SKKI

Cosmological Constraints from the Anisotropic Clustering Analysis using BOSS DR9

(w/ E. V. Linder, T. Okumura, C. G. Sabiu, Y. -S. Song)

UST- KASI

Astronomy and Space Science

MinJi Oh

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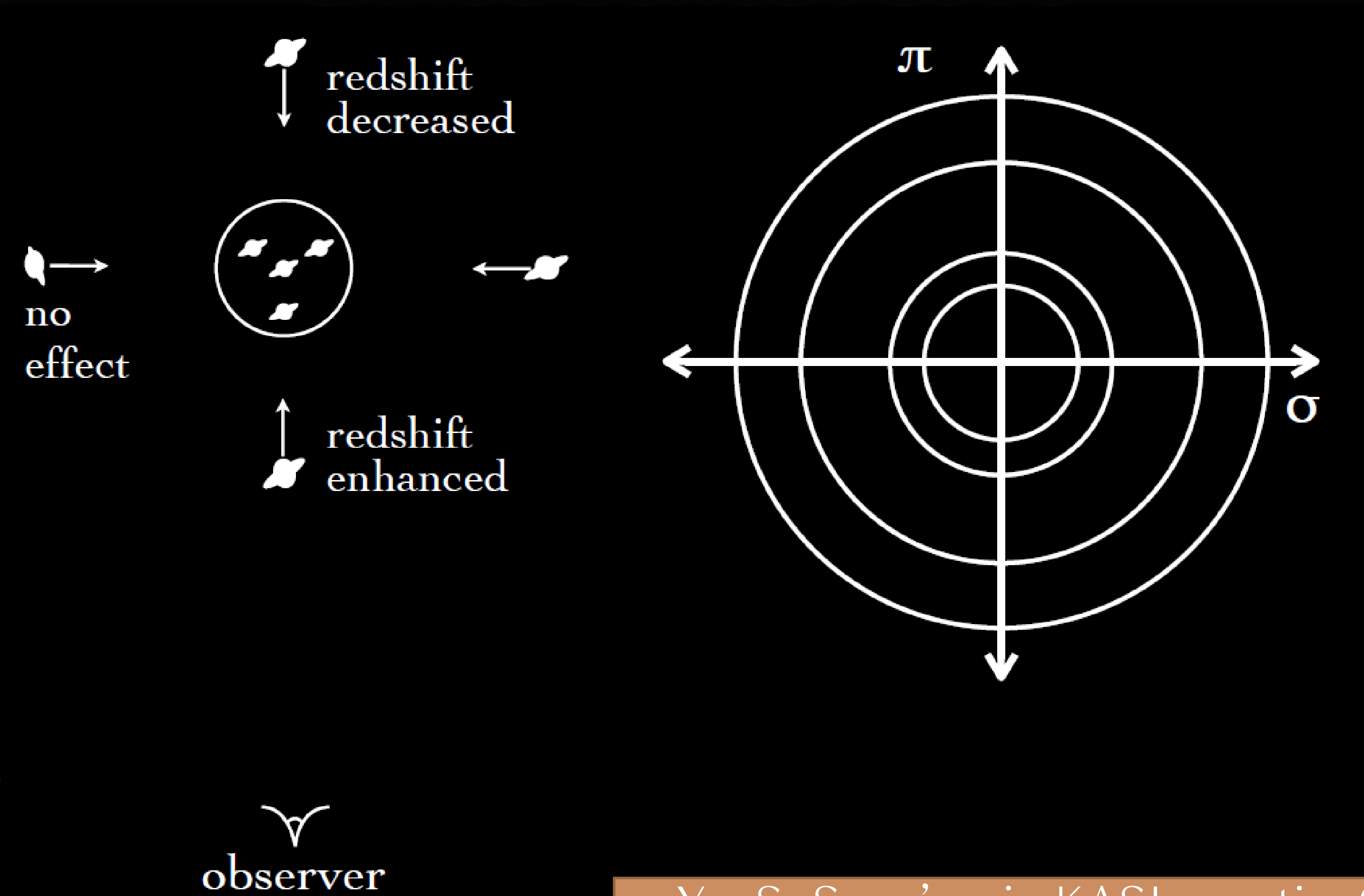
1. INTRODUCTION

