Impacts of satellite galaxies in measuring the cosmic growth rate

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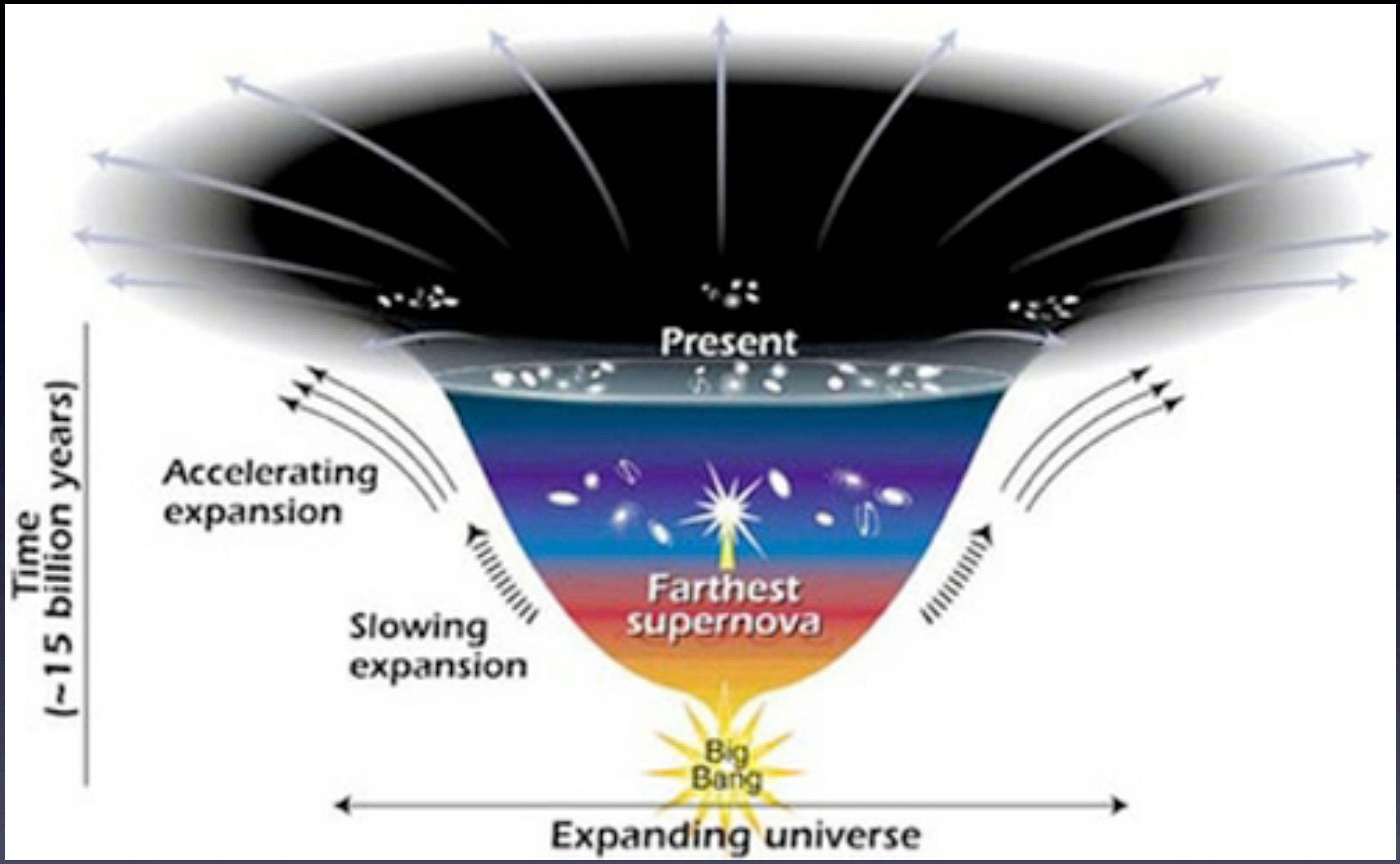
Ref. Hikage & Yamamoto JCAP 08 (2013) 19
(arXiv:1303.3380)

Accelerated expansion of the Universe



Modified Gravity or Dark Energy ?

$$R_{\mu\nu} - \frac{1}{2} R g_{\mu\nu} \overset{?}{=} \frac{8\pi G}{c^4} T_{\mu\nu}$$

