Testing gravity with large galaxy redshift surveys

Kazuhiro Yamamoto
Hiroshima University

T. Sato (Hiroshima)   G. Huetsi (UCL)

1. Introduction
2. Redshift-space distortion
3. Measurement of quadrupole
4. Constraint from the quadrupole
5. Summary and conclusions

2008 May @ Kona Hawaii

1. Introduction

Koyama's talk

Modified Gravity models as alternatives to the dark energy

f(R) gravity model, TeVeS theory, DGP model, etc. · · ·

Ambitious challenges to the fundamental physics
necessary to go beyond the standard model ?

A lot of observational projects for exploring the dark energy ,

WiggleZ, BOSS, WFMOS, HSC, DES, LSST, etc. · · ·
e.g., talks in this conference

Testing the general relativity on the scales of cosmology

Measurement of the growth of the density perturbation will be the key for testing the gravity theory.

(Linder 05, Linder Cahn 07, Amendola, Kunz, Supone 07 Heavens, Kitching, Verde 07, Maartens, Koyama 06, Jain, Zhang 07, …….)

Constraint on the growth factor and the growth rate for testing the gravity theory

(Nesseris, Perivolaropoulos 08 Porto, Amendola 08 Linder 07)

Constraint on the growth rate redshift –space distortion in the clustering of the VIMOS VLT Deep Survey (VVDS) galaxy

(Guzzo et al. 08)

This work : (K.Y., Sato, Huetsi)

measure the monopole spectrum and the quadrupole spectrum of the SDSS LRG sample,

detect the redshift-space distortion,

measure the growth rate,

test the general relativity

2. Redshift-space distortions

(Kaiser 87, Cole et al. 94, Hamilton 95, etc.)

Measuring the growth rate through the redshift-space distortion

$$f(a) = \frac{d \ln D_1(a)}{d \ln a}$$

linear velocity field follows

$$\frac{\partial \delta_m}{\partial t} + \frac{1}{a}\frac{\partial V^i}{\partial x^i} = 0 \quad \Rightarrow \quad \mathrm{div} V \propto a H(a) f D_1$$

Peculiar velocity of galaxy contaminates the observed redshift

$$\delta z = (1+z)\vec{\gamma} \cdot \vec{V}$$ (Doppler effect)

This causes the difference of the spatial clustering between the redshift space and the real space,

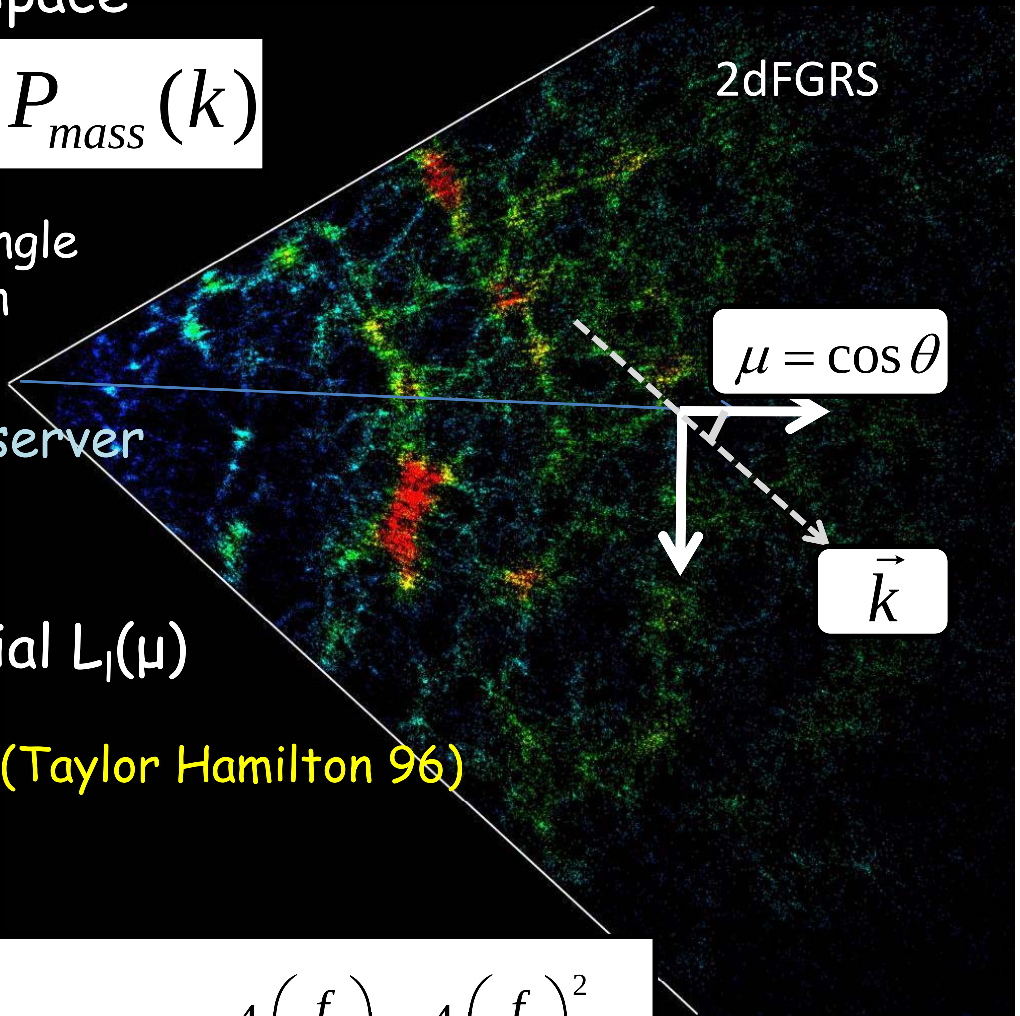
⇒ redshift-space distortion (Okumura, et al., 08)

Anisotropic correlation function in SDSS LRGs

Power spectrum in redshift-space

$$P(k,\mu) = (b(k) + f\mu^2)^2 P_{mass}(k)$$

μ is the directional cosine of the angle between the line of sight direction and the wave number vector.