1. Introduction

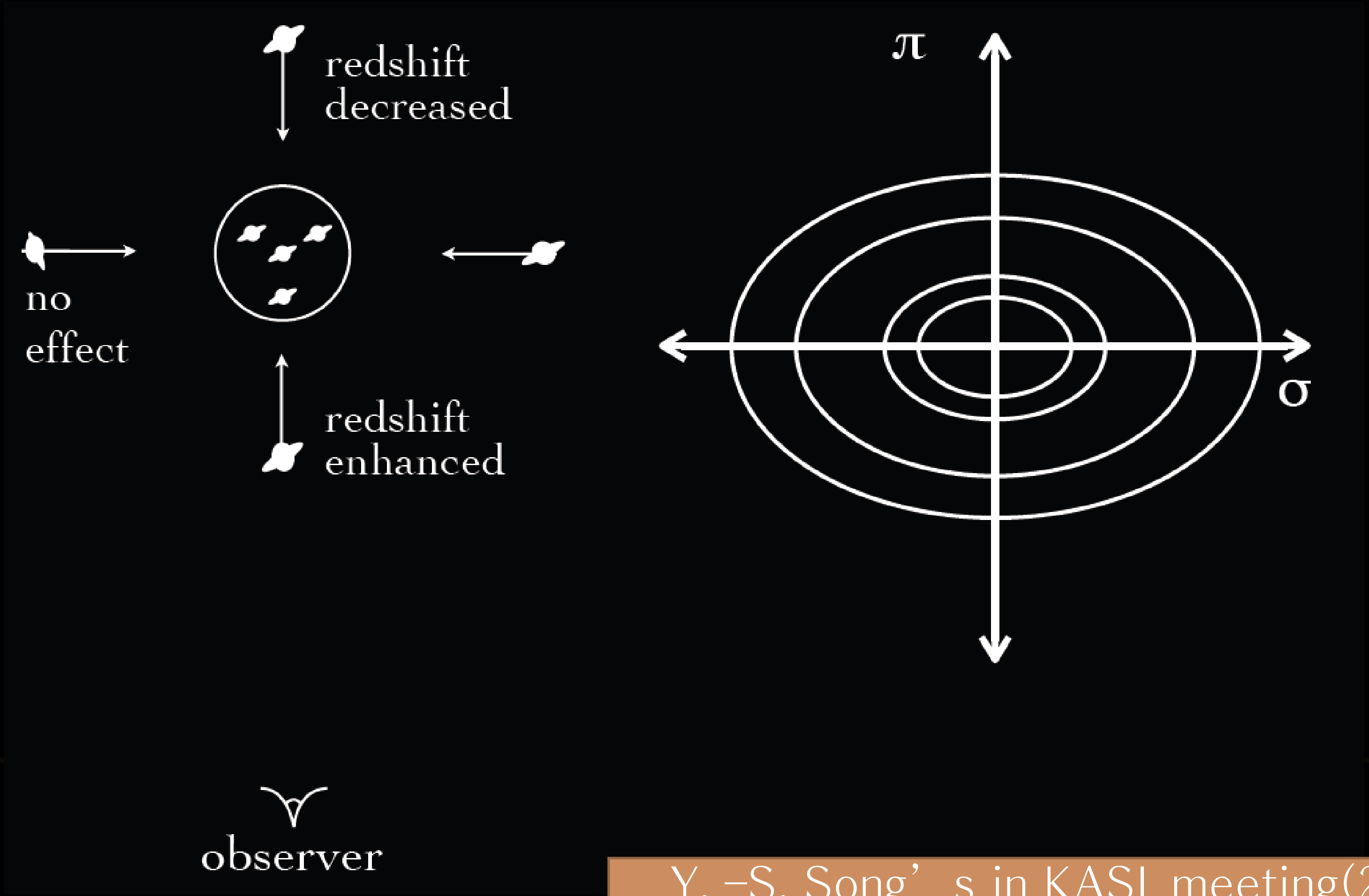
- Redshift-space distortion



Y. –S. Song's in KASI_meeting(2013)

1. Introduction

- Redshift-space distortion



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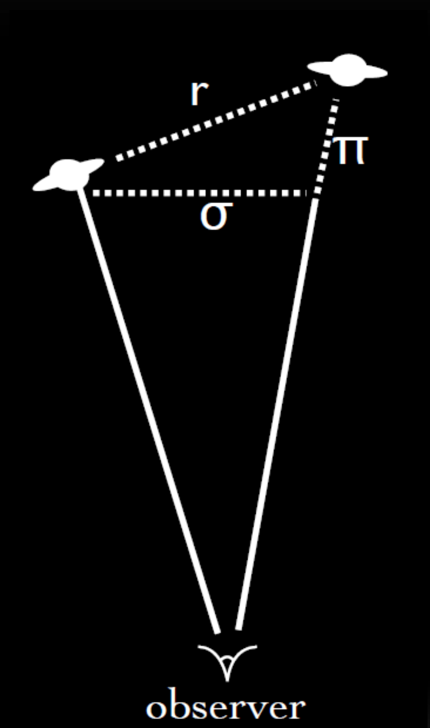
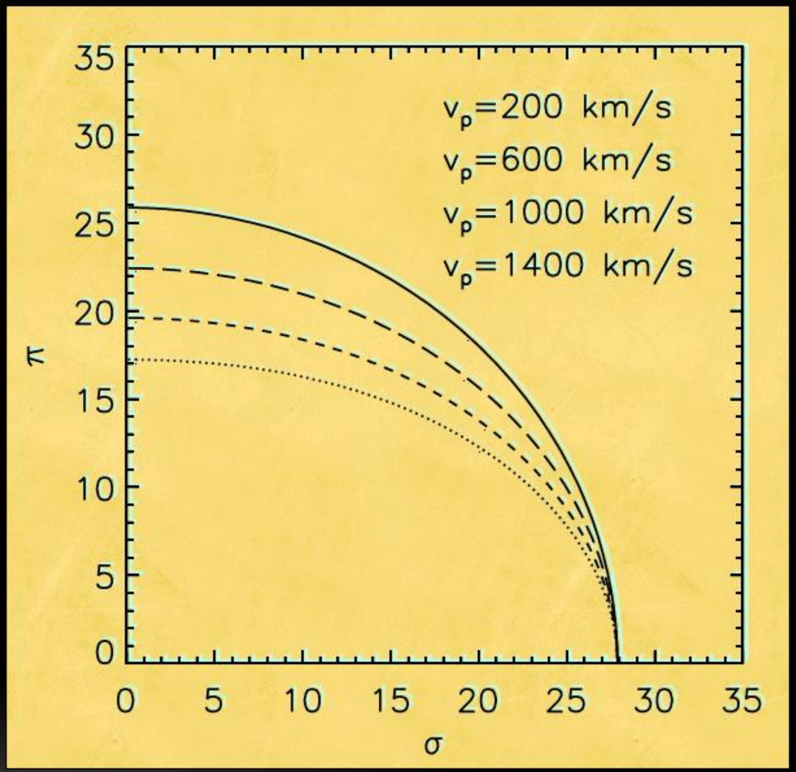
1. Introduction

- Redshift-space distortion



Radial direction w.r.t. l.o.s



Transeverse direction w.r.t l.o.s

Y. –S. Song’ s in KASI_meeting(2013)

Cosmological Constraints from the Anisotropic Clustering Analysis using BOSS DR9

2. THEORETICAL MODEL

2. Theoretical Model

- Redshift-space distortion(RSD)

  :An anisotropic features in the clustering pattern of galaxies in redshift space
- Main features in the resultant two-point correlation function, ξ_s
  - At linear regimes,
    - Kaiser effect- squeezed clustering pattern along l.o.s
    - enhance the amplitude of the observed correlation ftn
  - At non-linear regimes,
    - Finger of God effect- elongate clustering along l.o.s
    - caused by the random virial motions of galaxies residing at halos
  - cf. BAO peak

In the distant observer limit

2. Theoretical Model

- Redshift-space power spectrum

$$\tilde{P}(k,\mu) = \sum_{n=0}^{4} Q_{2n}(k)\mu^{2n} G^{FoG}(k\mu\sigma_p)$$

Taruya, Nishimichi, and Saito (2010)

$$cf.\ P_{Kaiser}(k,\mu) = \begin{cases} (1+f\mu^2)^2 P_{\delta\delta}(k) & ;\mathrm{linear} \\ P_{\delta\delta}(k) + 2f\mu^2 P_{\delta\theta}(k) + f^2\mu^4 P_{\theta\theta}(k) & ;\mathrm{non-linear} \end{cases}$$

N. Kaiser (1987)

- Redshift-space correlation function

$$\xi^s(\sigma,\pi) = \int \frac{d^3k}{(2\pi)^3} \tilde{P}(k,\mu) e^{i\vec{k}\cdot\vec{s}}$$

$$= \sum_{\mathrm{even}\ l} \xi_l(s) P_l(\nu) \quad \text{where } P_l \text{ is the Legendre polynomials}$$

$$\nu = \pi / s,\ \ s = (\sigma^2 + \pi^2)^{1/2}$$

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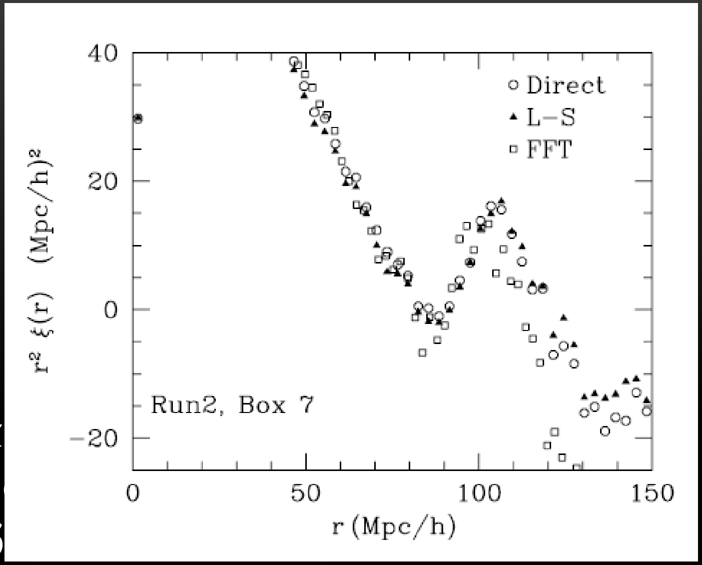
3. MEASUREMENTS