Cosmic Growth Rate

Matter evolution equation

$$\ddot{\delta} + 2H\dot{\delta} - 4\pi G\bar{\rho}_m a^2 \delta = 0$$

Modified Gravity

$G_{eff}(k,t)$

Growth rate

$$f \equiv \frac{d\ln D}{d\ln a} \simeq \Omega_m(z)^\gamma$$

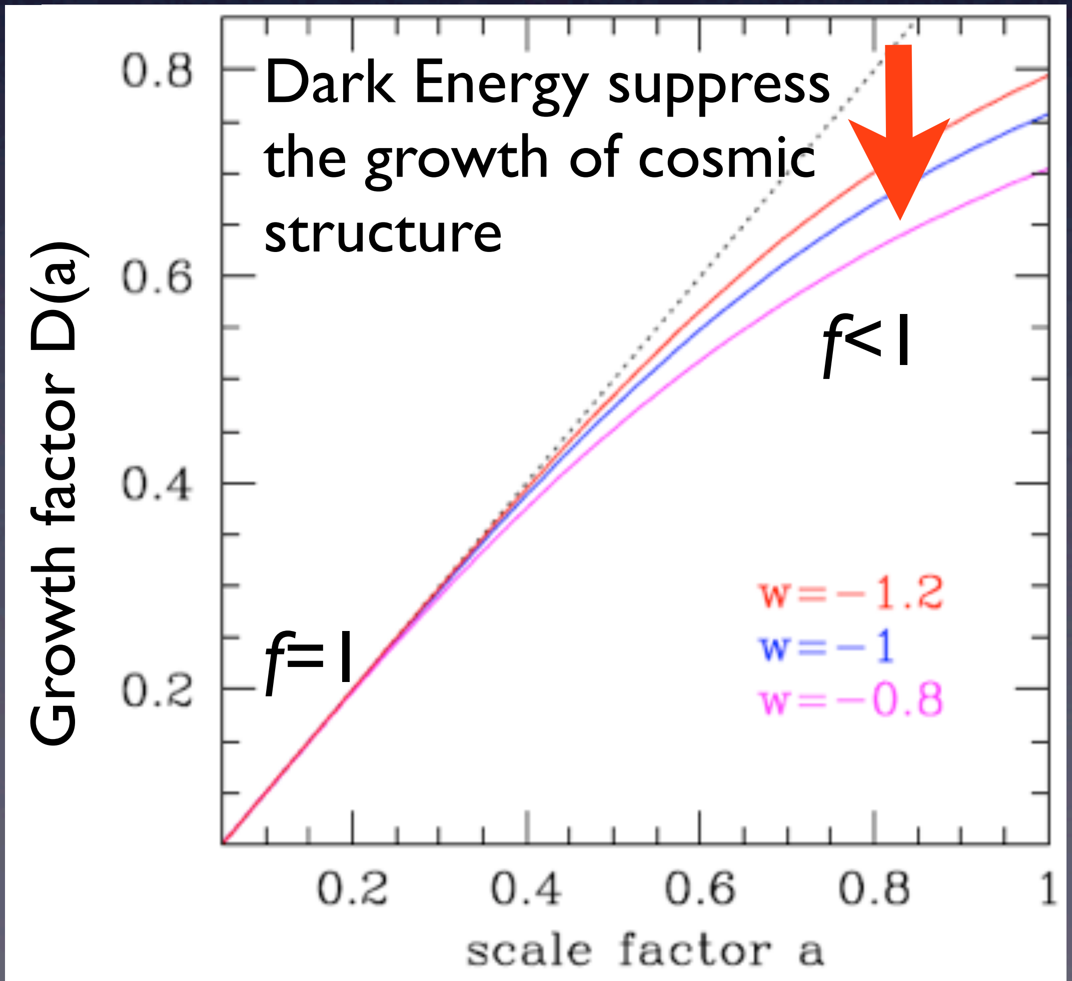
Growth rate index

(Peebles 1976, Lahav et al. 1991)

