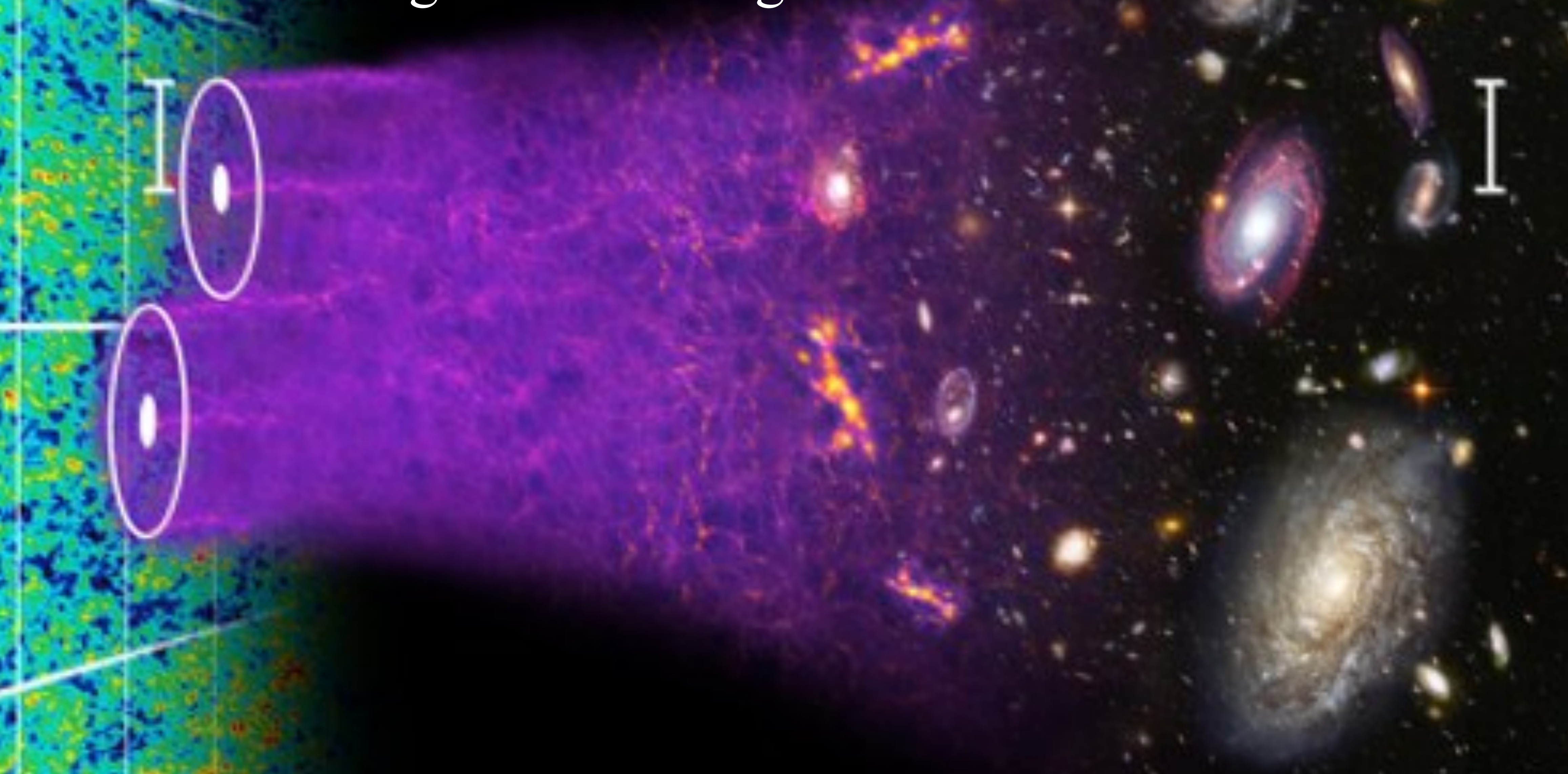
Dark Energy and Expansions History Constraints from Clustering of Galaxies

Cristiano G. Sabiu

Collaborators: **XiaoDong Li, Changbom Park,** Yuting Wang, Gong-bo Zhao, Hyunbae Park, Arman Shafieloo, Juhan Kim, Sungwook E. Hong



Dark Side of The Universe, IBS, Daejeon - July 12 - 2017

Background

- The goal of modern cosmology is to **understand the physics** that governs our Universe on the largest scales

- And figure out the **constituents of the Universe**

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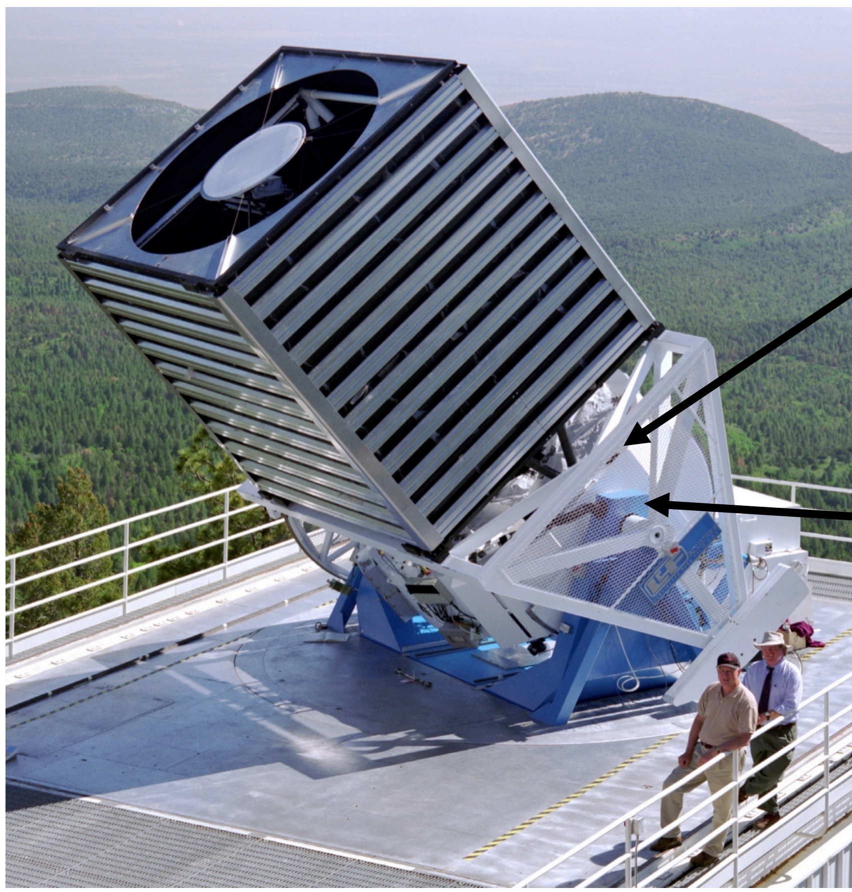
The game we play…

1) We start with Einstein's GR
2) Plug in a homogeneous/isotropic metric
3) Plug in energy/matter components
4) Obtain evolution equations for:
   - **Expansion of the Universe**
   - **Growth of density perturbations**

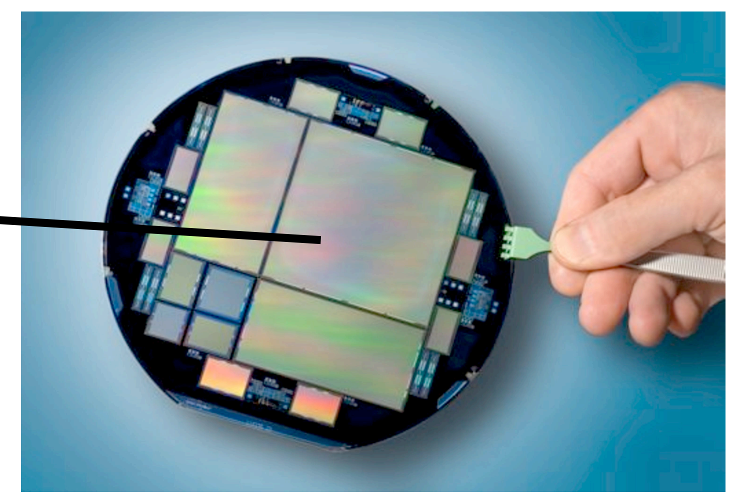
BOSS Galaxy Redshift Survey

SDSS telescope



Apache Point Observatory
(SDSS 2.5m telescope)

1000 small-core fibers to replace existing
(more objects, less sky contamination)