3. Measurements



Huff, E. et al. (2007)

- Data sample: BOSS galaxy samples, CMAS
- Coordinate transformation from (RA, dec, z
  two fiducial spatially-flat cosmological mo
  w_c=0.1138, H_0=70) and Planck (w_b=0.02206
- Landy-Szalay estimator(2D):

$$\xi(\sigma,\pi)=\frac{DD(\sigma,\pi)-2DR(\sigma,\pi)+RR(\sigma,\pi)}{RR(\sigma,\pi)}\approx\frac{DD(\sigma,\pi)}{RR(\sigma,\pi)}-1$$

correlation function

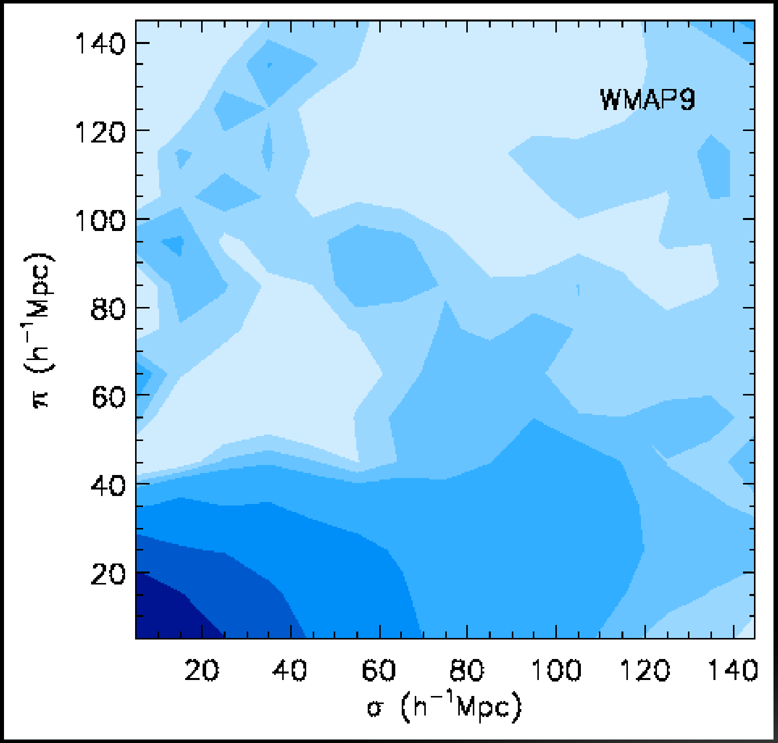
if the random map is perfectly random

Landy, S. D. & Szalay, A. S. (1993)

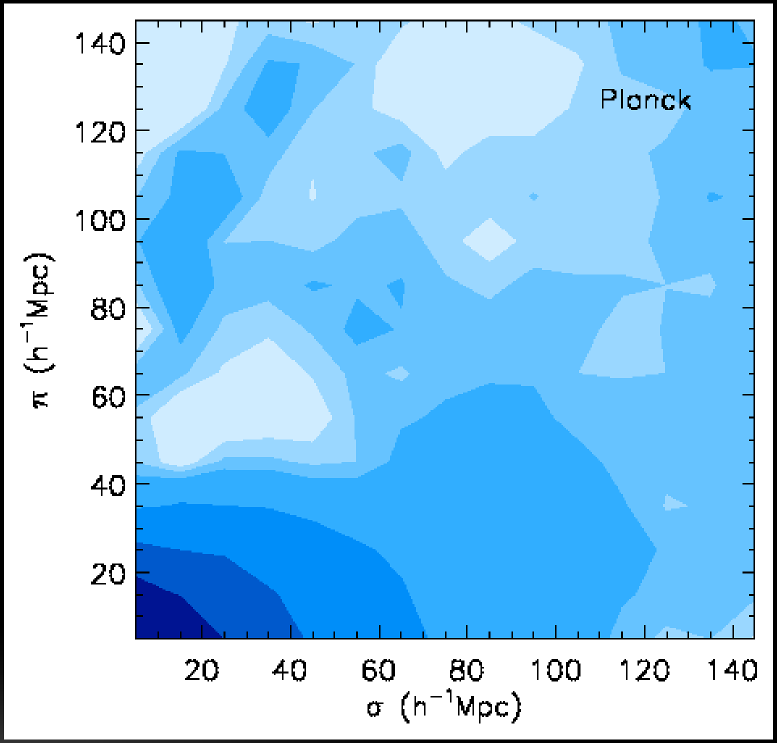
where DD(sigma, pi): the number of pairs in Data
with separation sigma+-del(sigma) and pi+-del(pi)

3. Measurements
:Measuring the correlation function

With WMAP9 early universe prior



With Planck early universe prior



- Kaiser effect at small sigma
- 2D BAO ring at sqrt(sigma^2+pi^2)~100Mpc/h

cf. The contour level=(0.2, 0.06, 0.016, 0.005, 0.002, −0.001, −0.006) from the inner one

4. Results of 2D Anisotropy Analysis

A. FITTED METHOD

4. Results of 2D Anisotropy Analysis

A. Fitting method

- Assumption:
  - the shape of the power spectra is given by CMB experiments
  - Evolve "coherently" through all scales from the LSS

4. Results of 2D Anisotropy Analysis

A. Fitting method

$$\xi^s(\sigma,\pi) = \int \frac{d^3k}{(2\pi)^3} \tilde{P}(k,\mu) e^{i\vec{k}\cdot\vec{s}} = \sum_{\text{even } l} \xi_l(s) P_l(\nu)$$

- The power spectra are given by,

$$P_{bb}(k,a) = D_m(k) G_b^2(a)$$

$$P_{\Theta\Theta}(k,a) = D_m(k) G_\Theta^2(a)$$

– where G_b and G_Θ : the growth functions of density and peculiar velocity

– $G_b \equiv b G_{\delta_m}$ where b is the standard linear bias parameter bet. δ_g and δ_m

– $D_m(k) = \frac{4}{9} \frac{k^4}{H_0^4 \Omega_m^2} D_\Phi(k)$: shape factor (given by CMB exp.)