$\gamma \simeq 0.55$ for ΛCDM

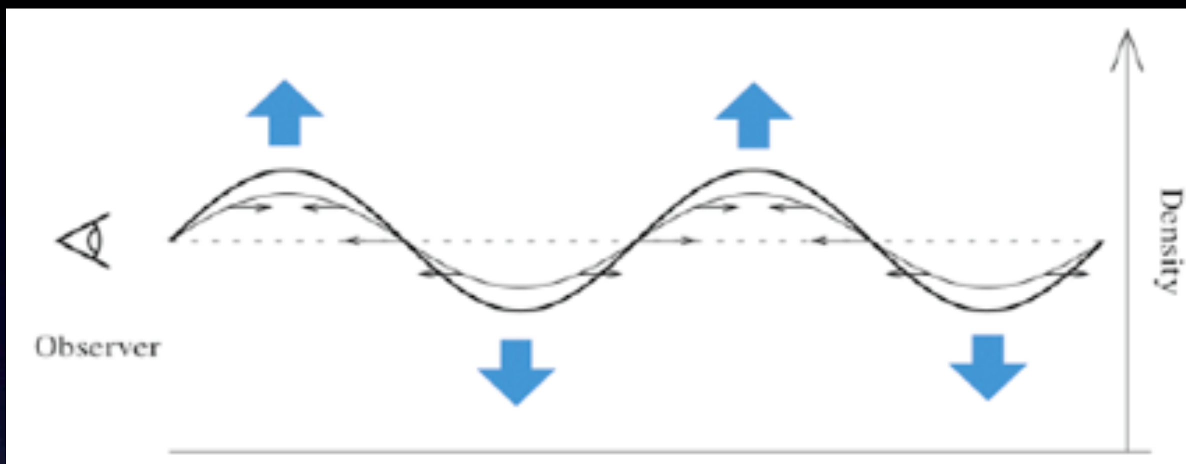
$\gamma \simeq 0.68$ for flat DGP (e.g., Linder & Cahn 2007)

$\gamma \simeq 0.43$ for $f(R)$ (e.g., Hu & Sawicki 2007)



Redshift-space distortion (RSD)

Bulk flow drives the growth of structure



Growth rate is proportional to the velocity divergence

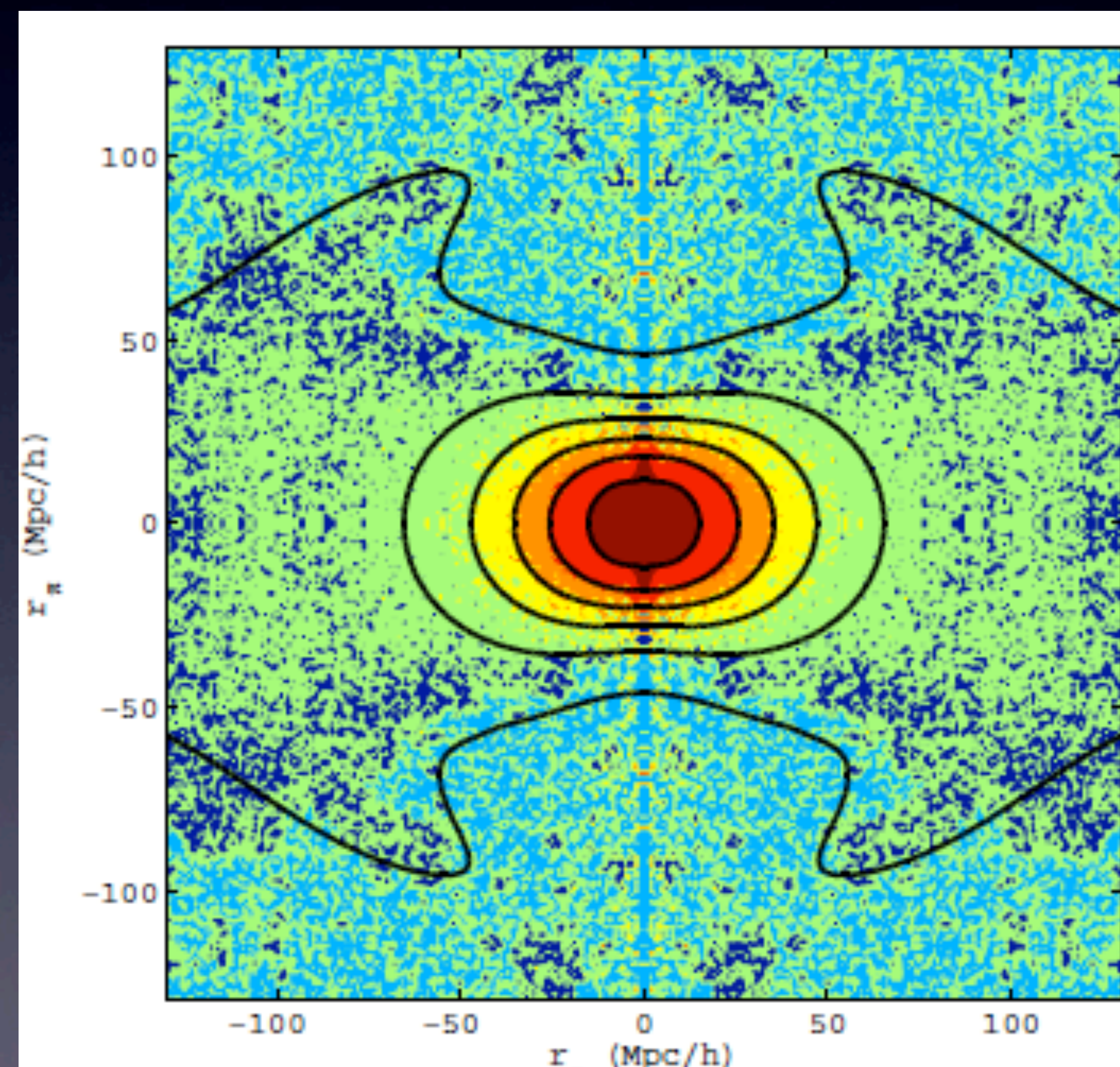
$$\dot{\delta}(z) = -(1+z)\nabla\cdot\mathbf{v}$$