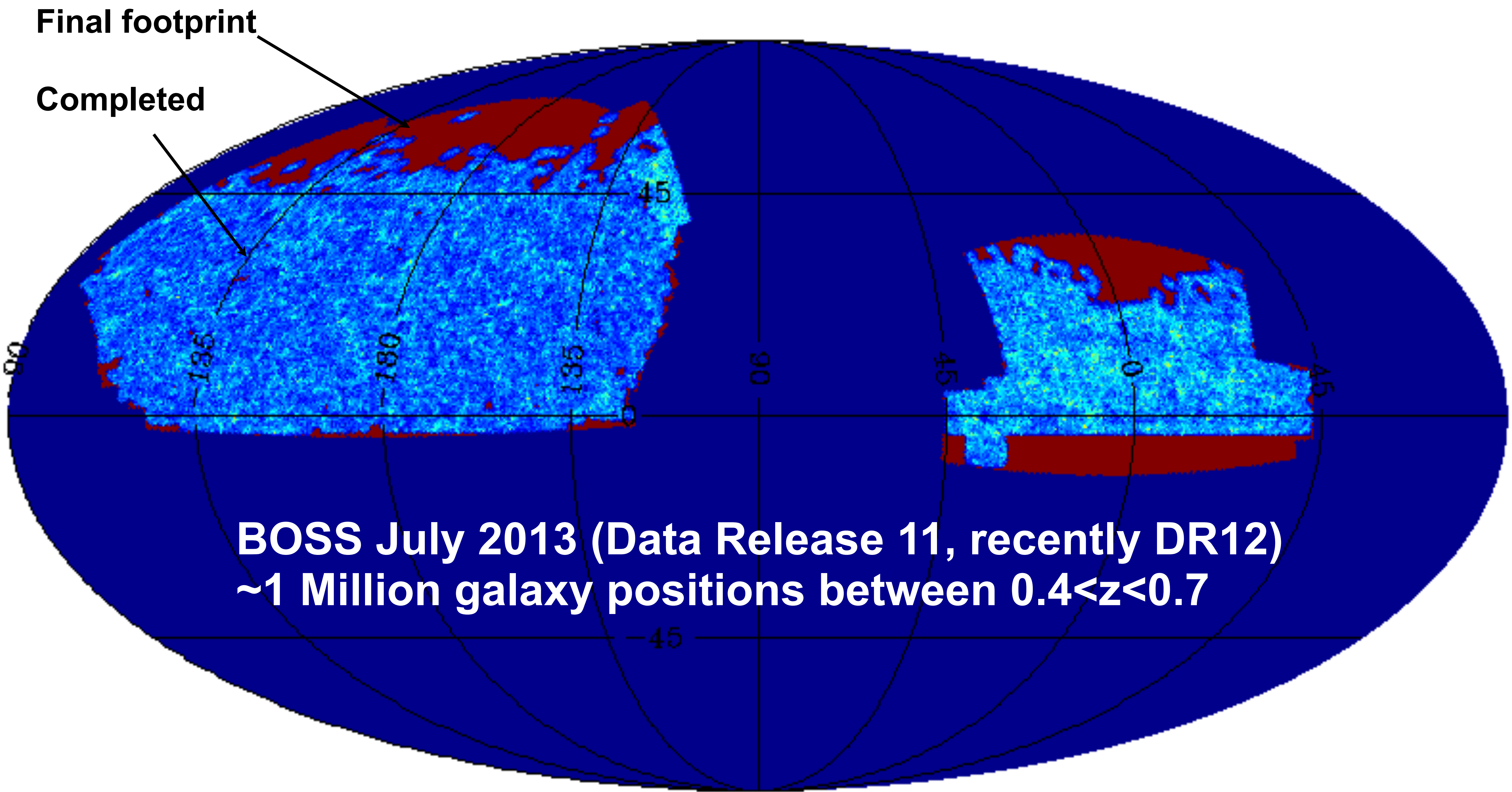
LBNL CCDs + new gratings improve throughput
Update electronics + DAQ

Photometry in standard UGRIZ bands

Imaging with 30 2048 × 2048 SITe/Tektronix 49.2 mm square CCDs on a field of view 2.5 deg operating in drift scan mode.

BOSS Galaxy Redshift Survey

The Sloan Digital Sky Survey's subproject:
Baryon Oscillation Spectroscopic Survey



Standard Methodology

Clustering of galaxies tells us a lot about cosmology

How do we do it practically…(ok slightly simplified)…

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3) Visit each galaxy and count the number of neighbour galaxies in shells of different radii <u>OR</u> download my super-duper correlation function code ;) KSTAT - https://bitbucket.org/csabiu/kstat

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4) Fit a theoretical model to the result and constrain cosmological parameters

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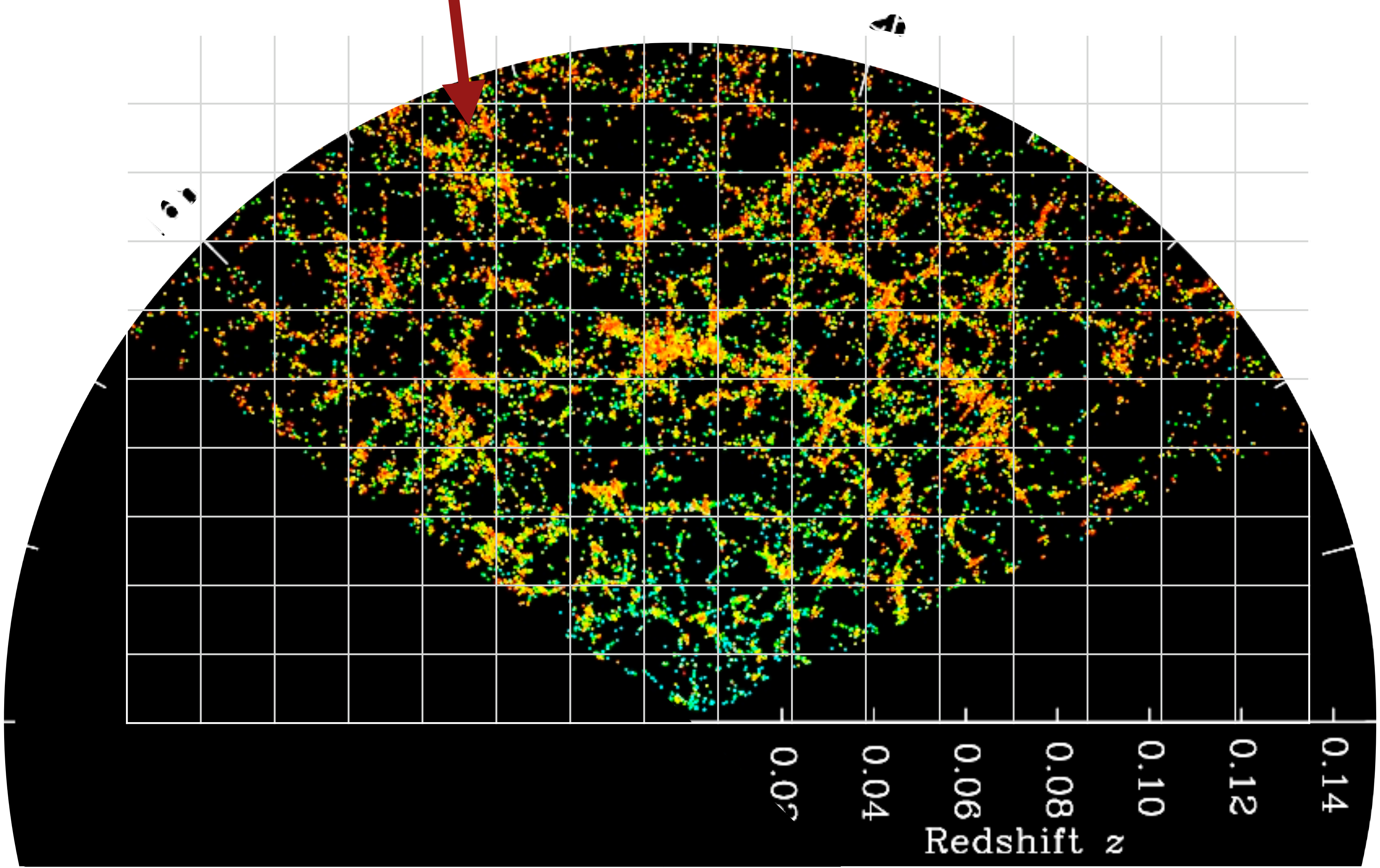
Standard Methodology

Count galaxies in cells and compute:

$$\xi(r) = \langle \delta(x)\delta(x+r) \rangle_x$$

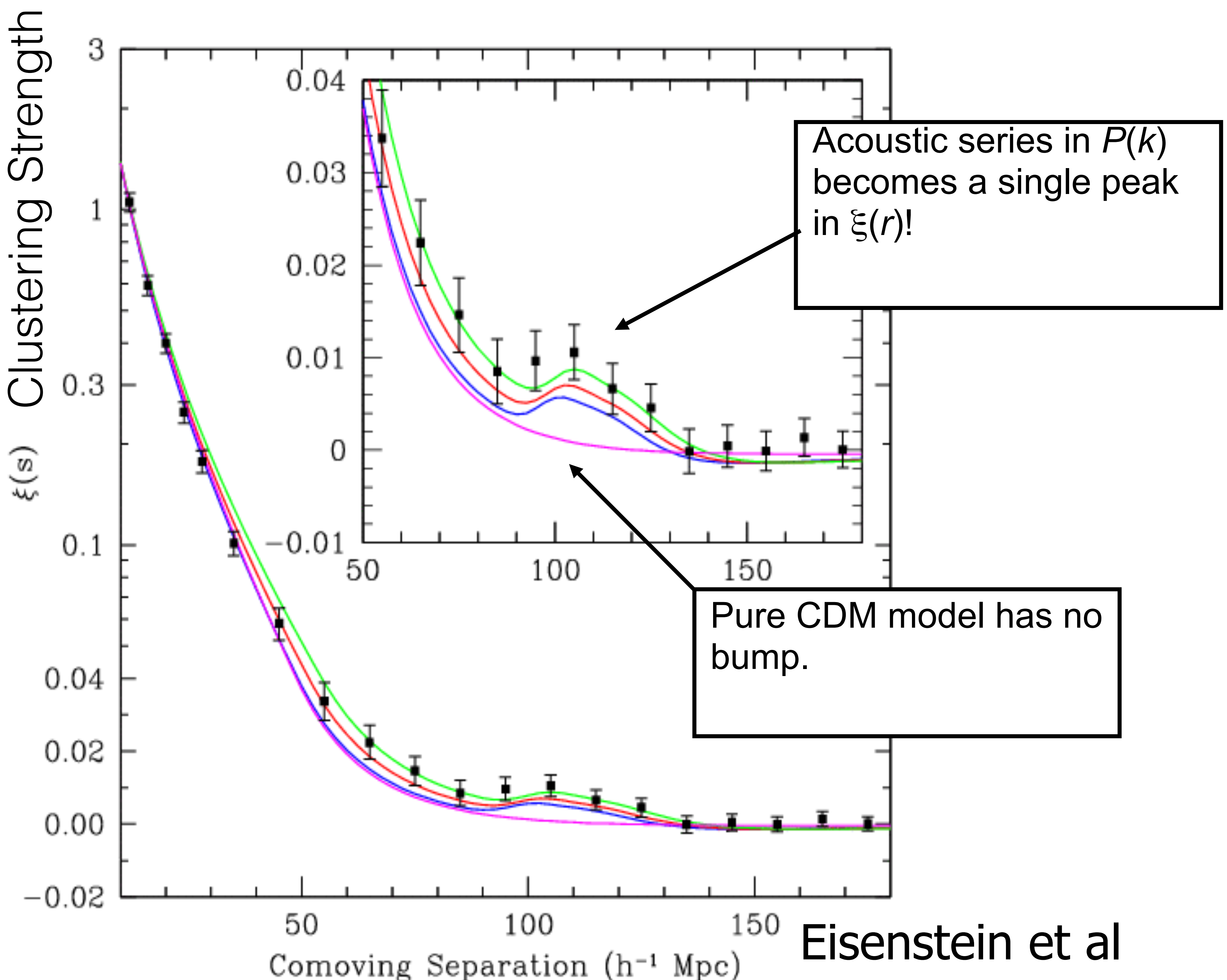


SDSS

Standard Methodology

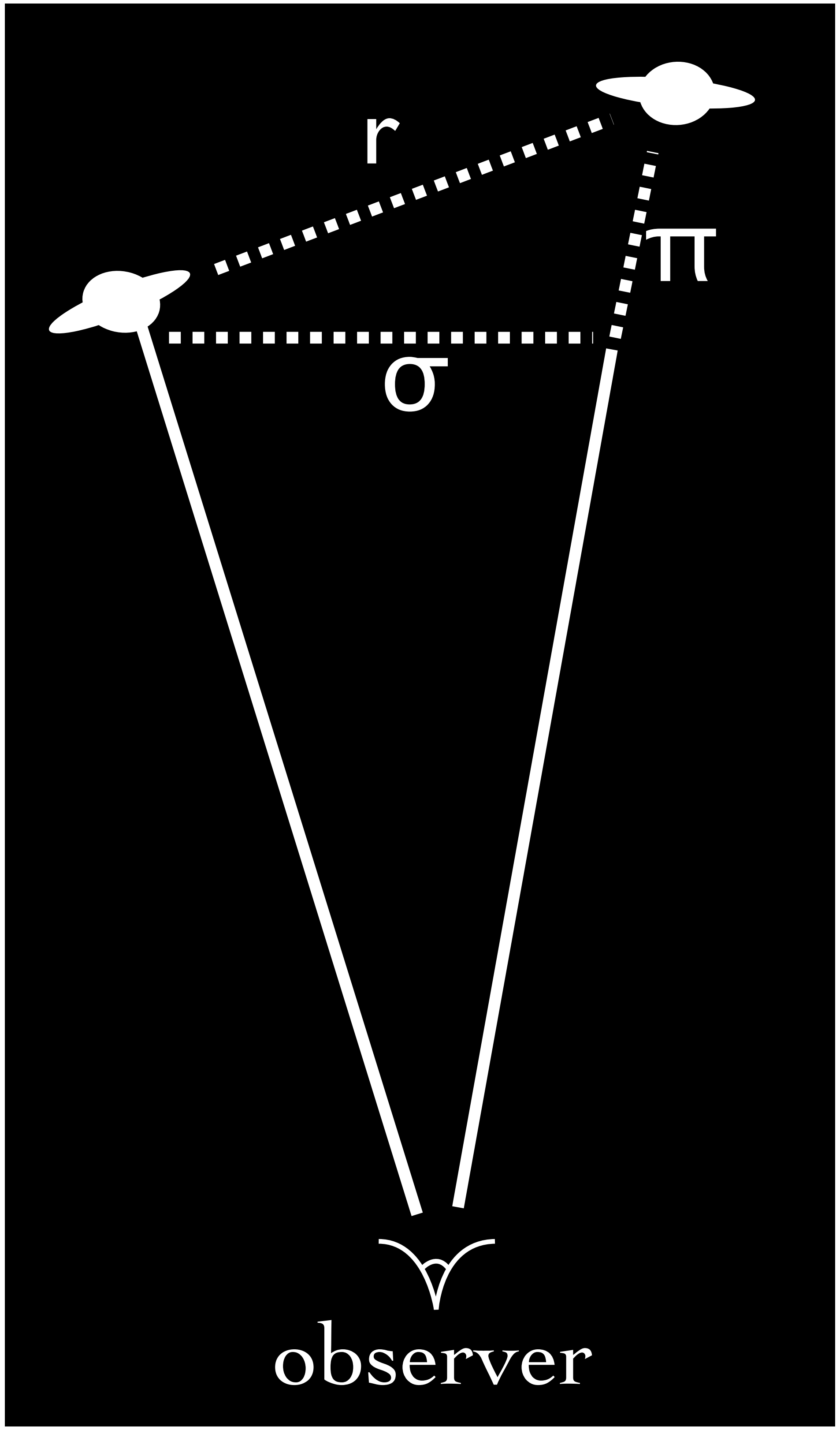
The measured correlation function

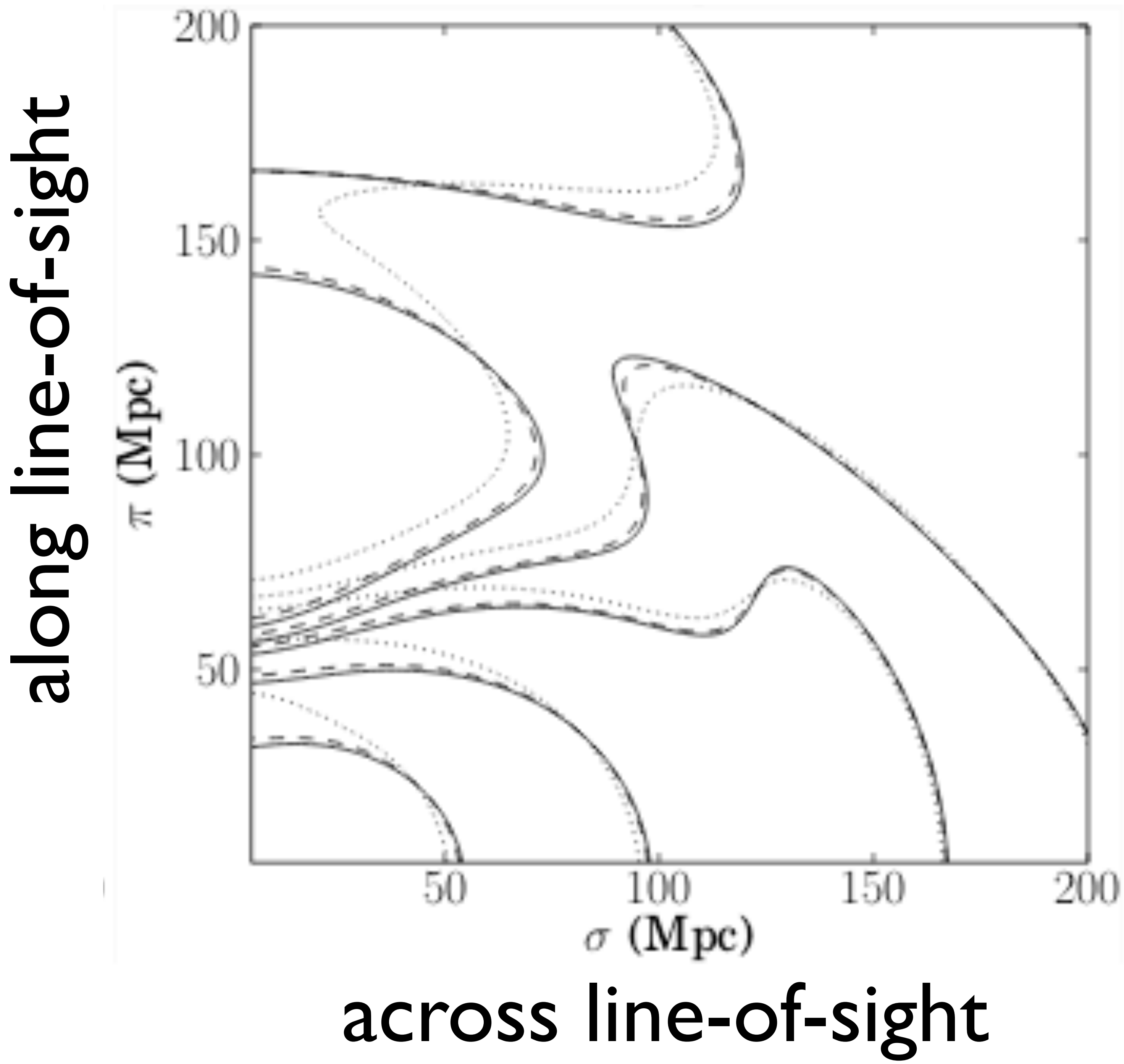
It can be used to fit models and constrain parameters