Multipole expansion of P(k,μ) with the Legendre polynomial $L_l(\mu)$

$$P(k,\mu) = \sum_{l=0,2,4,\ldots} P_l(k) L_l(\mu)$$

(Taylor Hamilton 96)

$P_0(k)$ monopole

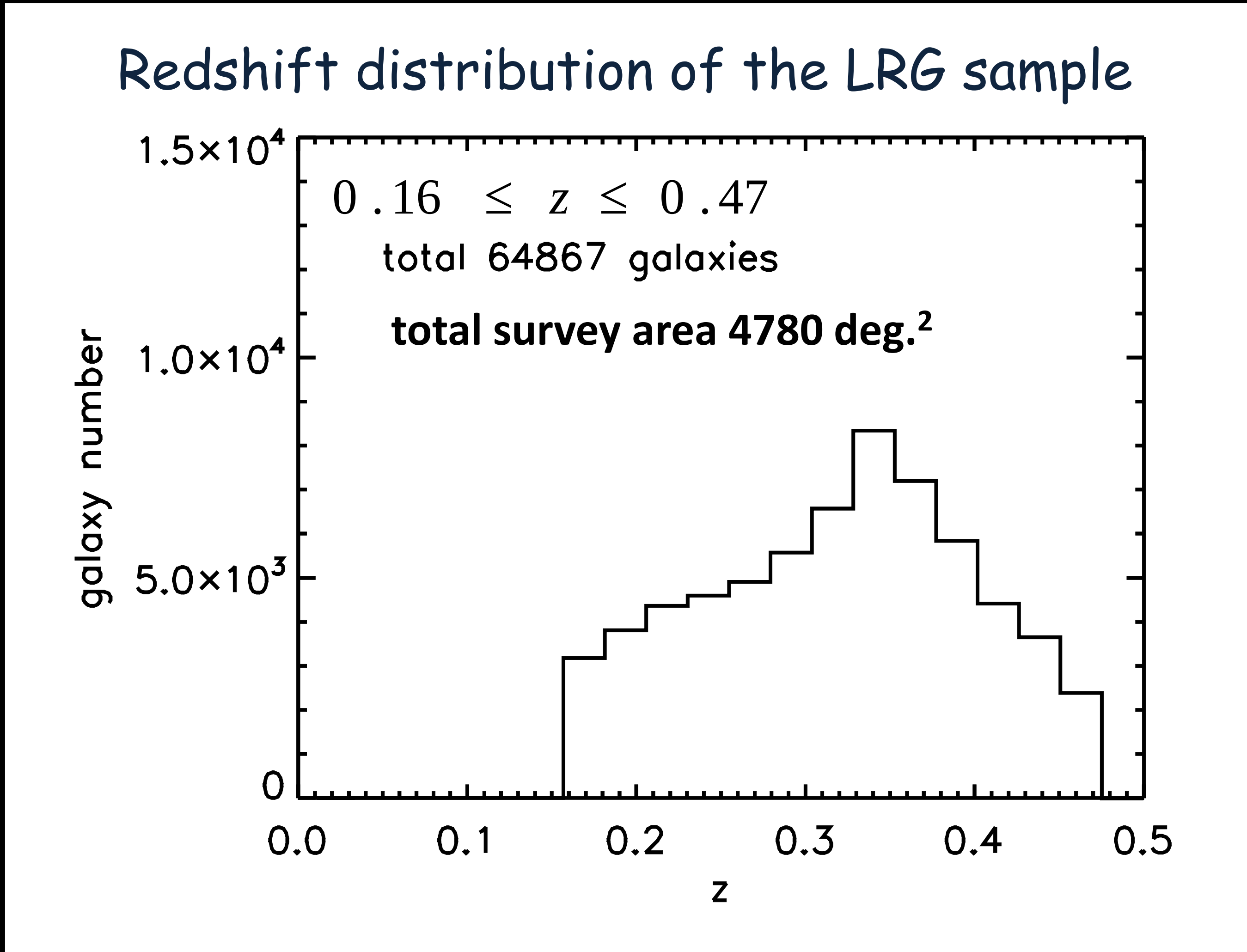
$P_2(k)$ quadrupole

the leading anisotropies

$$\frac{P_2(k)}{P_0(k)} = \frac{\frac{4}{3}\left(\frac{f}{b}\right) + \frac{4}{7}\left(\frac{f}{b}\right)^2}{1 + \frac{2}{3}\left(\frac{f}{b}\right) + \frac{1}{5}\left(\frac{f}{b}\right)^2}$$