Redshift-space distortion:
Peculiar motion of galaxies generates the anisotropy of galaxy clustering in redshift-space

$$P_{\rm g}(k,\mu) = (b + f\mu^2)^2 P_{\rm m}(k) \quad \text{(Kaiser1987)}$$

b: linear galaxy bias $\mu = k_{||}/k$

2-point correlation functions for BOSS CMASS samples $\xi(r_p, r_\pi)$



Reid et al. 2012

line-of-sight direction

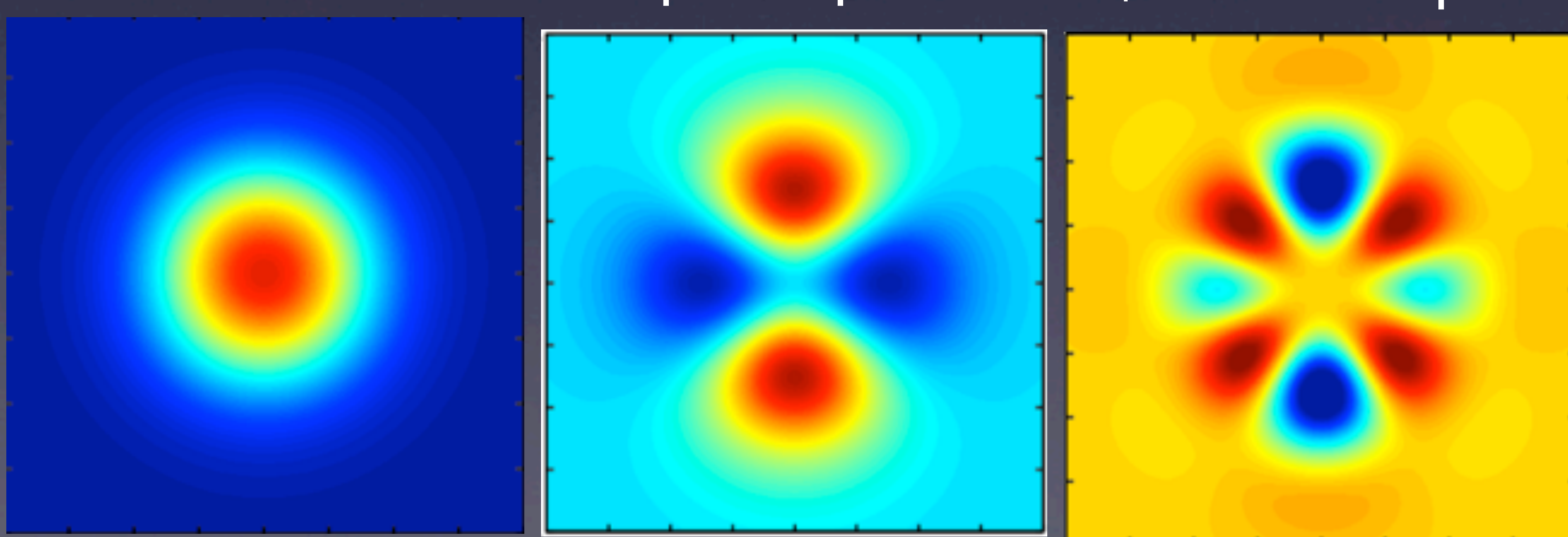
Multipole expansion of galaxy correlation functions/power spectrum

