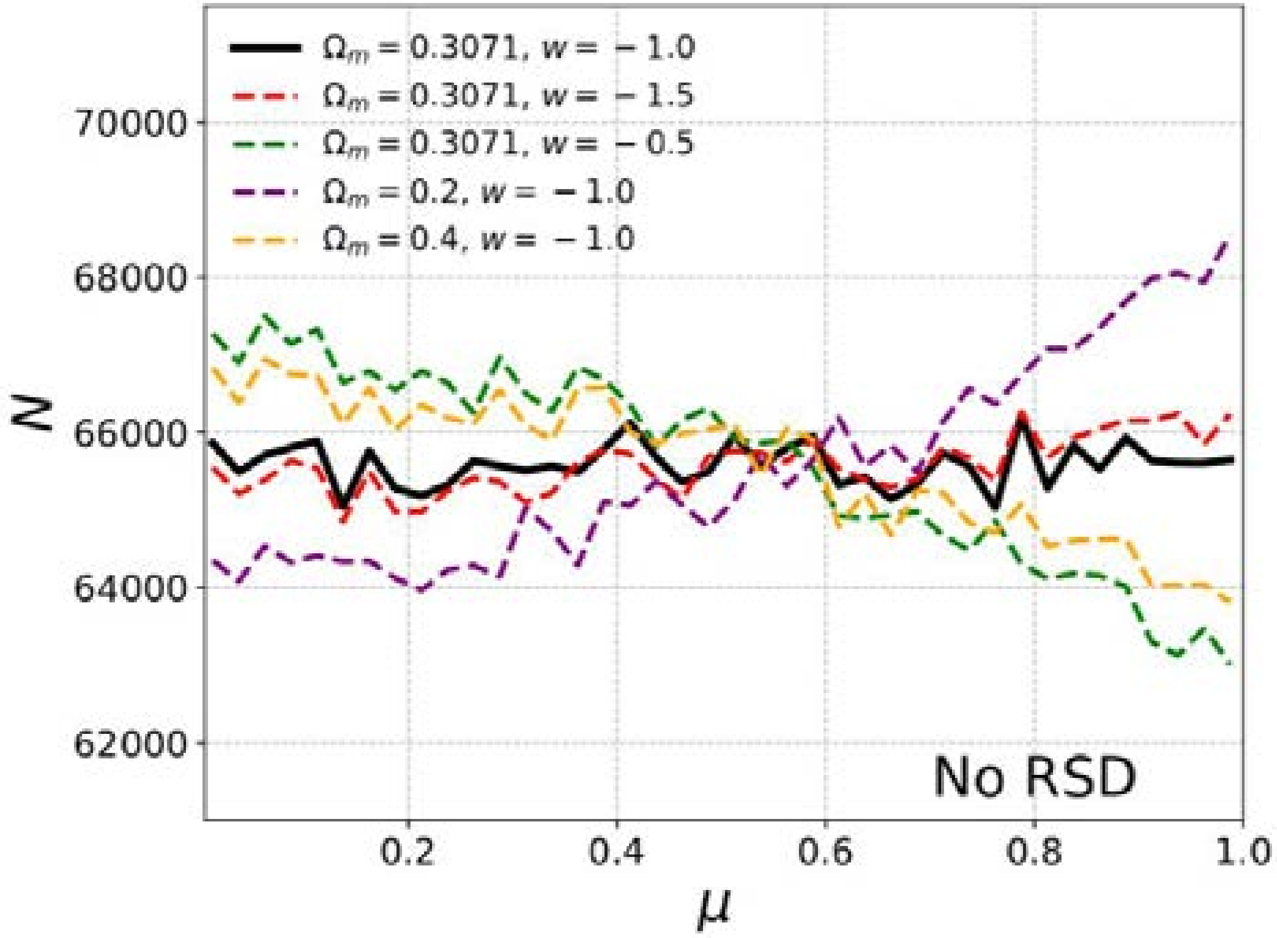
Feng et al., MNRAS, 2018



- 4 BigMDPL snapshots at redshifts 0, 0.3, 0.6, and 0.9
- **FOG peak location invariant with redshift**
  - **can be used to probe volume effect**

β-skeleton

Feng et al., MNRAS, 2018



- **Distribution of μ in different wrong cosmological models**

can be used to constrain cosmology!