Song, Sabiu, Kayo and Nichol(2011)

cf. $\Phi(\vec{\mathrm{k}}, \mathrm{a}) = \Phi_\mathrm{p}(\vec{k}) \times \mathit{Transfer\ Function}\ (k) \times \mathit{Growth\ Function}\ (a)$

4. Results of 2D Anisotropy Analysis

A. Fitting method

- Fitting by rescaling the transverse and radial distances

$$\sigma^{\mathrm{fid}} = \frac{D_A^{\mathrm{fid}}}{D_A^{\mathrm{true}}}\sigma^{\mathrm{true}}, \quad \pi^{\mathrm{fid}} = \frac{H^{-1\,\mathrm{fid}}}{H^{-1\,\mathrm{true}}}\pi^{\mathrm{true}}$$

$$\xi^{\mathrm{fid}}(\sigma^{\mathrm{fid}},\pi^{\mathrm{fid}}) \leftarrow -\, \textit{fitted}\ \text{by}\ \textit{rescaling} -\ \xi^{\mathrm{true}}(\sigma^{\mathrm{true}},\pi^{\mathrm{true}})$$

-↑ The observed anisotropy correlation ftn using 'LCDM concordance model'

-The theoretical C.F.↑

- Another fitting parameter, σ_{p} representing non-linear contamination to the power spectra of the density and velocity fields (FoG/ Gaussian)

4. Results of 2D Anisotropy Analysis

B. CUT-OFF SCALES AND 2D BAO CIRCLE

4. Results of 2D Anisotropy Analysis
B. Cut-off scales and 2D BAO circle

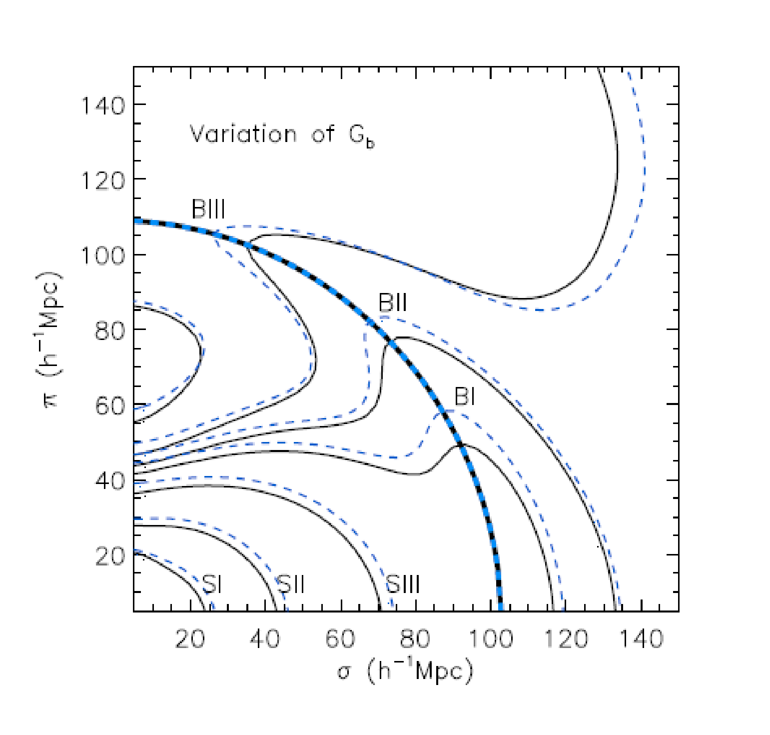
- The appropriate cut-off scales:
  1) S_{cut}: the scales in which non-linear description of cross correlation is broken
     - 50Mpc/h
     - Allows the perfect cross-correlation between density and velocity fields
  2) σ_{cut}: The scales in which Gaussian FoG functional form is not appropriate
     - because the improved $\xi(\sigma, \pi)$ is not applicable at bins in which the higher order terms of non-perturbative effect are dominant along l.o.s.
     - 20Mpc/h reproduced the true values successfully for DR7 CMASS
     - ? for DR9 CMASS

Song, Okumura and Taruya et al.(2013)

4. Results of 2D Anisotropy Analysis
B. Cut-off scales and 2D BAO circle

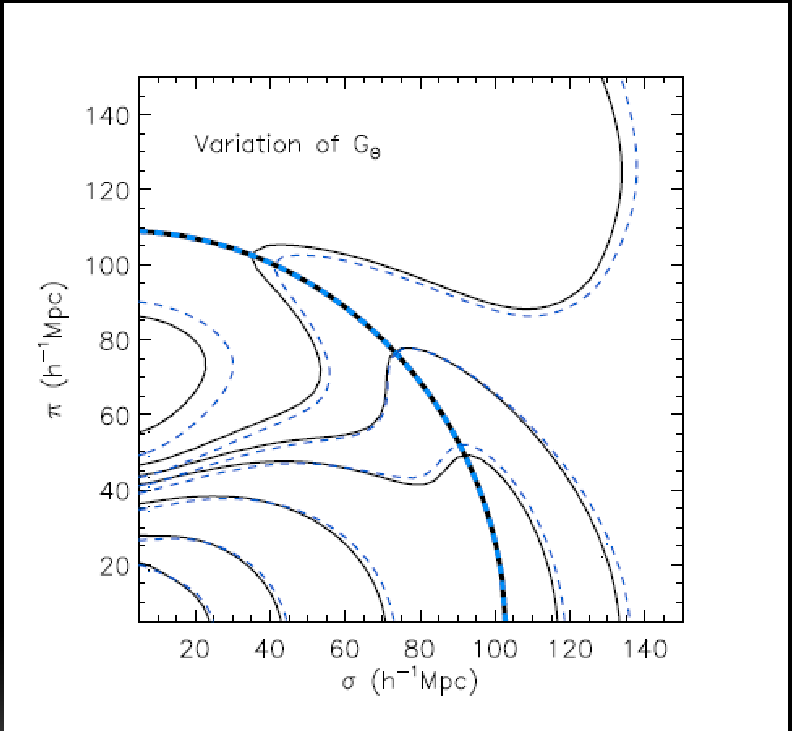
Increase Gb by10%

(Thin black solid to thin blue dashed)



Increase Gtheta by 10%

(Thin black solid to thin blue dashed)



- The BAO tip points move counter-clockwise
- 2D BAO circle: inv.

- The BAO tip points shrink toward the pivot point
- 2D BAO circle: inv.

Song, Okumura and Taruya et al.(2013)

4. Results of 2D Anisotropy Analysis
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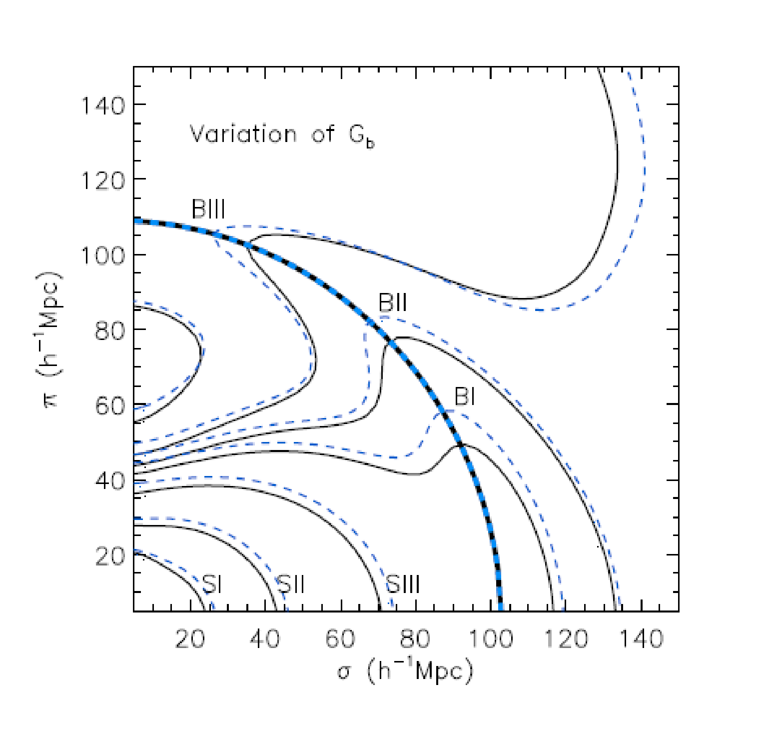


$$\xi_s(\sigma,\pi)(a) = \left(g_b^2 + \frac{2}{3}g_b g_\Theta + \frac{1}{5}g_\Theta^2\right)\xi_0(r)\mathcal{P}_0(\mu) - \left(\frac{4}{3}g_b g_\Theta + \frac{4}{7}g_\Theta^2\right)\xi_2(r)\mathcal{P}_2(\mu) + \frac{8}{35}g_\Theta^2\xi_4(r)\mathcal{P}_4(\mu),$$

Song, Sabiu, Kayo and Nichol(2011)

- The BAO tip points move counter-clockwise
- 2D BAO circle: inv.