Eisenstein et al SDSS data

Clustering in 2D

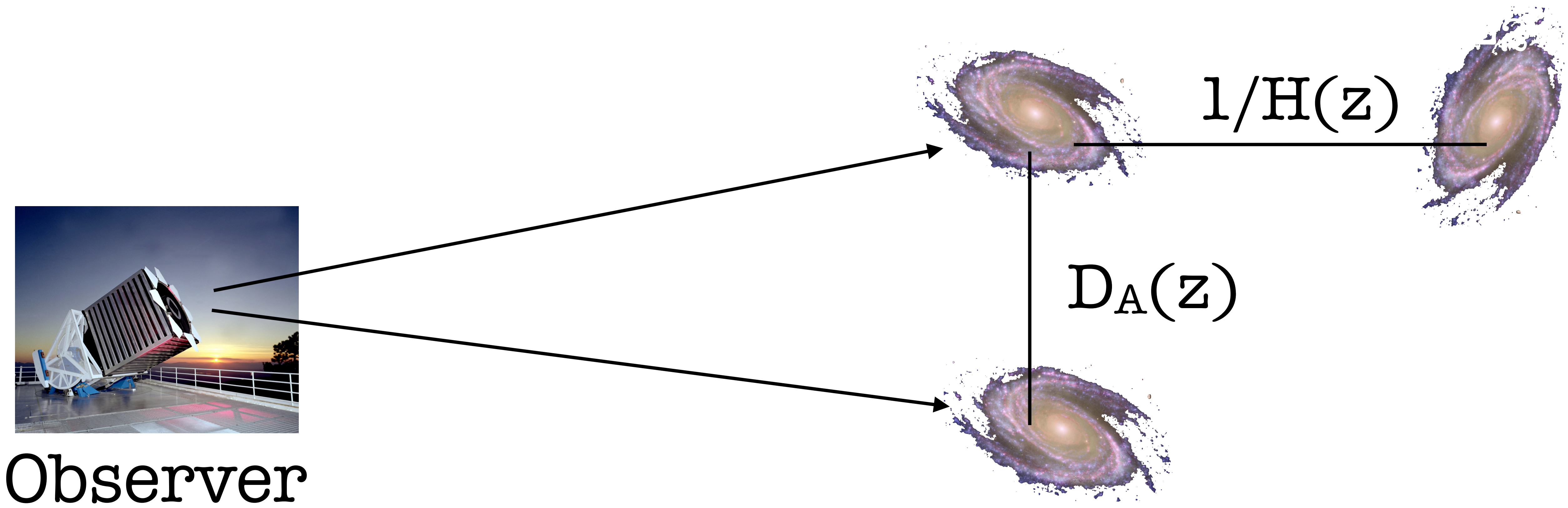




Alcock-Paczynski Effect

We measure RA, Dec and Redshift for each galaxy. However we must choose a cosmological model to convert these positions into a cartesian comoving coordinate system.

We can measure the clustering **along** and **perpendicular** to the line of sight and thus constrain the combination of $D_A * H$



Alcock-Paczynski Effect

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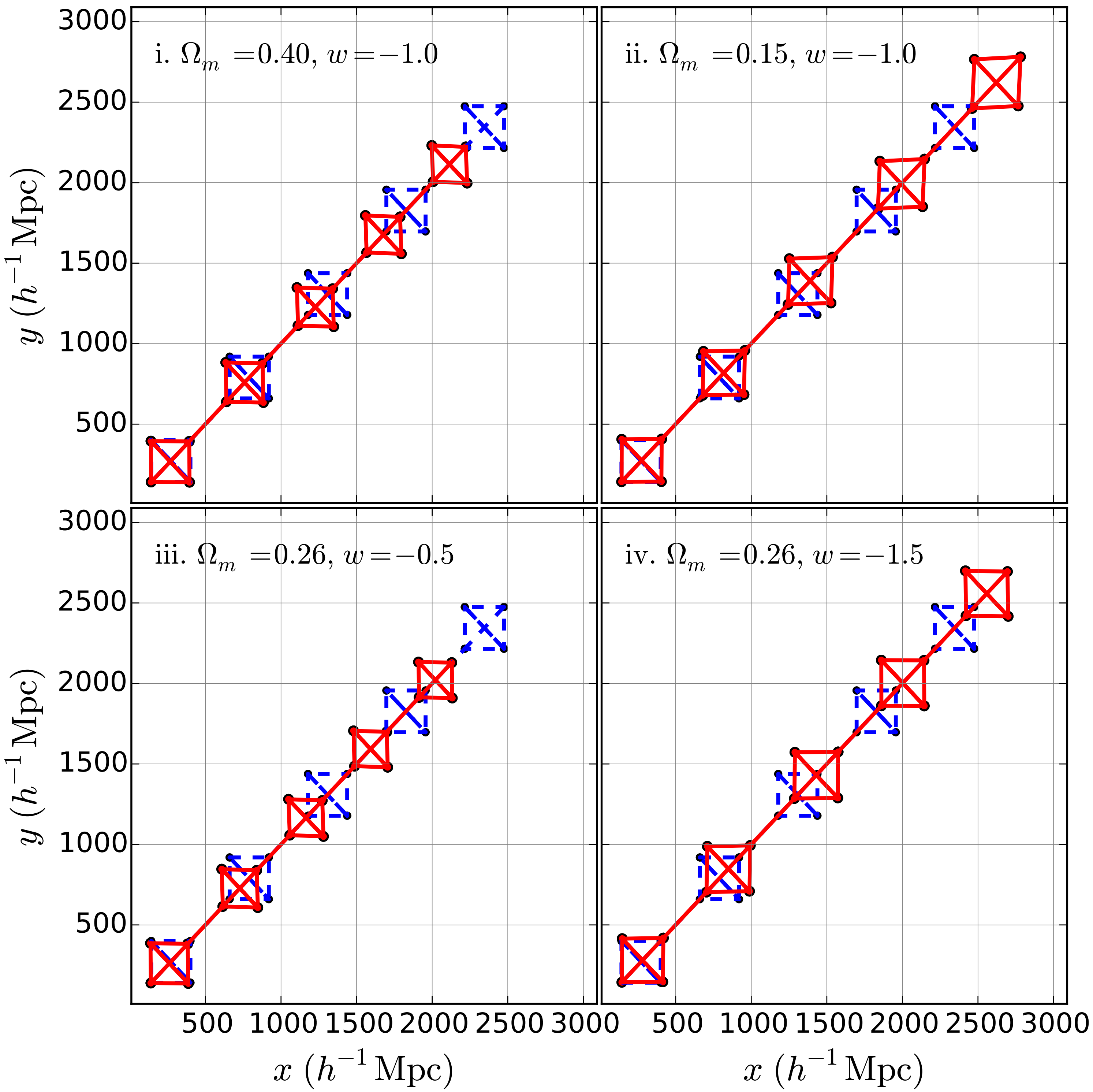
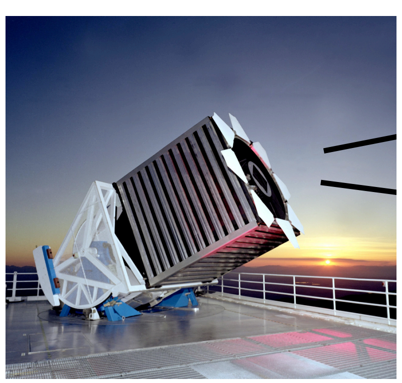


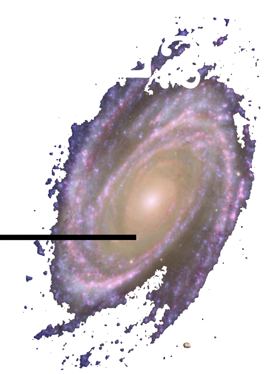


Observe

However we
positions into

licular to the
D_A * H

./H(z)



)

Alcock-Paczynski Effect

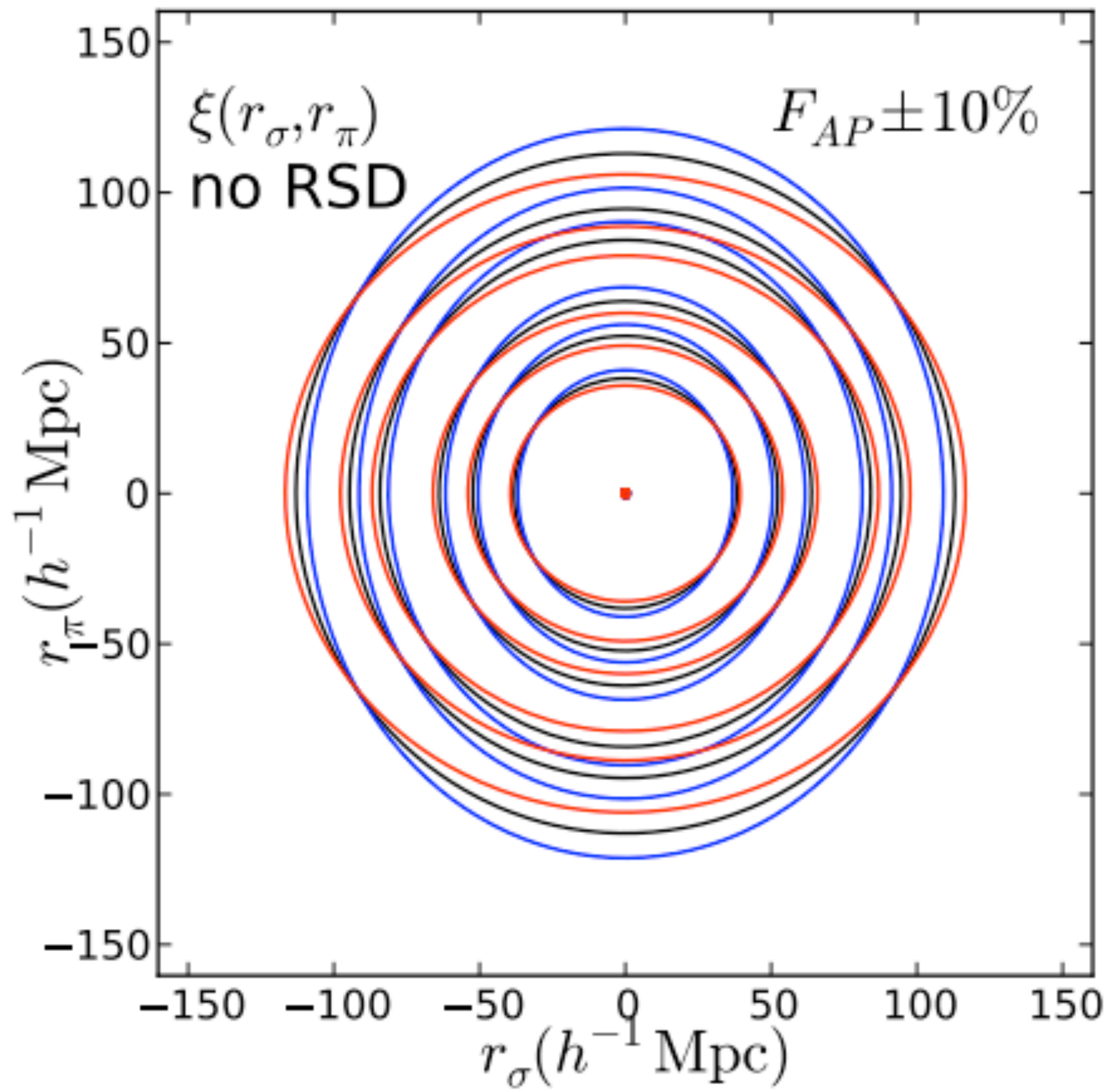
$\xi(r_p, \pi)$ appears anisotropic if you assume the wrong cosmology;

constrains the combination:
$F(z) \equiv (1+z)\, D_A(z)\, H(z)/c$

However geometric distortions can be modeled exactly:

$$\xi^{\rm fid}(r_\sigma, r_\pi) \quad = \quad \xi^{\rm true}(\alpha_\perp r_\sigma, \alpha_\parallel r_\pi),$$

$$\alpha_\perp = \frac{D_A^{\rm fid}(z_{\rm eff})}{D_A^{\rm true}(z_{\rm eff})}, \qquad \alpha_\parallel = \frac{H^{\rm true}(z_{\rm eff})}{H^{\rm fid}(z_{\rm eff})},$$