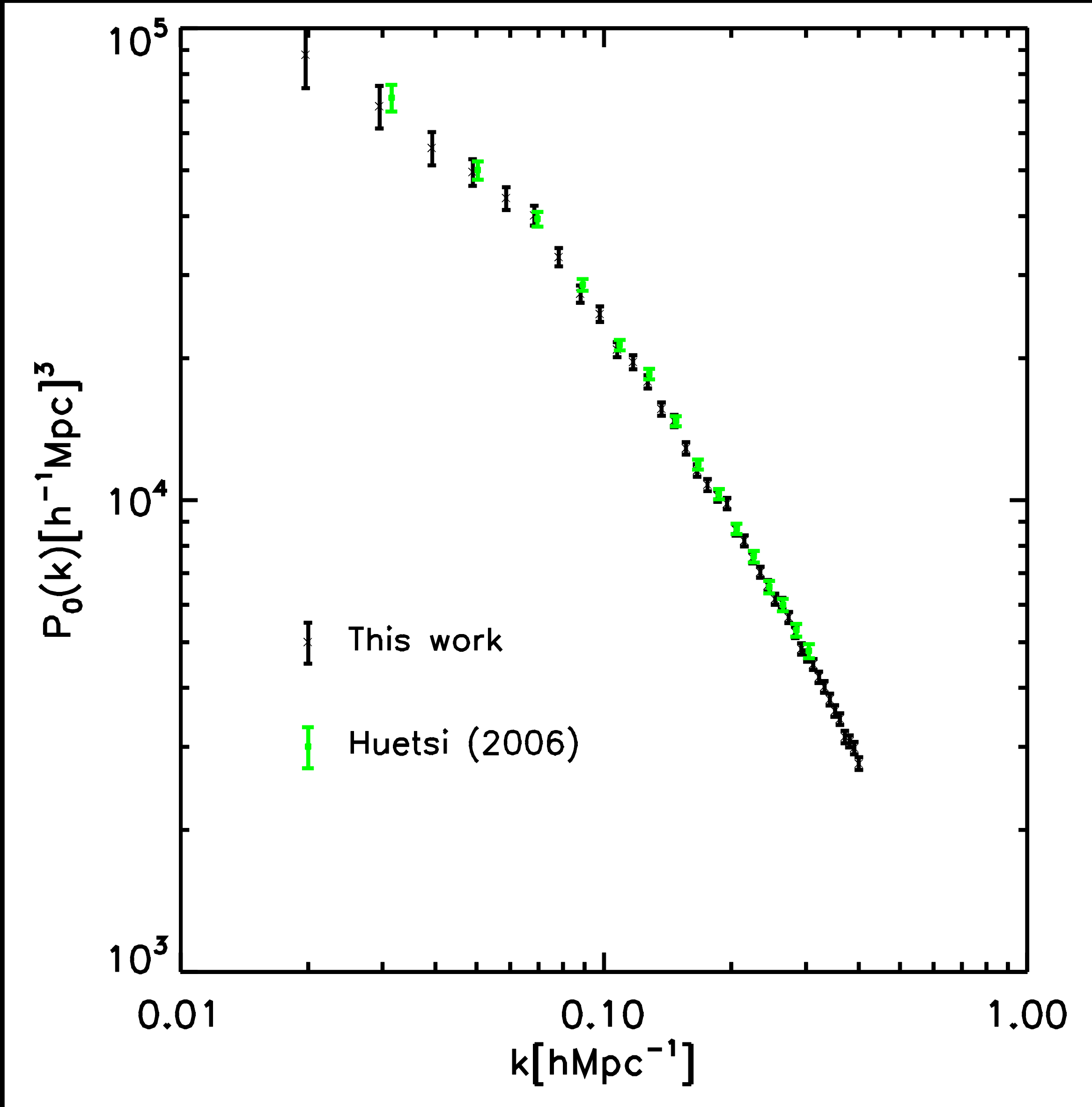
K.Y, Sato, Huetsi, in prep

3. Measurement of monopole and quadrupole of SDSS LRG (Luminous Red Galaxy) sample in DR5



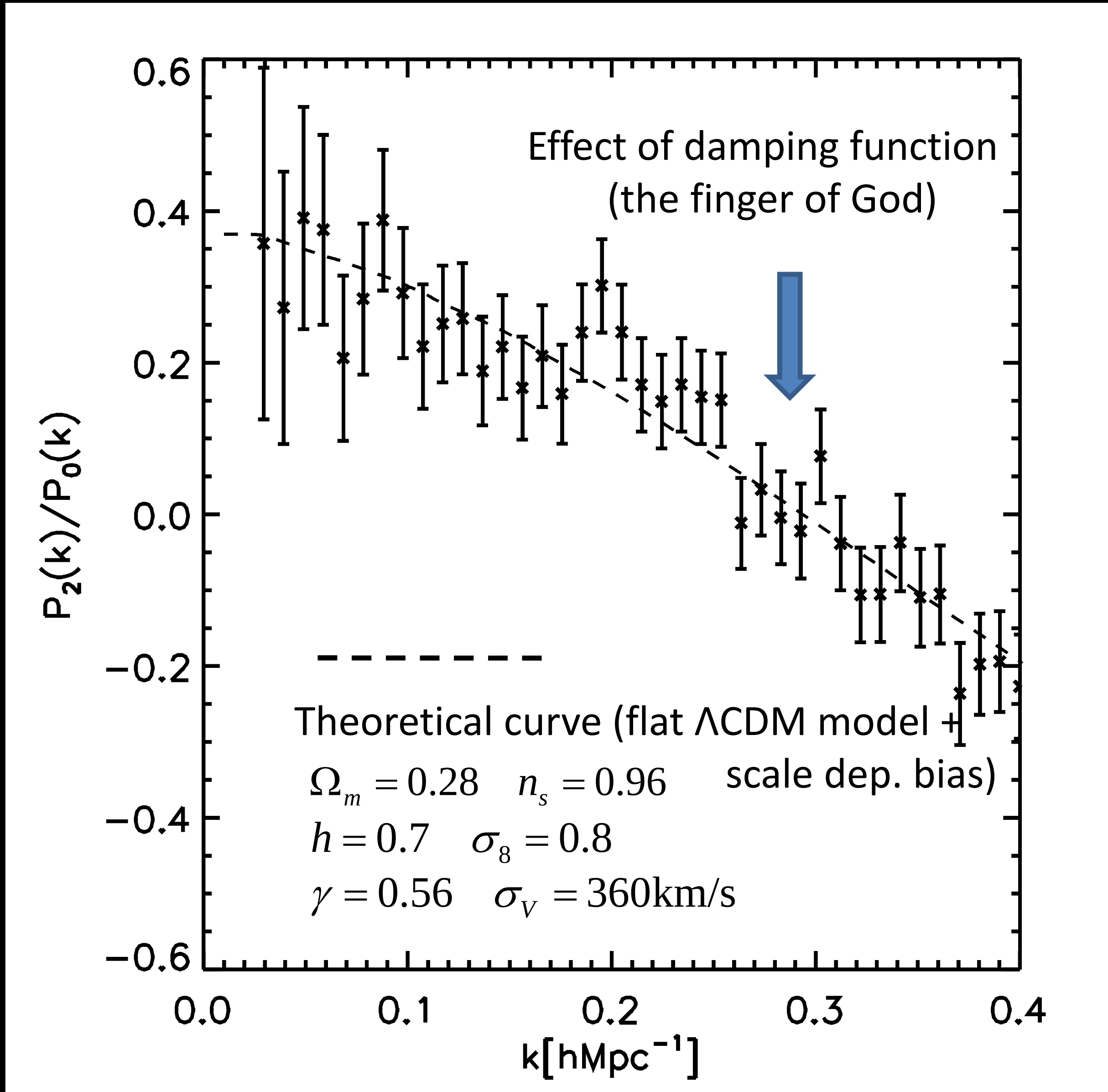
K.Y., Sato, Huetsi, in prep.