4. Results of 2D Anisotropy Analysis

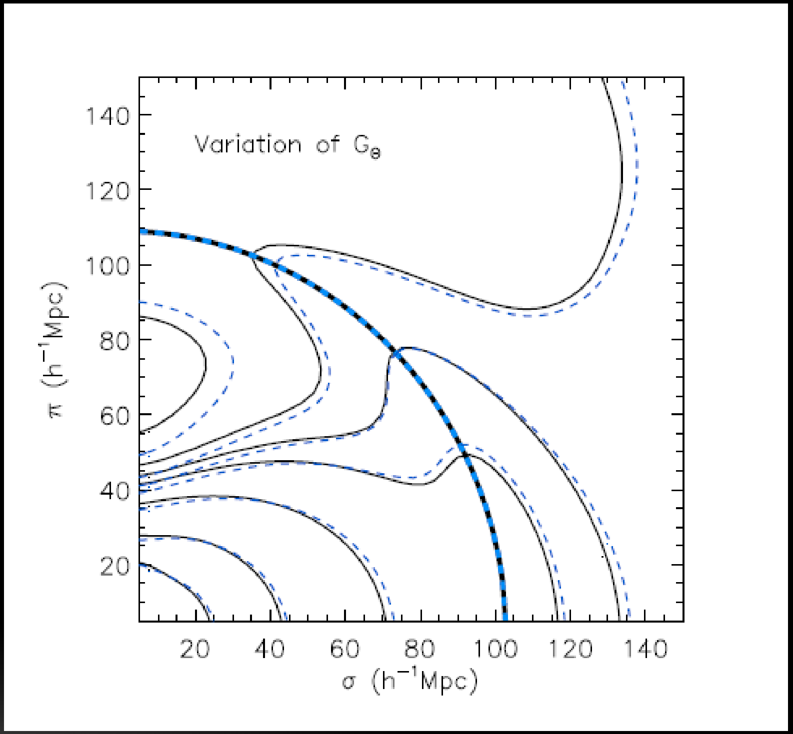
B. Cut-off scales and 2D BAO circle

$$
\begin{aligned}
\xi_s(\sigma,\pi)(a) = {} & \left(g_b^2 + \frac{2}{3} g_b g_\Theta + \frac{1}{5} g_\Theta^2\right) \xi_0(r)\mathcal{P}_0(\mu) \\
& - \left(\frac{4}{3} g_b g_\Theta + \frac{4}{7} g_\Theta^2\right) \xi_2(r)\mathcal{P}_2(\mu) \\
& + \frac{8}{35} g_\Theta^2 \xi_4(r)\mathcal{P}_4(\mu),
\end{aligned}
$$

Song, Sabiu, Kayo and Nichol(2011)

Increase Gtheta by 10%

(Thin black solid to thin blue dashed)

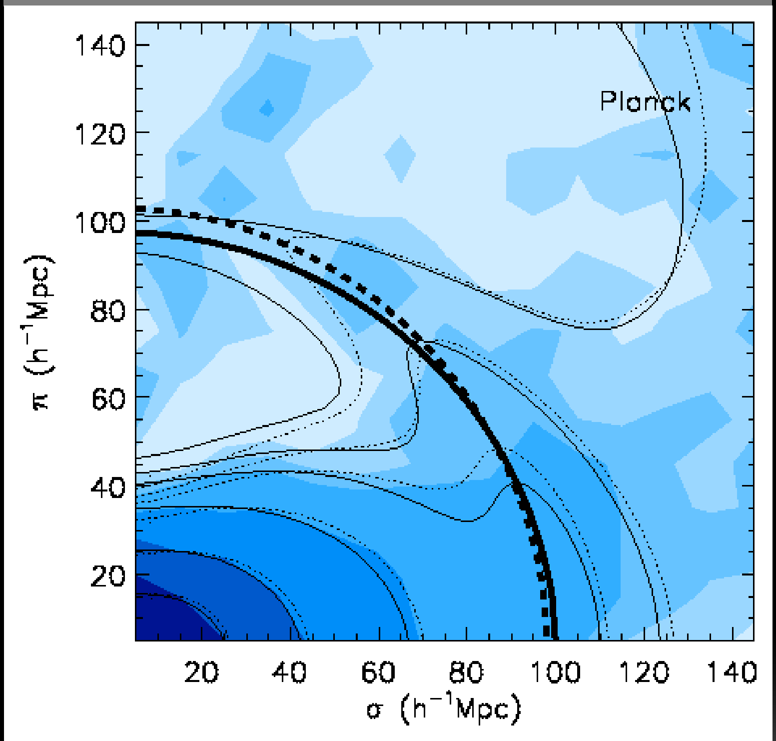


- The BAO tip points shrink toward the pivot point
- 2D BAO circle: inv.

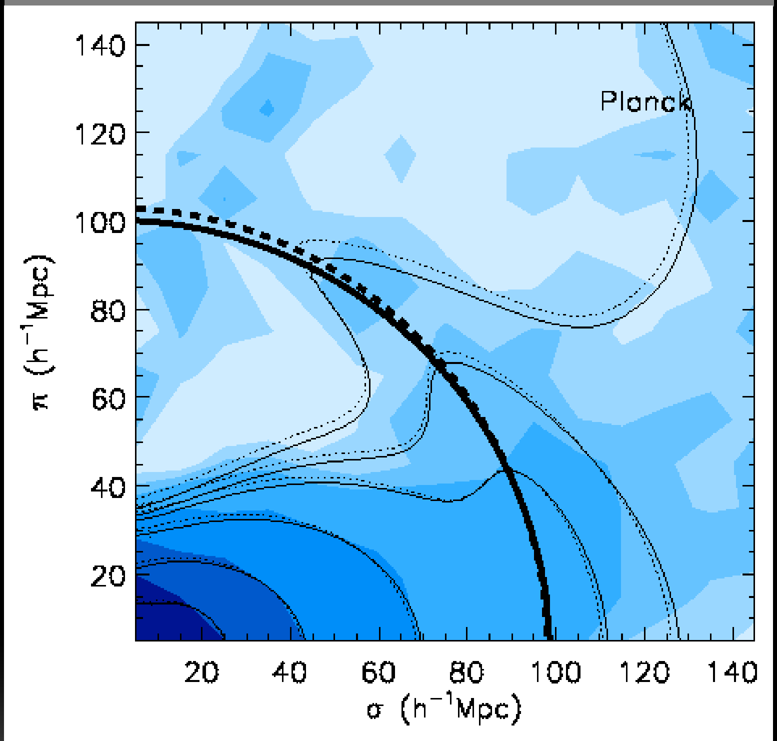
4. Results of 2D Anisotropy Analysis

B. Cut-off scales and 2D BAO circle

$\sigma_{\mathrm{cut}} = 20\mathrm{Mpc}/h$



$\sigma_{\mathrm{cut}} = 40\mathrm{Mpc}/h$



where the thin black solid represents the best fit and the thin dashed 'LCDM concordance' model
cf. The contour level=(0.2, 0.06, 0.016, 0.005, 0.002, -0.001, -0.006) from the inner one