Clustering Shells

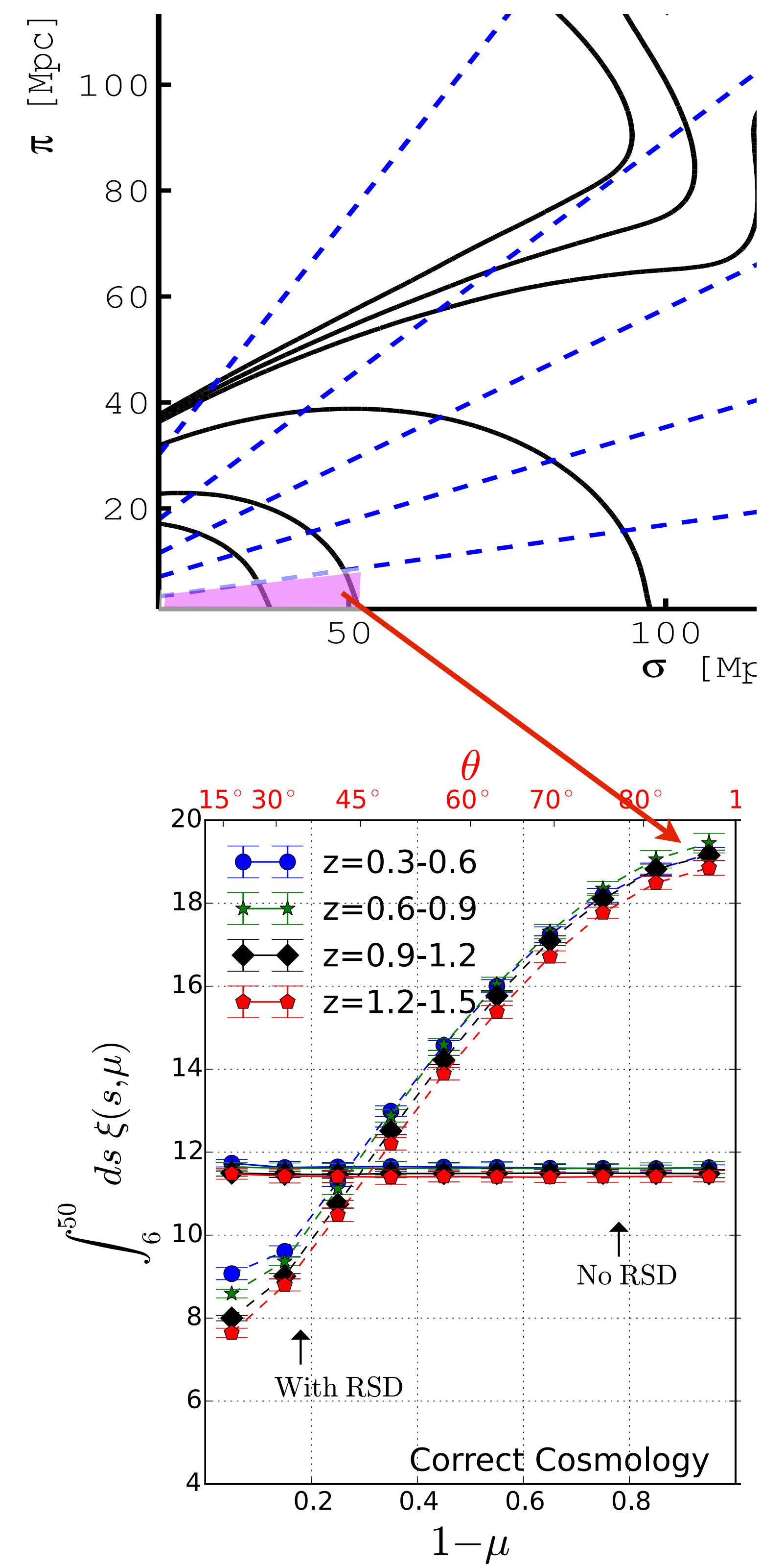
Can we construct a clustering statistic that is redshift invariant?

The integrated clustering strength as a function of angle at varies redshifts.

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

In the no RSD case in the correct cosmology the curves are flat.

With RSDs we see much more variation in shape and amplitude.



Clustering Shells

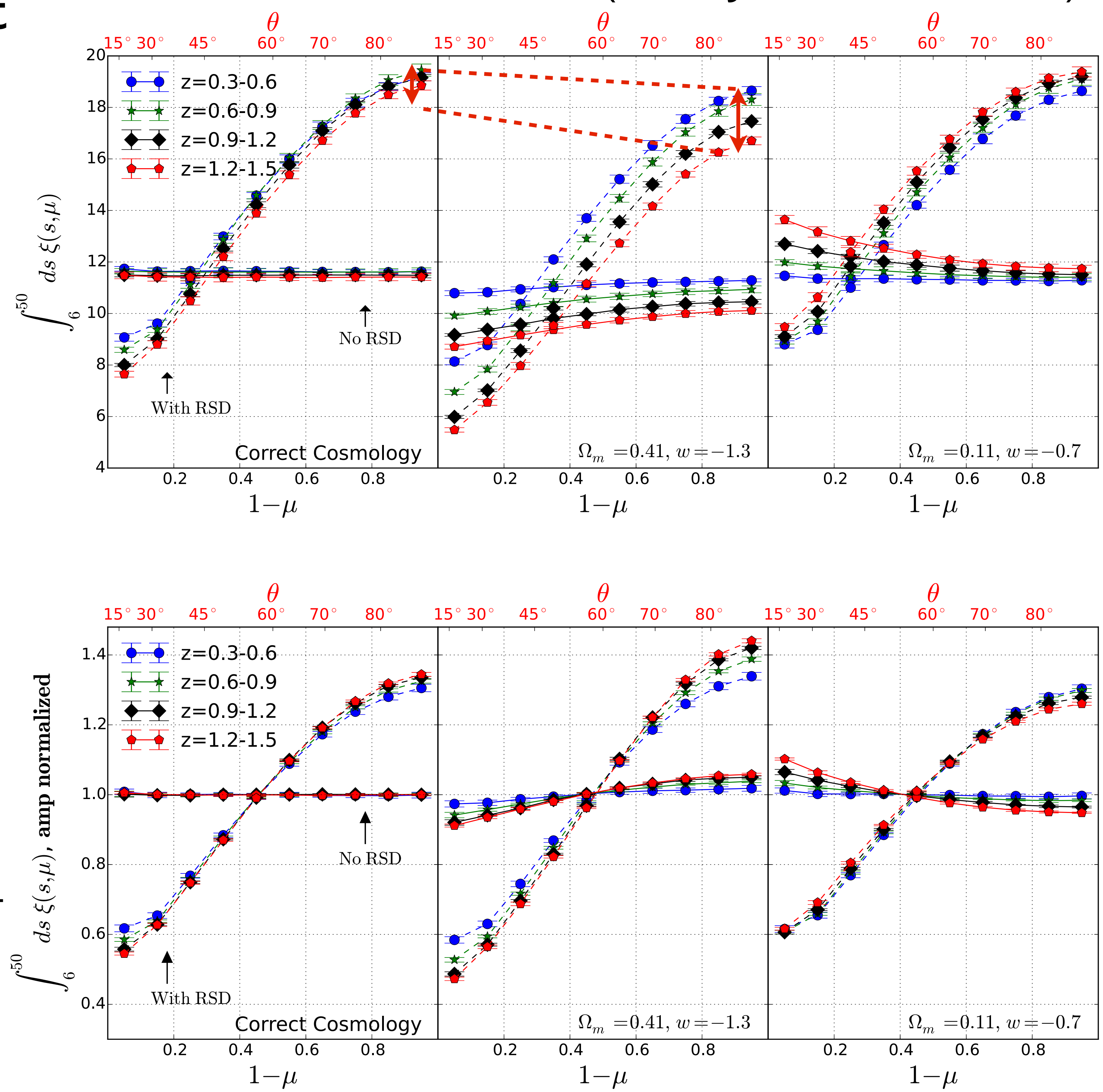
The **integrated clustering strength** as a function of angle at <u>various redshifts</u>

In the no RSD case in the <u>correct cosmology the curves are flat</u>. In the wrong cosmologies they are <u>distorted</u>

We <u>normalise the curves</u> to remove amplitude information, minimise the volume effect thus focusing on a **pure AP effect**