Measurement of the monople $P_0(k)$



Measurement of P_2/P_0

K.Y., Sato, Huetsi



4. Constraint from the quadrupole spectrum

Galaxy power spectrum in redshift-space

$$P(k,\mu) = (b(k) + f\mu^2)^2 P_{mass}(k)\mathfrak{D}(k,\mu)$$

⟶ Monopole and quadrupole

Peacock, Dodds 94

① Nonlinear velocity effect (finger of God)

Phenomenological damping function $\mathfrak{D}(k,\mu)$

$$\mathfrak{D}(k,\mu) = \frac{1}{1 + \frac{1}{2}\left(k\mu\sigma_V / H_0\right)^2}$$

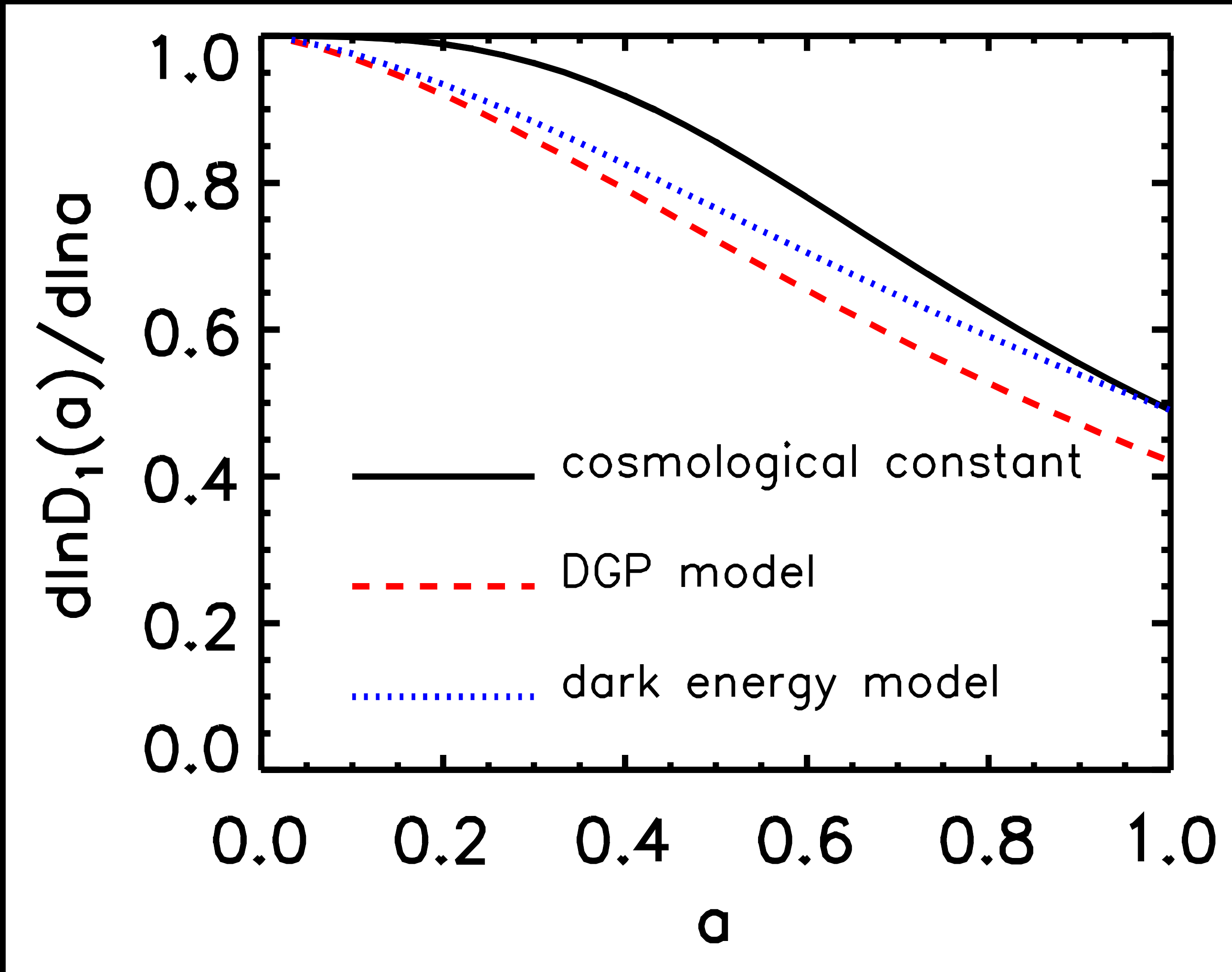
Exponential distribution function for the pair-wise peculiar velocity

$$\sigma_V$$

② Linear redshift-space distortion

$$f(a) = \frac{d\ln D_1(a)}{d\ln a}$$

Growth rate as a probe of modified gravity



Parameterization of the growth rate

(Linder 05,
Lahav 91,
Wang, Steinhardt 98,
Percival 05,)

$$f(a) = \frac{d\ln D_1(a)}{d\ln a} \cong \Omega_m(a)^{\gamma}$$

$$\Omega_m(a) = \frac{H_0^2 \Omega_m a^{-3}}{H(a)^2}$$

for general relativity
(include dark energy)

$$\gamma = 0.55 + 0.05(1 + w(z=1))$$
$$\cong 0.55 \sim 0.56$$

for the DGP model

$$\gamma \cong 0.68$$

γ characterizes the difference of the gravity theory,
measurement of γ is a simple test of the gravity theory

③ Clustering bias b(k)