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B. Cut-off scales and 2D BAO circle

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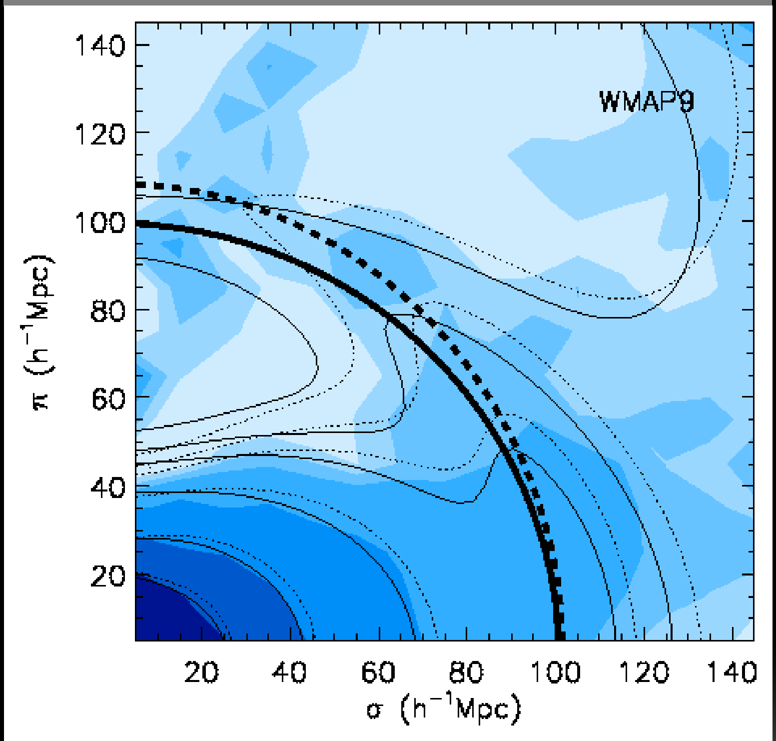
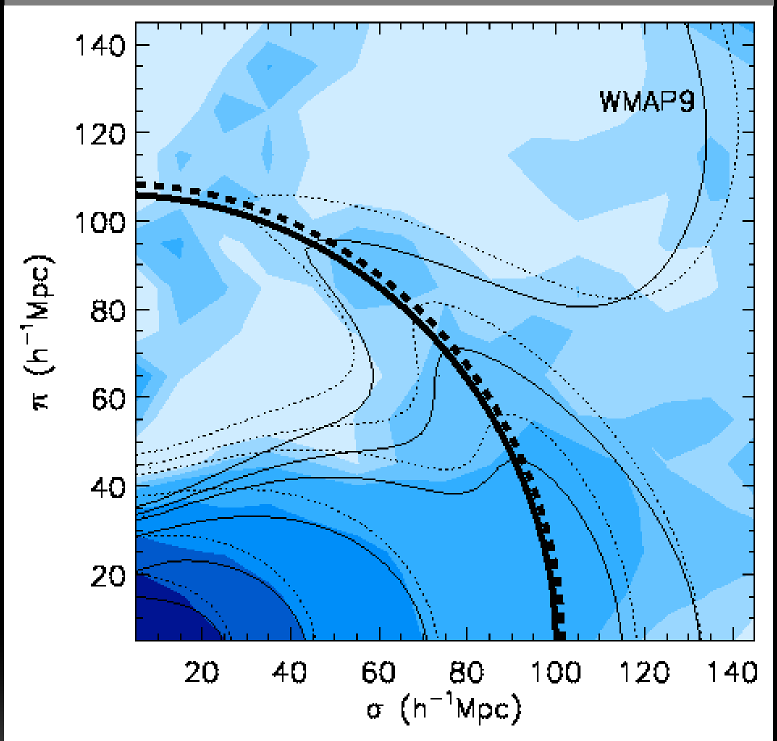


$\sigma_{\text{cut}} = 40\text{Mpc}/h$



where the thin black solid represents the best fit and the thin dashed 'LCDM concordance' model
cf. The contour level=(0.2, 0.06, 0.016, 0.005, 0.002, -0.001, -0.006) from the inner one

4. Results of 2D Anisotropy Analysis
C. The measured distances and growth fn

Parameters	Fiducial values	Measurements
	With WMAP9 prior	
$D_A\,(h^{-1}\,\mathrm{Mpc})$	946.0	$916.2^{+27.2}_{-25.4}$
$H^{-1}\,(h^{-1}\,\mathrm{Mpc})$	2241.5	$2163.1^{+102.0}_{-85.8}$
G_b	–	$1.07^{+0.07}_{-0.09}$
G_Θ	0.44	$0.51^{+0.09}_{-0.08}$
$\sigma_p\,(h^{-1}\,\mathrm{Mpc})$	–	$1.0^{+4.6}$
Parameters	Fiducial values	Measurements
	With Planck prior	
$D_A\,(h^{-1}\,\mathrm{Mpc})$	932.6	$939.7^{+26.7}_{-32.6}$
$H^{-1}\,(h^{-1}\,\mathrm{Mpc})$	2177.5	$2120.5^{+82.3}_{-100.6}$
G_b	–	$1.11^{+0.07}_{-0.10}$
G_Θ	0.46	$0.47^{+0.10}_{-0.07}$
$\sigma_p\,(h^{-1}\,\mathrm{Mpc})$	–	$1.2^{+4.0}$

The applied cut -off
- S_{cut}=50Mpc/h
- σ_{cut}=40Mpc/h

- For WMAP9,
  - Consistent with LCDM prediction
  - exits a little Tension, relative to Planck
- For Planck,
  - Consistent with LCDM prediction