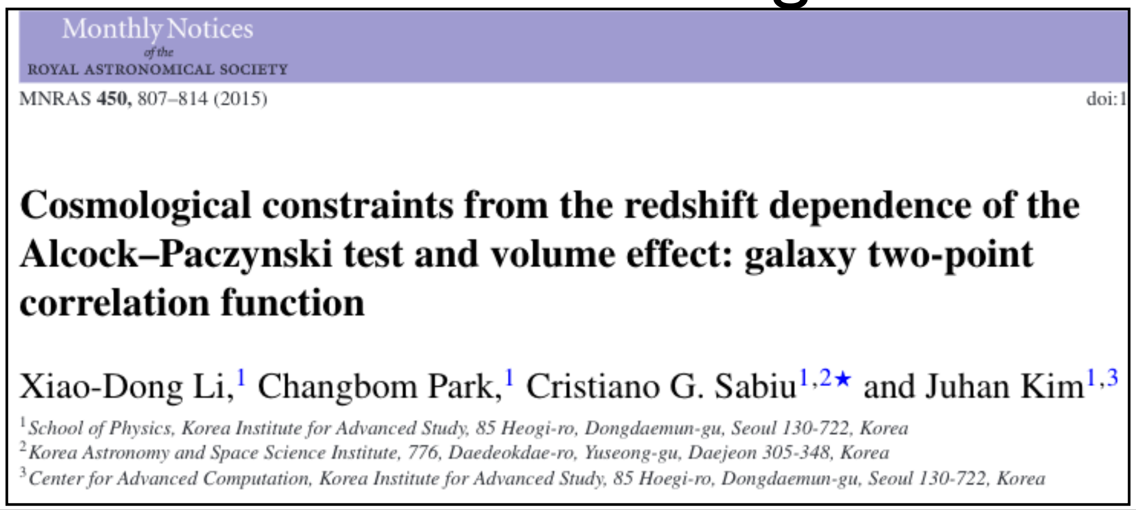
We construct a <u>likelihood function</u> by requiring that the shape change as a function of redshift is minimized

Using mock many catalogues drawn from the Horizon Run simulations (from Juhan Kim, KIAS)



Who needs the BAO? Go to small scales

with Xiao-Dong Li & Changbom Park (KIAS) et al

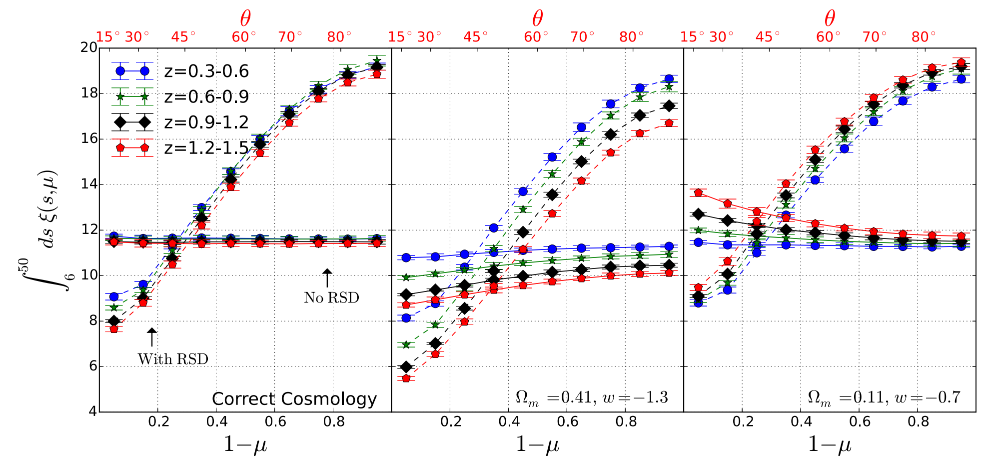

Monthly Notices of the Royal Astronomical Society

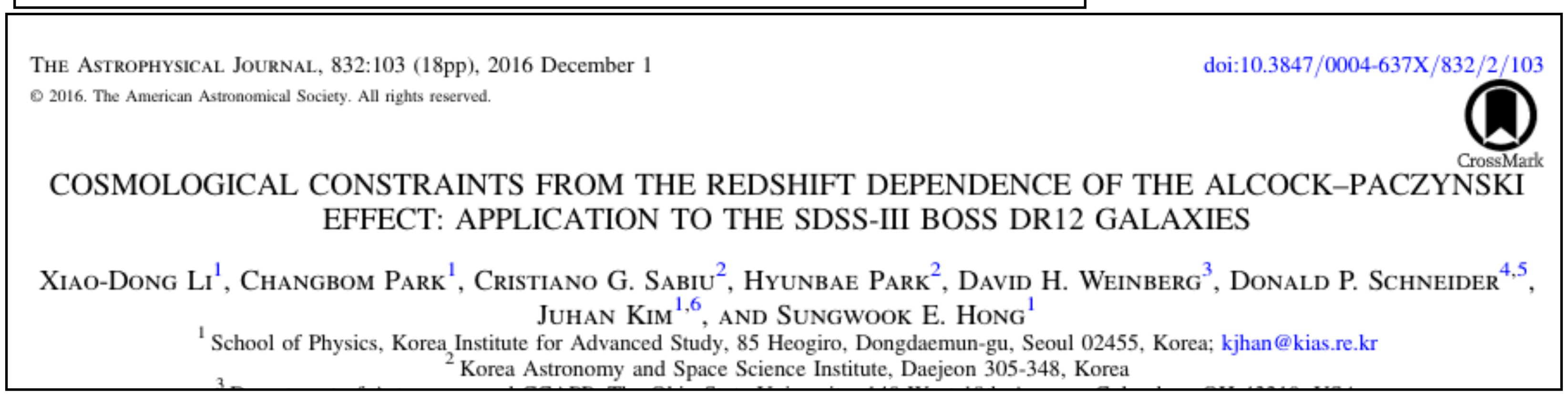
MNRAS 450, 807–814 (2015) doi:1

Cosmological constraints from the redshift dependence of the Alcock–Paczynski test and volume effect: galaxy two-point correlation function

Xiao-Dong Li,[1] Changbom Park,[1] Cristiano G. Sabiu[1,2★] and Juhan Kim[1,3]

[1]*School of Physics, Korea Institute for Advanced Study, 85 Heogi-ro, Dongdaemun-gu, Seoul 130-722, Korea*
[2]*Korea Astronomy and Space Science Institute, 776, Daedeokdae-ro, Yuseong-gu, Daejeon 305-348, Korea*
[3]*Center for Advanced Computation, Korea Institute for Advanced Study, 85 Hoegi-ro, Dongdaemun-gu, Seoul 130-722, Korea*




THE ASTROPHYSICAL JOURNAL, 832:103 (18pp), 2016 December 1 doi:10.3847/0004-637X/832/2/103

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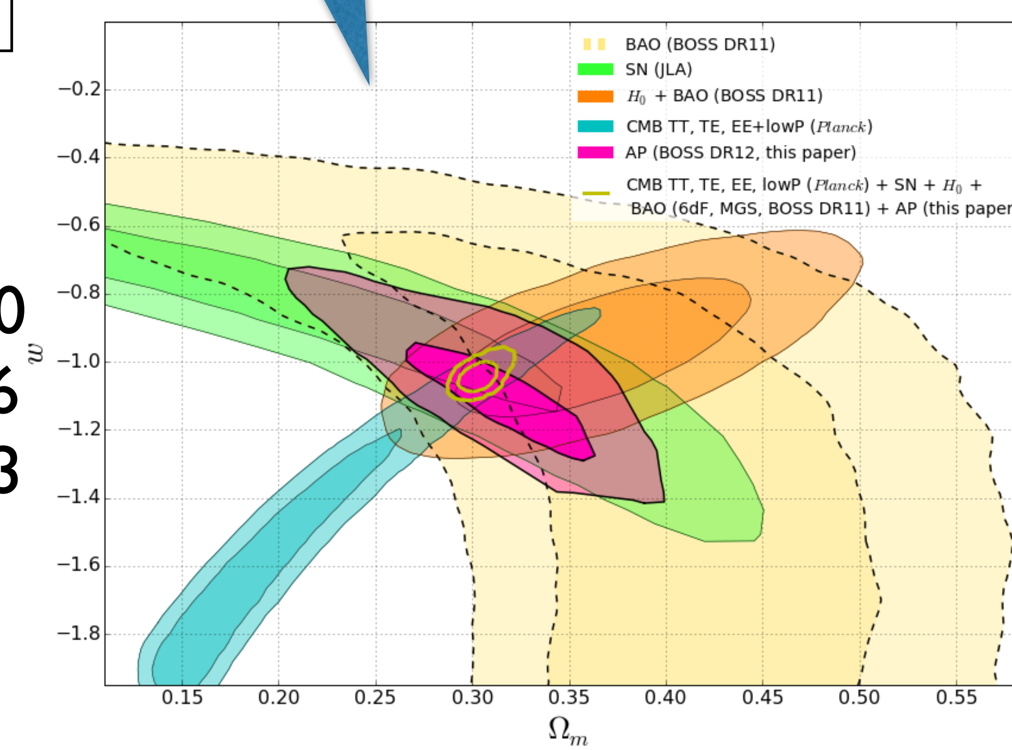
COSMOLOGICAL CONSTRAINTS FROM THE REDSHIFT DEPENDENCE OF THE ALCOCK–PACZYNSKI EFFECT: APPLICATION TO THE SDSS-III BOSS DR12 GALAXIES

Xiao-Dong Li[1], Changbom Park[1], Cristiano G. Sabiu[2], Hyunbae Park[2], David H. Weinberg[3], Donald P. Schneider[4,5], Juhan Kim[1,6], and Sungwook E. Hong[1]

[1] School of Physics, Korea Institute for Advanced Study, 85 Heogiro, Dongdaemun-gu, Seoul 02455, Korea; kjhan@kias.re.kr
[2] Korea Astronomy and Space Science Institute, Daejeon 305-348, Korea