$$\delta_{galaxy} = b\,\delta_{mass}$$

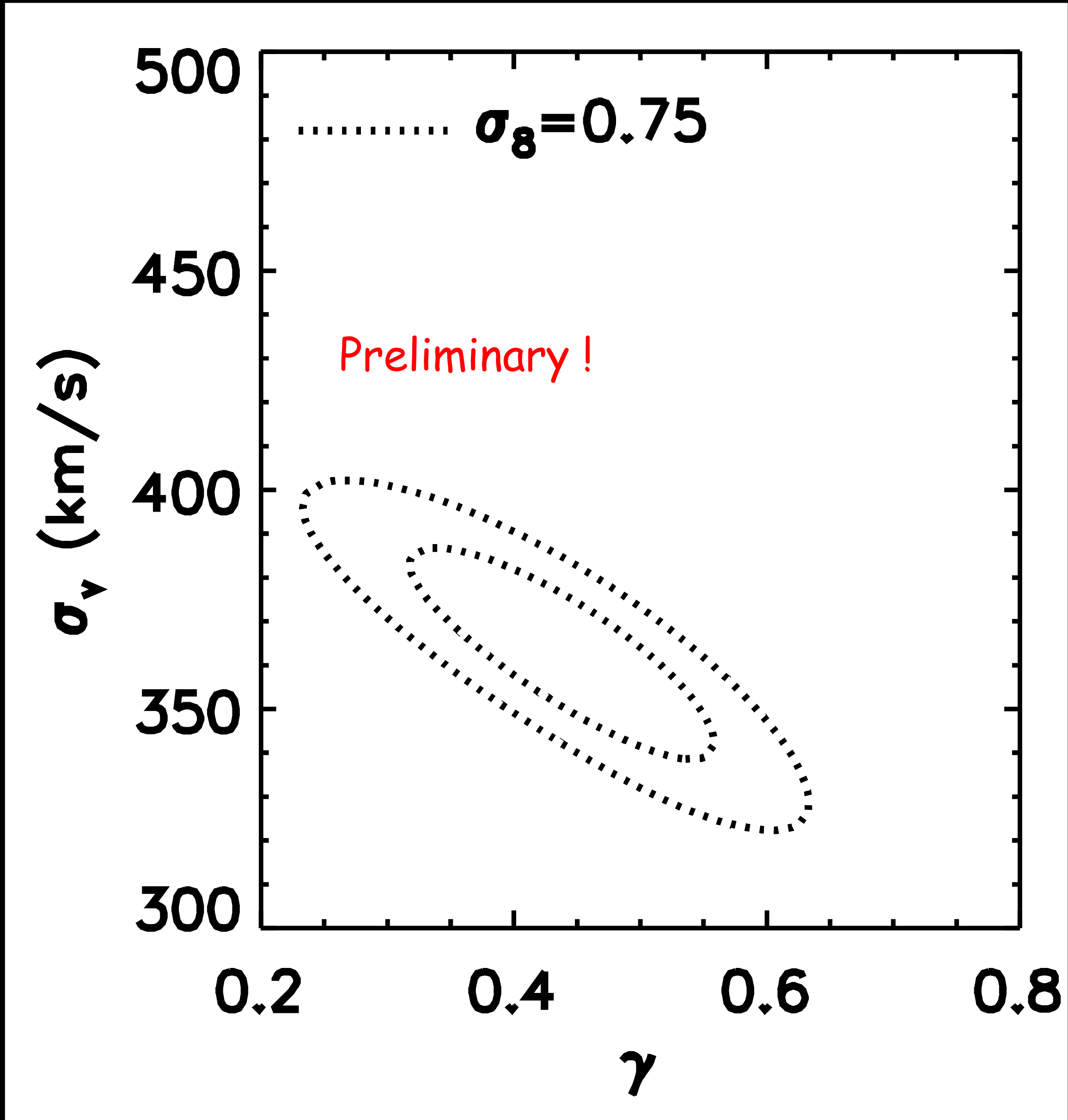
If σ_8 is fixed, the clustering bias b(k) is determined by $P_0(k)$

$P_0(k)$ ⟶ b(k)