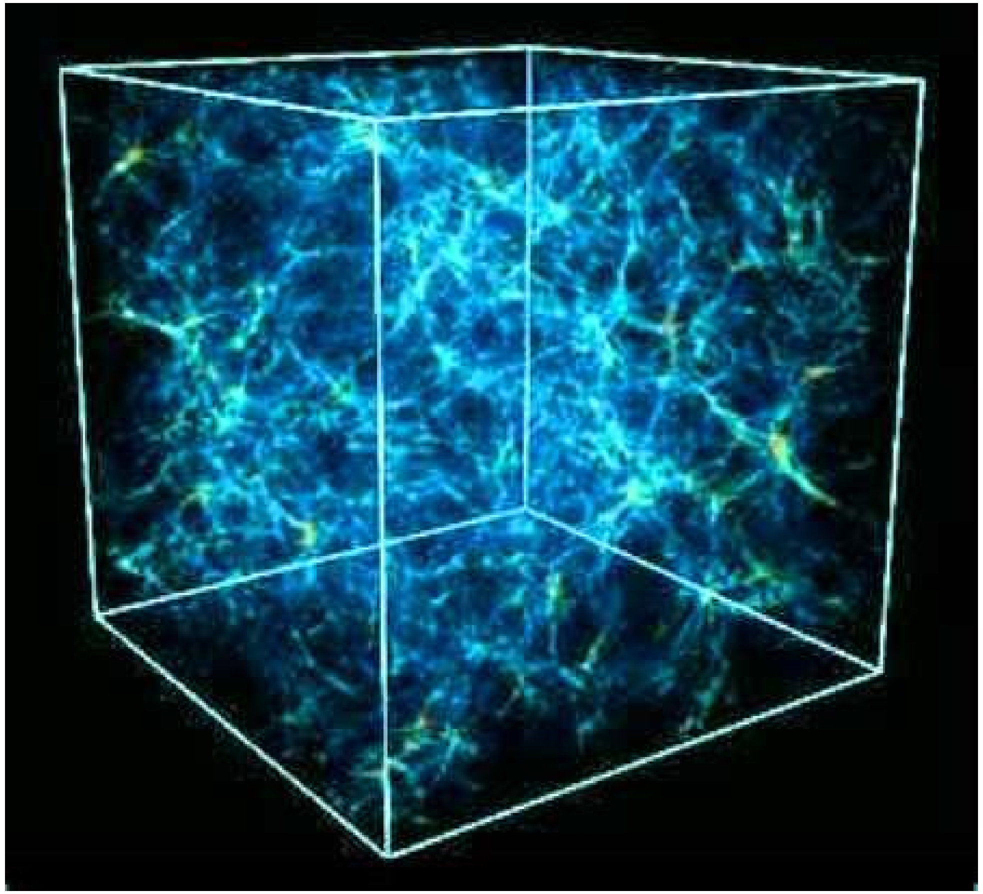
Machine learning cosmology

In progress ...

LSS is a very very complicated system

No man-designed statistics can capture everything

MACHINES should be better than human



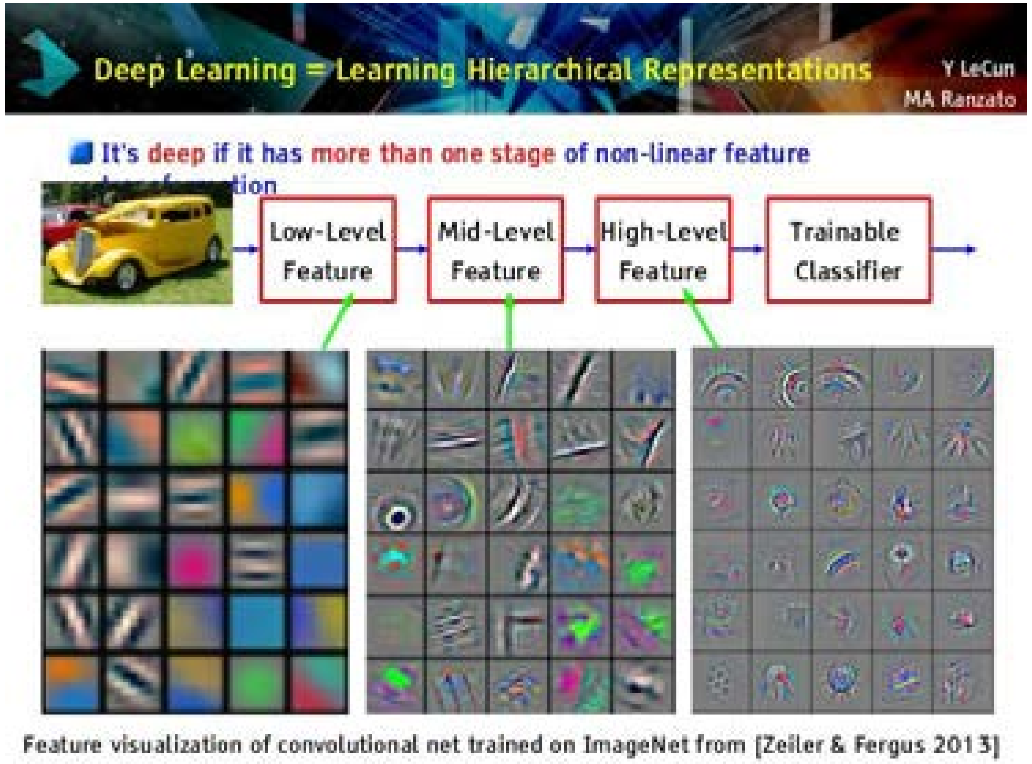
Machine learning cosmology

In progress ...

1. Learn to estimate the cosmological parameters (led by Xiao-Dong)

2. Learn to fast simulation: 600 hrs -> 1s (Kwan Chuen Chan)

3. Learn to reconstruct BAO (Xin Wang)



Conclusion

The end... is just the beginning

Bethany Hamilton

Of course, it is important to construct powerful experiments...

People get very excited when they launched some big guy.

At the same time, having a good analysis method is EQUALLY IMPORTANT!

It is not easy to tackle the **DARK ENERGY**

2019 年度中山大学青年学者珠海论坛

5.31 - 6.2

聚贤纳才，共创未来

- 招聘岗位：
  - 教授、副教授
  - 特聘研究员/副研究员
  - 博士后
- 方向
  - 天琴计划
  - 天文学
  - 理论物理
  - 量子工程与精密测量
  - 量子信息与测控
  - 空间科学技术

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