Xiao-Dong Li, Changbom Park, Cristiano G. Sabiu, +++
Mon.Not.Roy.Astron.Soc. 450 (2015) 807 arXiv:1504.00740
Astrophysical Journal (2016) 832 103 arXiv:1609.05476
Astrophysical Journal (2017) accepted arXiv:1706.09853

Using 3PCF - Li, Sabiu, Park, etal - in prep

Results: in preparation

Cosmological constraints from the redshift dependence of the Alcock-Paczynski effect: significant improvement in the dark energy figure of merit

Xiao-Dong Li,[1] Cristiano G. Sabiu,[2] Changbom Park,[1] Yuting Wang,[3] Gong-bo Zhao,[3]
Hyunbae Park,[2] Arman Shafieloo,[2] Juhan Kim,[4] and Sungwook E. Hong[2][1,2,3,4]

Focusing now on the **evolving dark energy models**, we consider the CPL parameterisation:

$$w(z) = w_0 + w_a(1-a) = w_0 + w_a\frac{z}{1+z}.$$

We combine with CMB, Supernovae and BAO data
Then marginalise other parameters to obtain constrains on $\mathbf{w_0}$ **and** $\mathbf{w_a}$

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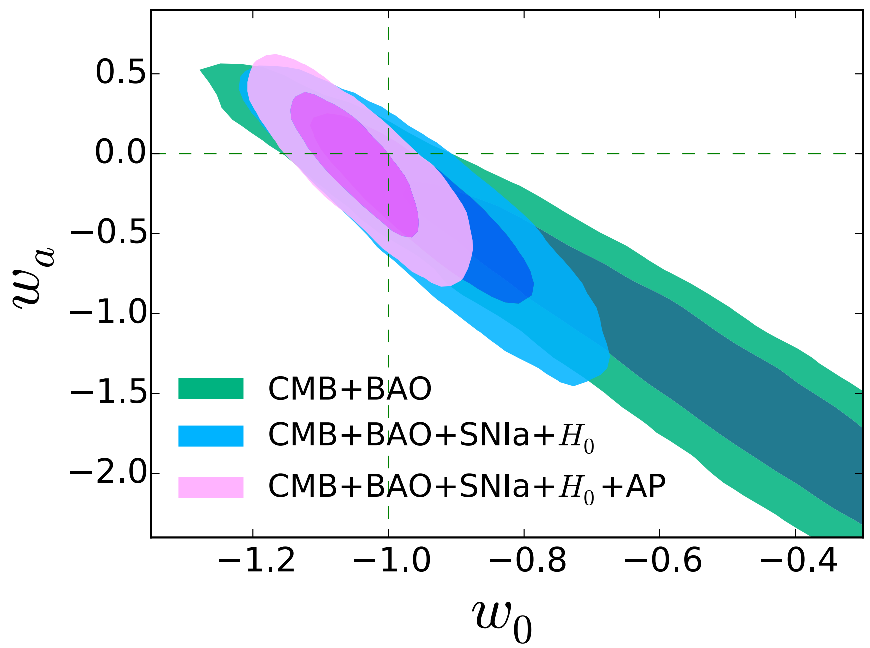
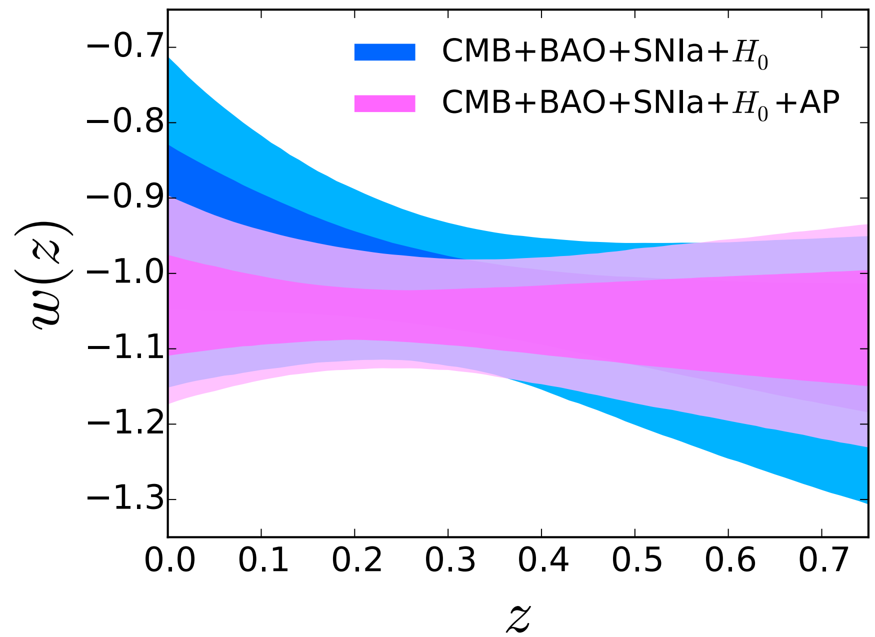
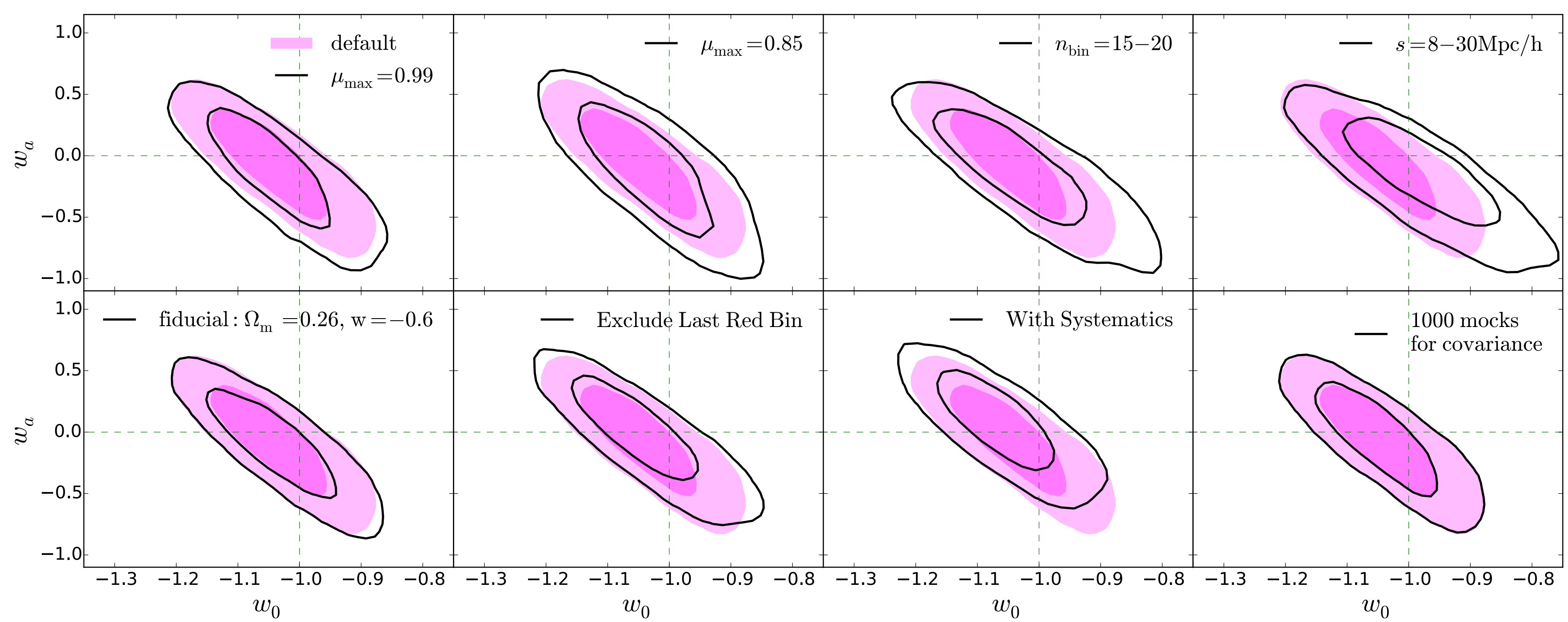
Factor of 2 improvement in constraints compared to <u>standard BAO</u>