$P_2(k)$ ⟶ constraint on γ and σ_V

K.Y., Sato, Huetsi

Constraint on γ and σ_V

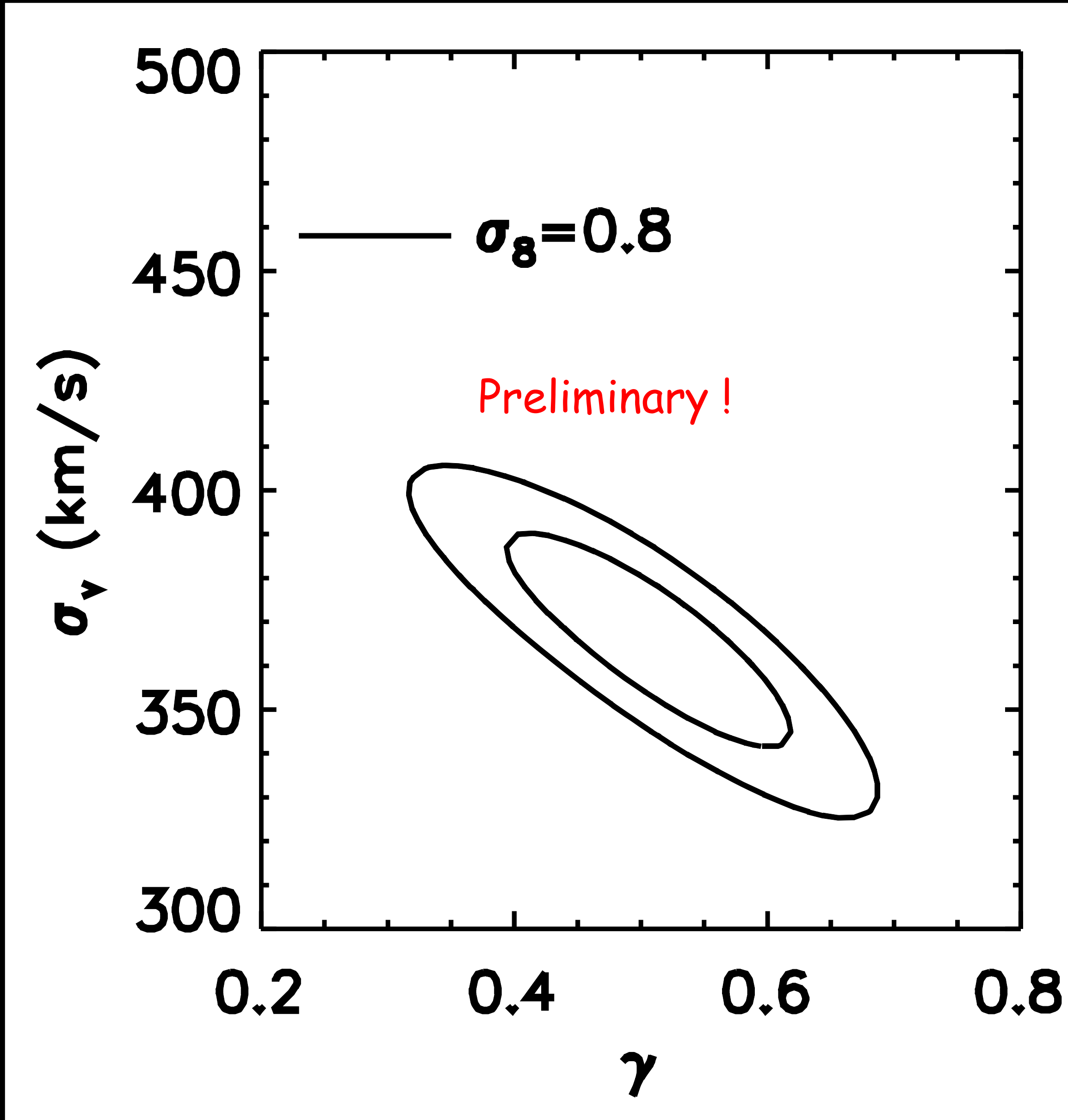


$\gamma = 0.44 \pm 0.08$

$\sigma_V = 363 \pm 16 \mathrm{km/s}$

K.Y., Sato, Huetsi

Constraint on γ and σ_V

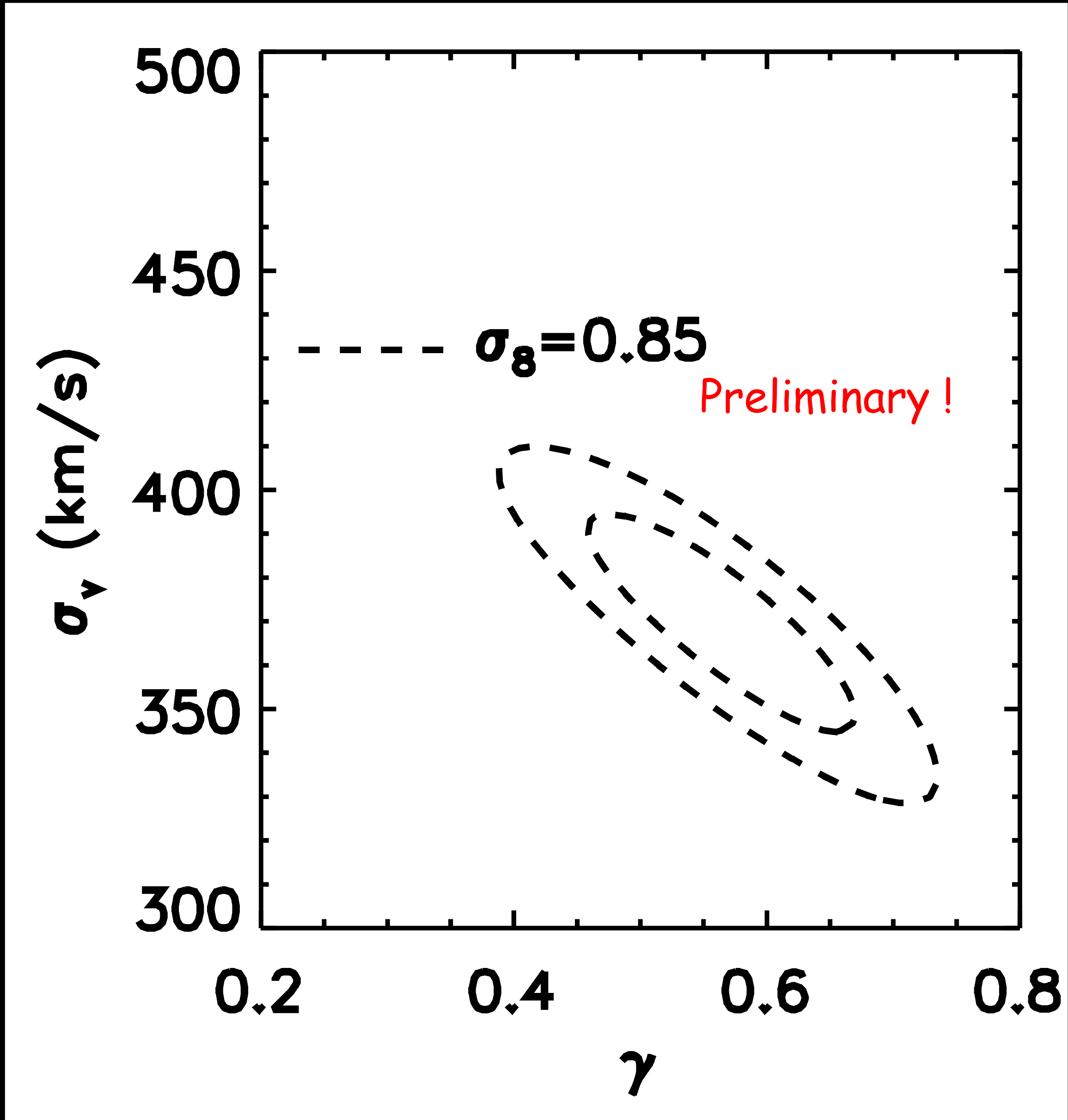


$\gamma = 0.51 \pm 0.08$

$\sigma_V = 366 \pm 16 \mathrm{km/s}$

K.Y., Sato, Huetsi

Constraint on γ and σ_V



$$\gamma = 0.57 \pm 0.08$$

$$\sigma_V = 369 \pm 16 \text{km/s}$$

The constraint on γ

$$\gamma = 0.51 + 1.3(\sigma_8 - 0.8) \pm 0.08$$

at 1 σ confidence level

↕

general relativity γ = 0.55～0.56
DGP model γ = 0.68

This is consistent with the general relativity, however, is inconsistent with the cosmological DGP model, γ = 0.68, as long as $\sigma_8 < 0.87$.

cf. $\sigma_8 = 0.8 \pm 0.036$ (WMAP 5year)

5. Summary and conclusions

We measured the monopole and quadrupole spectra in the spatial clustering of the SDSS LRG galaxy sample.

Using the quadrupole spectrum, we measured
the γ parameter for the linear growth rate and
the pair-wise peculiar velocity dispersion.