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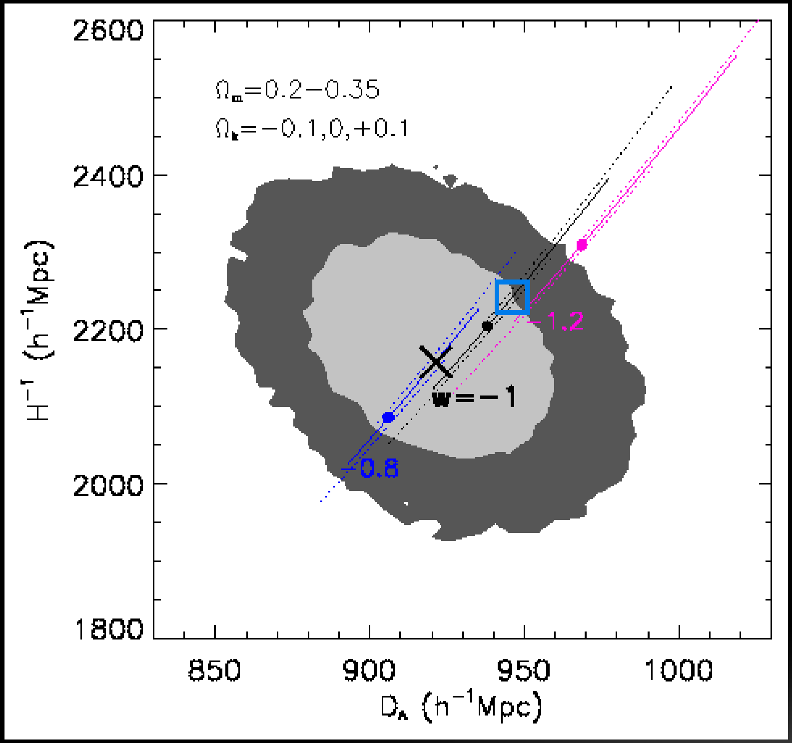
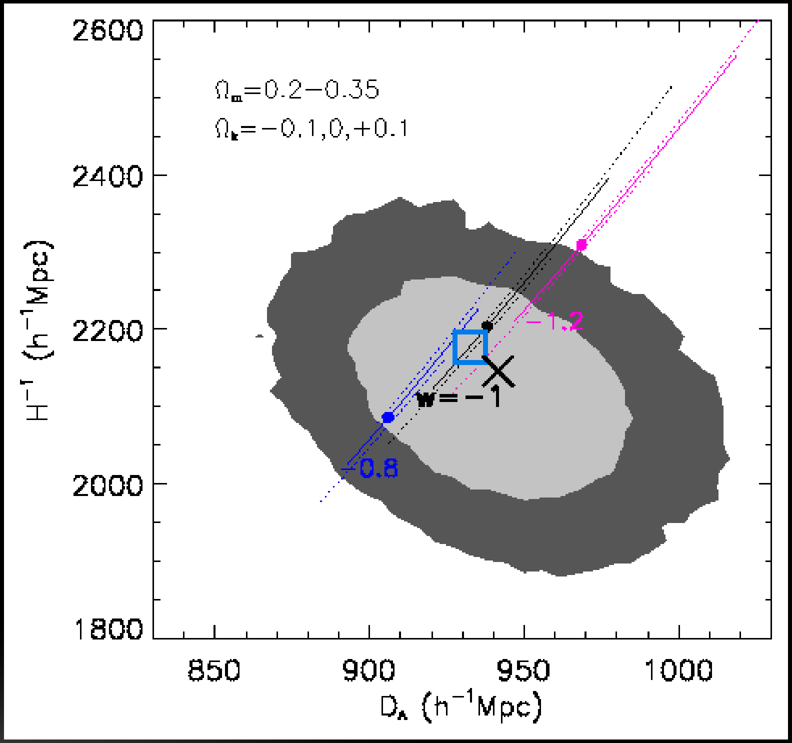
5. TESTING COSMOLOGY

5. Testing Cosmology

WMAP9 (DA-Hinv plane)

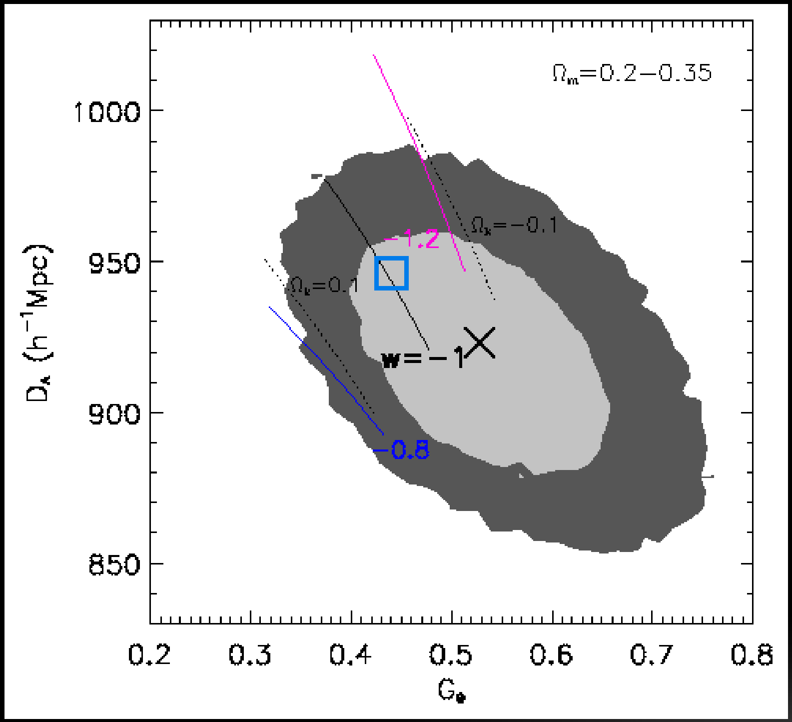


Placnk (DA-Hinv plane)

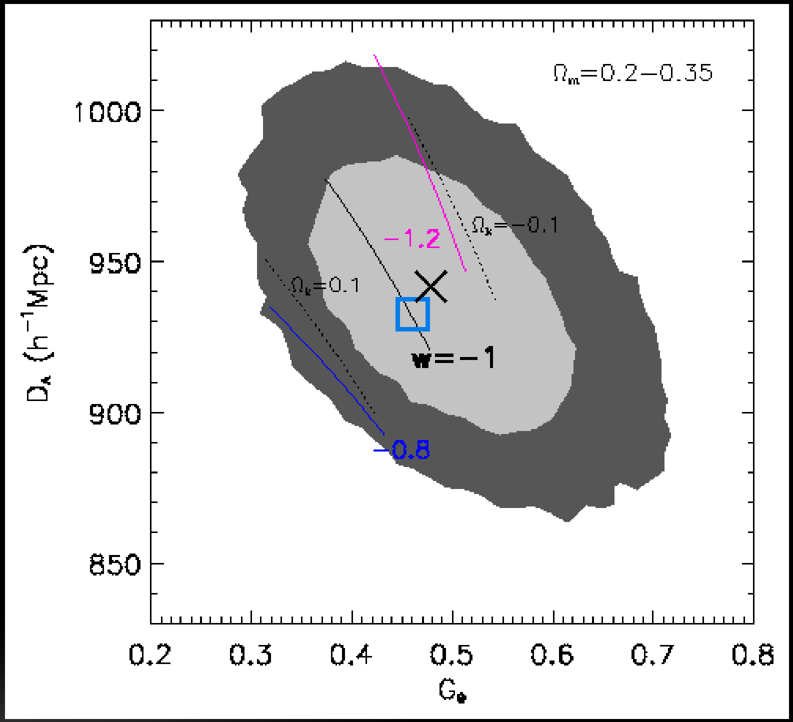


5. Testing Cosmology

WMAP9 (Gtheta-DA plane)