Results are robust and Systematics seem under control

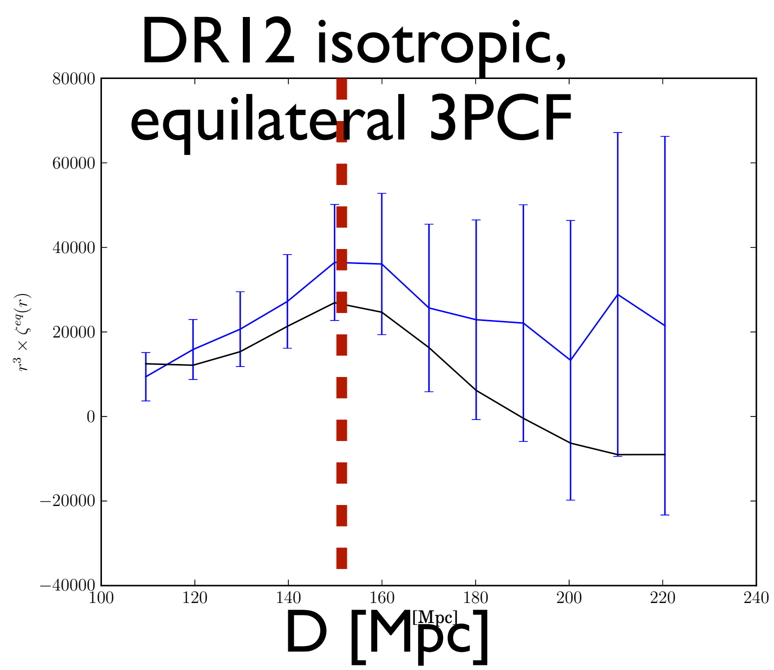


Short Advert: BAO at Higher Order

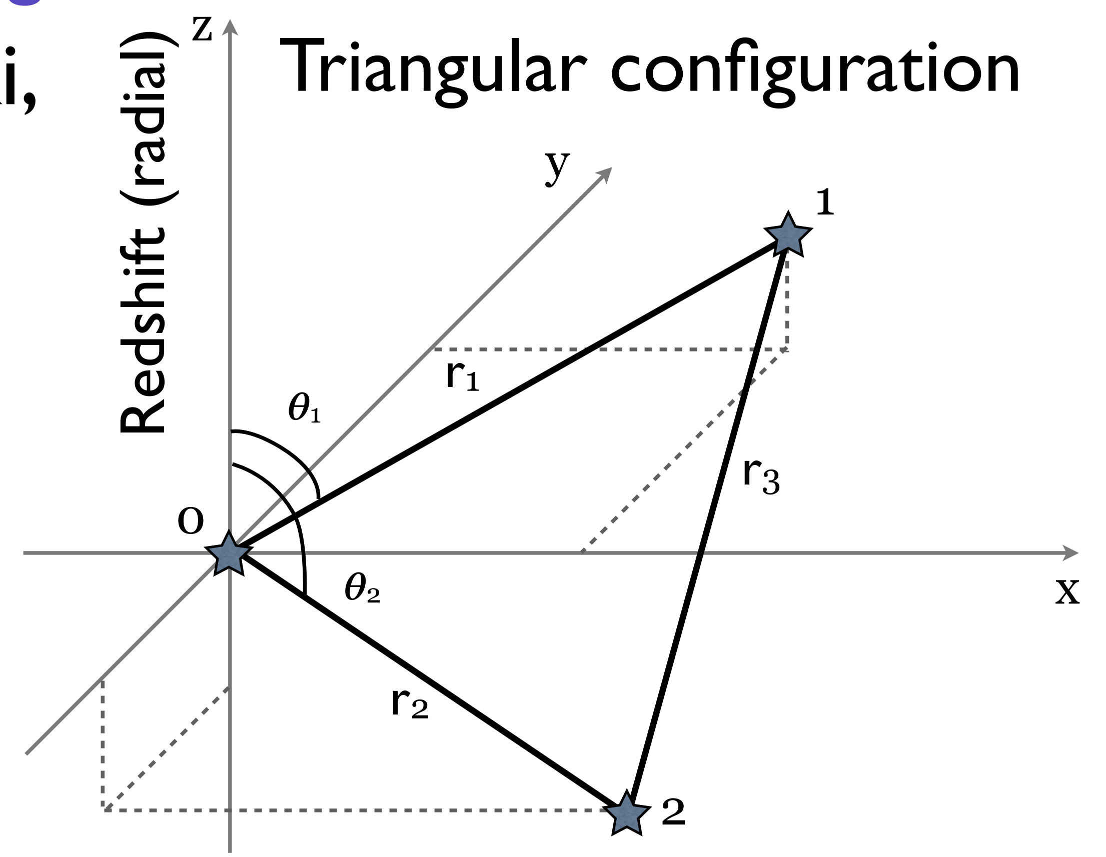
Higher Order Clustering Statistics: Towards the generalised BAO membrane

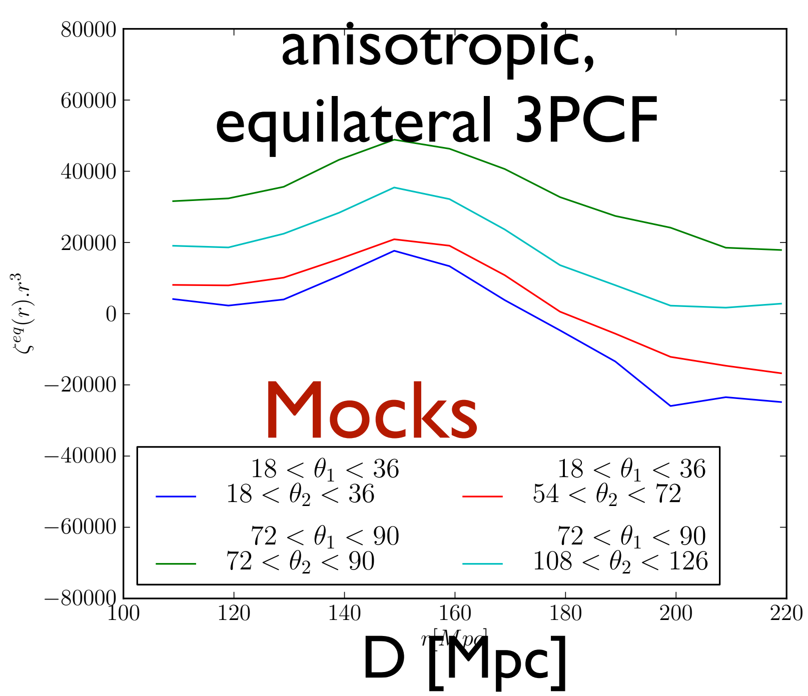
D_A, H^{-1} from higher order Alcock-Paczynski, i.e.

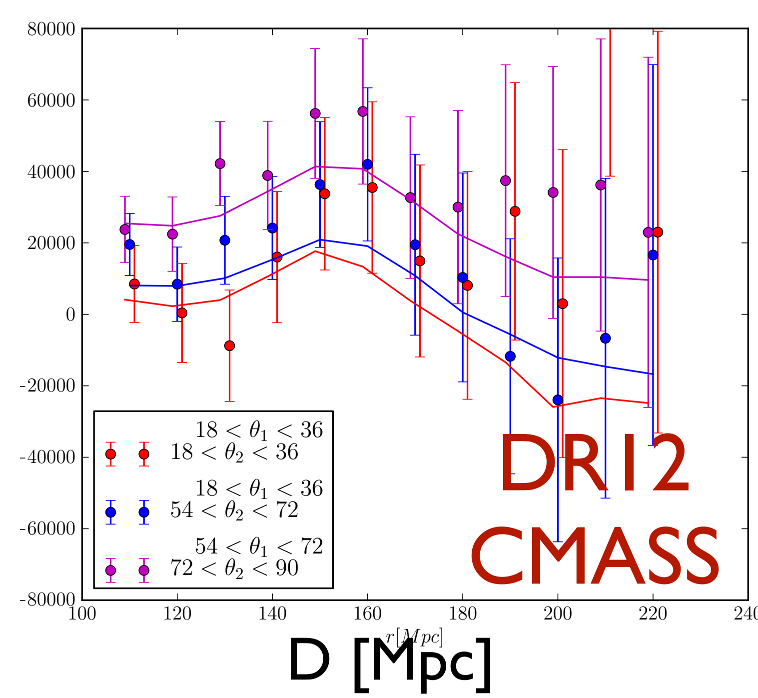
$$\tilde{B}^{\rm obs}(k_1,k_2,k_3,\mu_1,\mu_2) = \left(\frac{H^{\rm true}}{H^{\rm fid}}\right)^2 \left(\frac{D_A^{\rm fid}}{D_A^{\rm true}}\right)^4 \times \tilde{B}(q_1,q_2,q_3,\nu_1,\nu_2)\,.$$

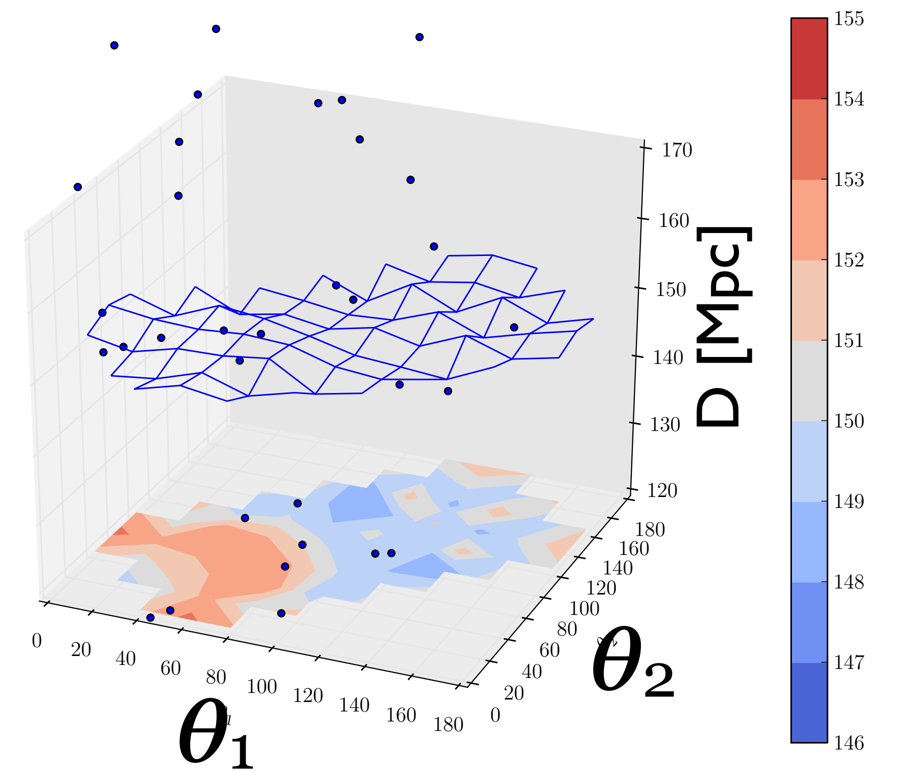


From isotropic to anisotropic to the generalised BAO membrane









Conclusions

We searched for **redshift invariant clustering** signal, to maximise Alcock Paczynski (incorrect model) Effect

- we found normalised anisotropic clustering shells
- their redshift evolution is minimal in correct cosmology

We wanted clean measurements of Da and H(z) as they are fundamental quantities that describe the **geometry** and **evolution** of the background universe.

- we have measured the anisotropic clustering shells in BOSS
- We constrain the CPL Dark Energy parameters
- Found a **factor of 2 improvement** over standard BAO
- or factor of 2 improvement in Cost/Science ratio for DE surveys!