The measurement of γ is a simple test of the general relativity.
The measured value of γ is

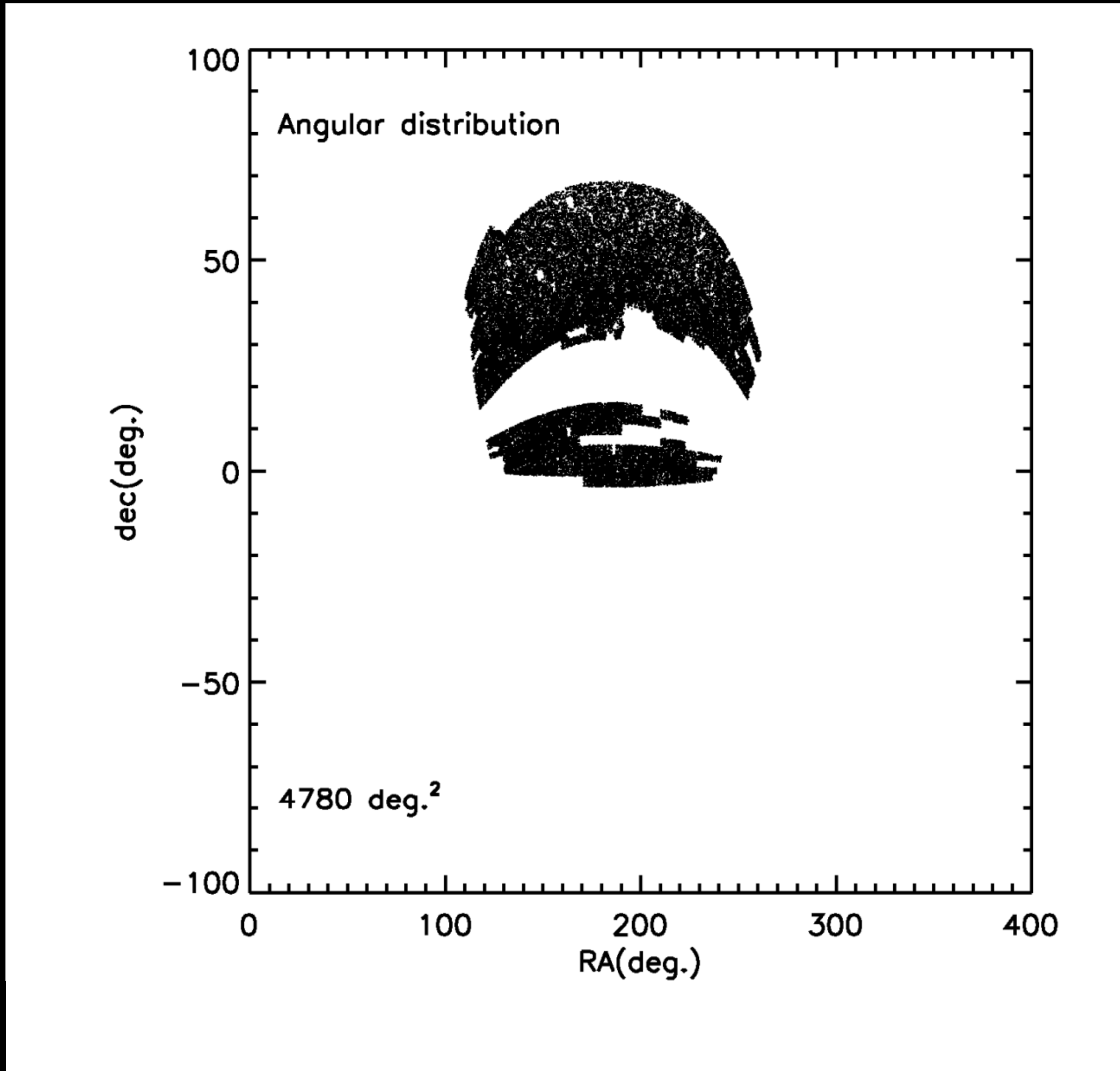
$$\gamma = 0.51 + 1.3(\sigma_8 - 0.8) \pm 0.08$$

(at 1 sigma confidence level)

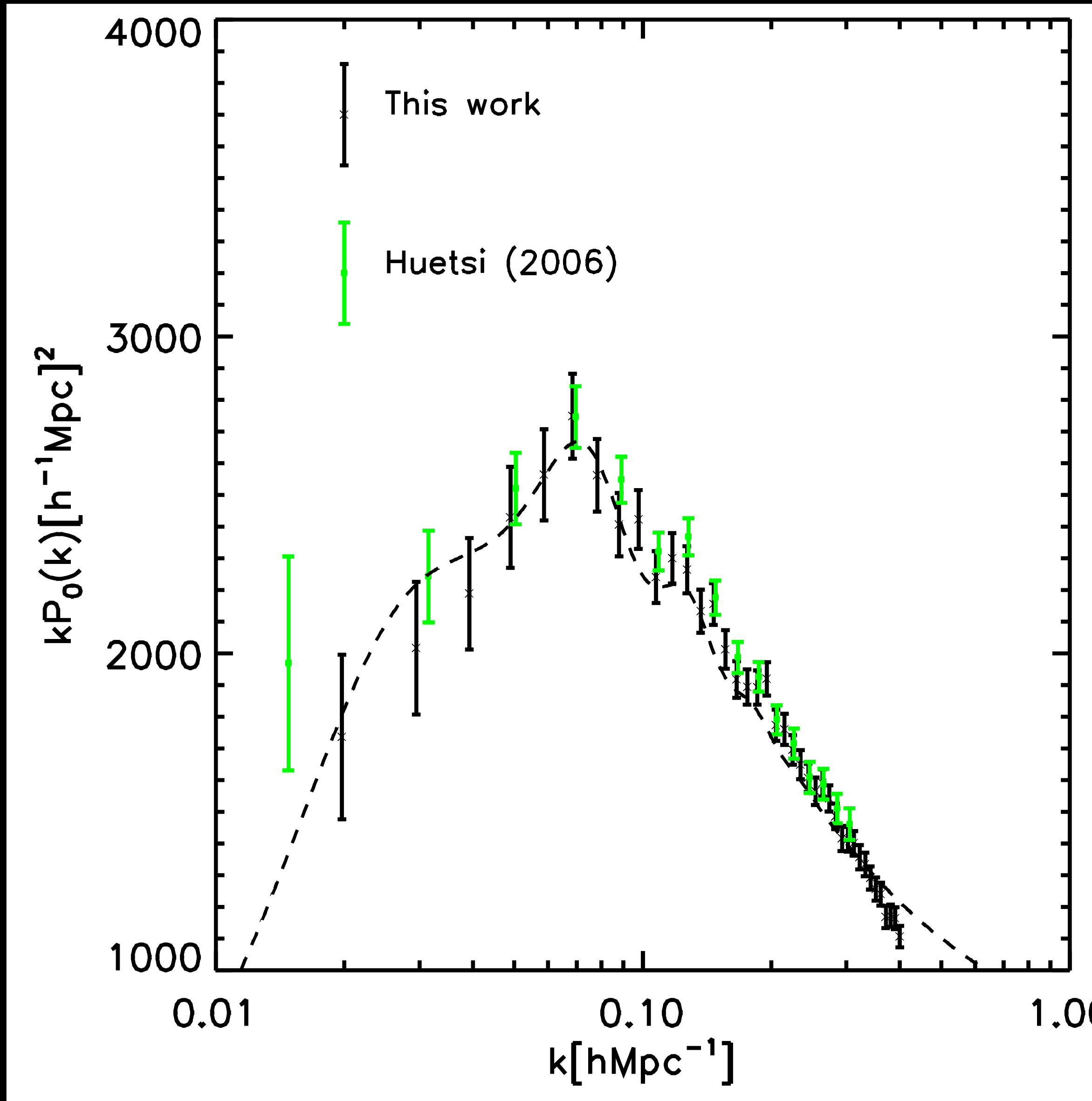
This is consistent with the general relativity, however, is inconsistent with the cosmological DGP model, $\gamma = 0.68$, as long as σ_8 is less than 0.87.