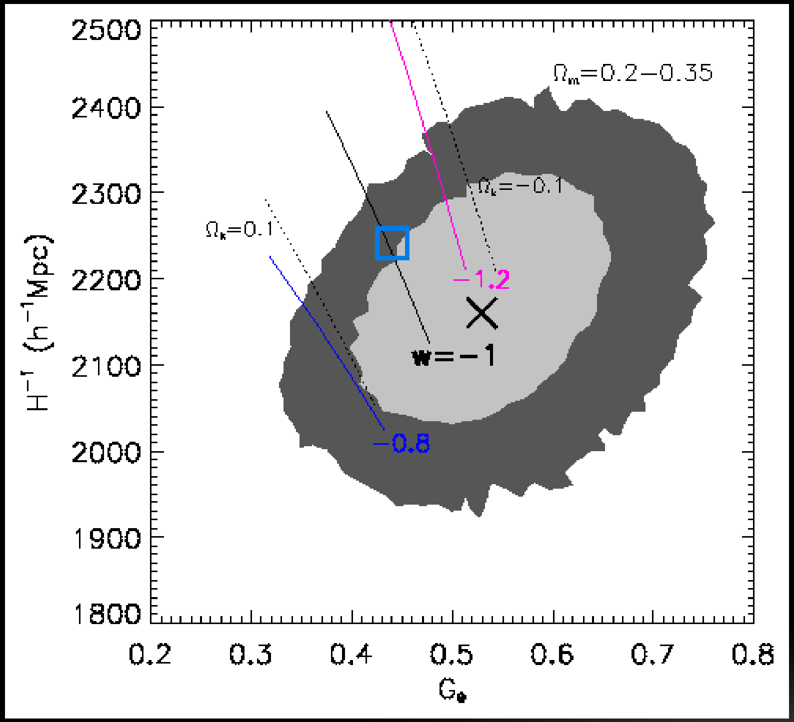


Placnk (Gtheta-DA plane)

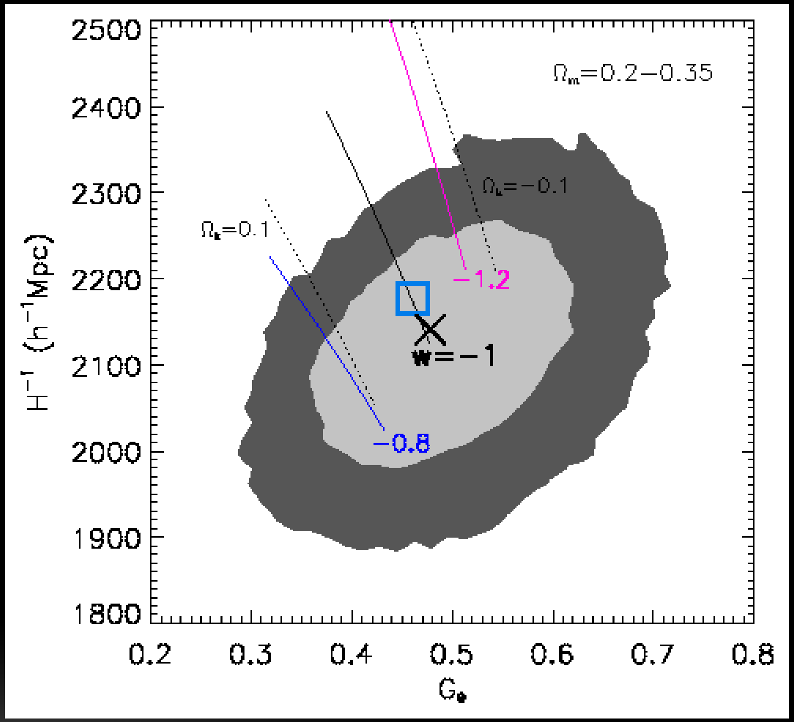


5. Testing Cosmology

WMAP9 (Gtheta-Hinv plane)



Placnk (Gtheta-Hinv plane)



5. Testing Cosmology

- Testing Cosmology suggests
  - In D_A-H_{inv},
    - The cosmological models all lie within a narrow region, somewhat seperated from the best fit point in the Planck case
    - However, the 68% confidence level contour of the measurements overlaps the LCDM model
  - In G_{theta}-D_A &G_{theta}-H_{inv},
    - The cosmologies span a wider range of the space
    - The measurements are consistent with LCDM model at the 68% level confidence level
  - No sign of significant deviation from LCDM in either distances or growth, and hence no sign of deviation from general relativity either?

5. Testing Cosmology

- Testing Cosmology suggests
  - However, for smaller cut-off, allowing using data in small scales, we do find deviation.
    - Gtheta: underestimated 0.42, 0.34 for smaller cut-off= 30Mpc/h, 20Mpc/h, repectively. But, above 40Mpc/h, invariant, indicating convergence

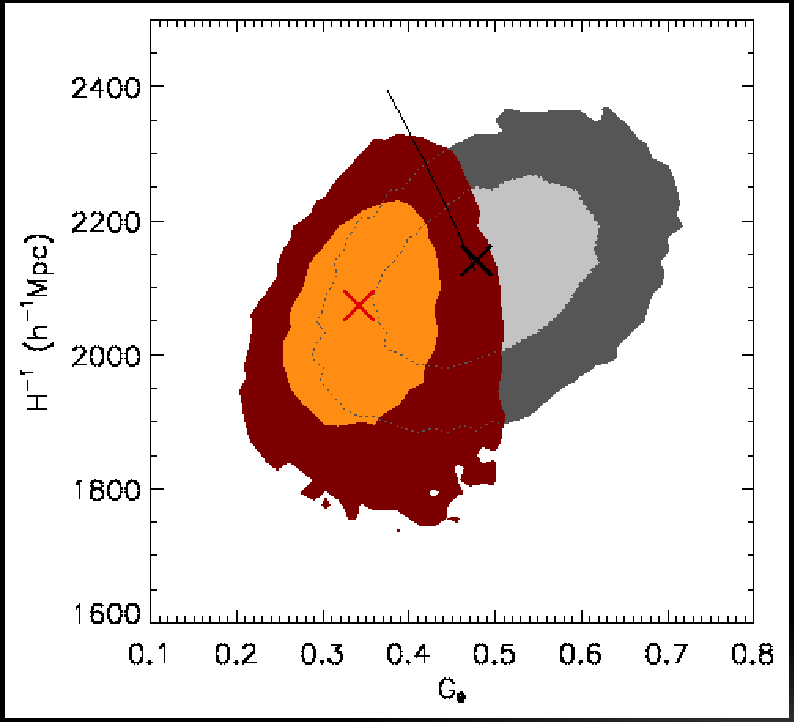
- ➢ No cosmology giving good fits to the measurement contour
- ➢ And evidence for a violation of general relativity.
  - The strong growth suppression in the measured growth rate would yield an apparent gravitational growth index > 0.7, in contrast to the value 0.55 for general relativity.

Linder. E. V.(2005)

5. Testing Cosmology

Planck

(Cut-off=20Mpc/h with 40Mpc/h)



- The shifting of the best fit values & the reduction in the uncertainty of Gtheta
- ➢ Indicating:
  - ➢ Substantial information to fit cosmology is coming from small scales, not just the BAO rings.
- Sensitivity of the results to low cut-off
- ➢ Indicating:
  - ➢ Modeling on small scales is inadequate.

2D Clustering Anisotropy Analysis using BOSS DR9

6. CONCLUSION

6. Conclusion

- Using BOSS CMASS DR9 galaxies with CMB prior,
- From the clustering correlation function,
- We can extract the angular diameter distance D_A, Hubble scale H_{inv}, and growth rate G_{theta}, consistent with LCDM
- And by comparing expansion of comic distance with growth of cosmic structure, we also test general relativity, consistent.

- But, improvement is necessary in using small scales data to obtain more robust result.
- The sensitivity of low cut-off to the results gives a spurious signature of breakdown of GR.

Thank you