3. Measuring the monopole, quadrupole of SDSS LRG (Luminous Red Galaxy) sample in DR5

K.Y., Sato, Huetsi

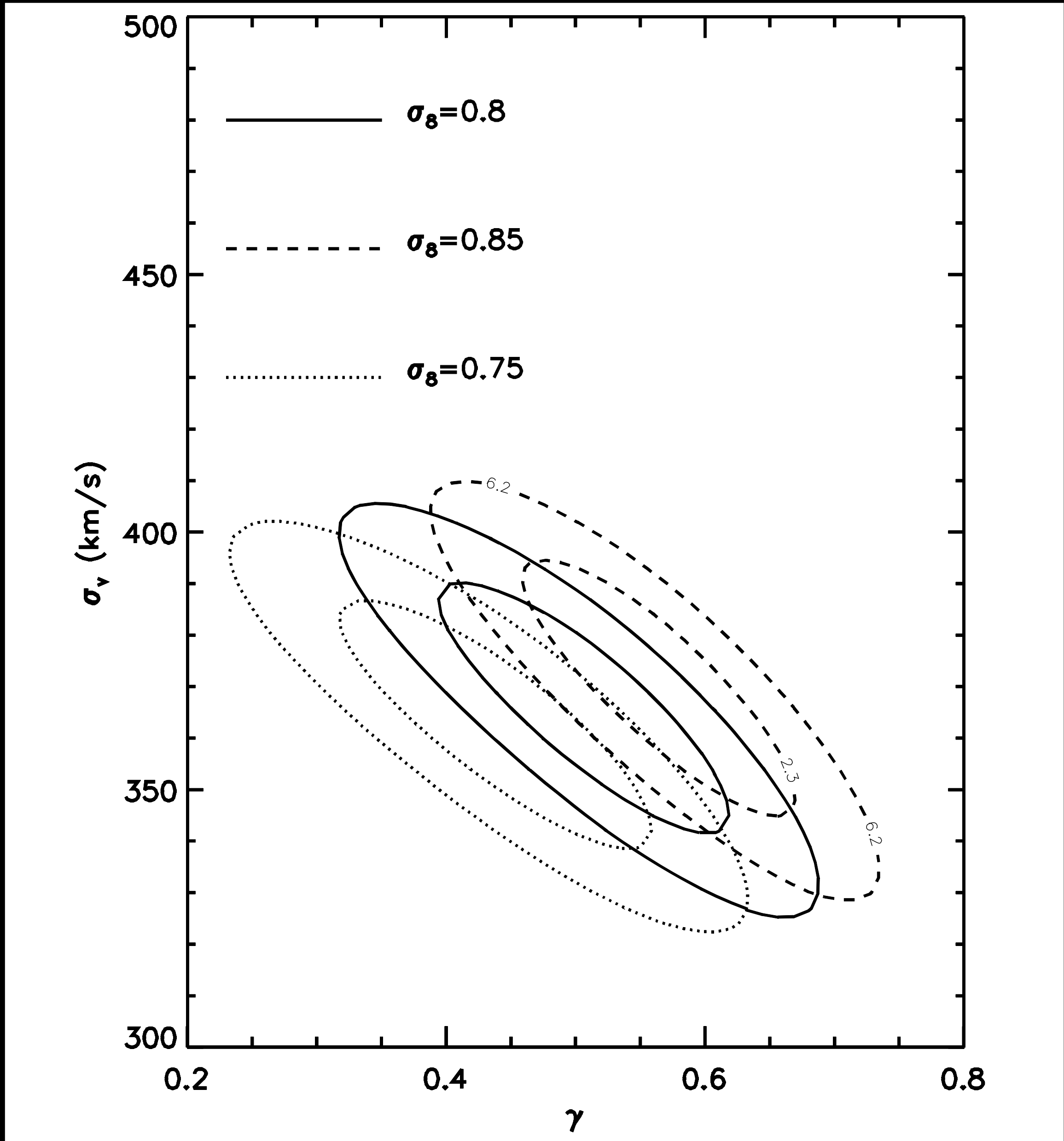


K.Y., Sato, Huetsi



K.Y., Sato, Huetsi

Measurement of γ and σ_V of the SDSS LRG



WMAP 5year

σ_8=0.8±0.036

$\sigma_8 = 0.75$

$\gamma = 0.44 \pm 0.08$

$\sigma_8 = 0.8$

$\gamma = 0.51 \pm 0.08$

$\sigma_8 = 0.85$

$\gamma = 0.57 \pm 0.08$

$\sigma_V = 370 \pm 16\mathrm{km/s}$

Clustering bias Ⅰ

$$b(k) = 1.85 \times \left(1 + 0.2 \left(\frac{k}{0.1h\mathrm{Mpc}^{-1}} \right)^{1/2} \right)$$

Clustering bias Ⅱ

Determined b(k) to match the observed $P_0(k)$