Anisotropy of galaxy clustering is described with the multipole power spectra or correlation functions

$$P_\ell(k) = \frac{1}{2}\int_{-1}^{+1} P(k,\mu)\mathcal{L}_\ell(\mu)d\mu,$$

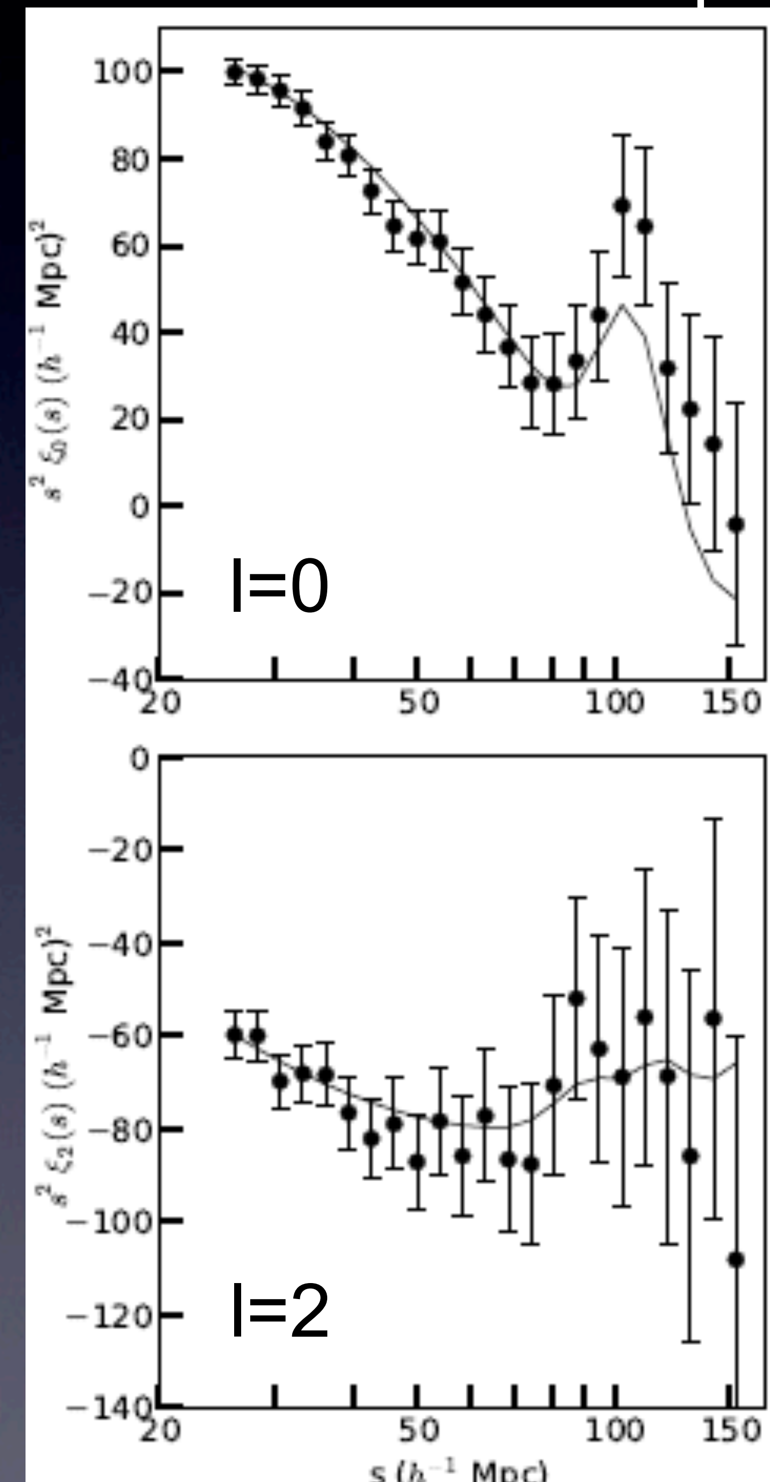
$\mathcal{L}_l$:Legendre polynomials $\mu = k_{||}/k$

P_0: monopole P_2: quadrupole P_4: hexadecapole



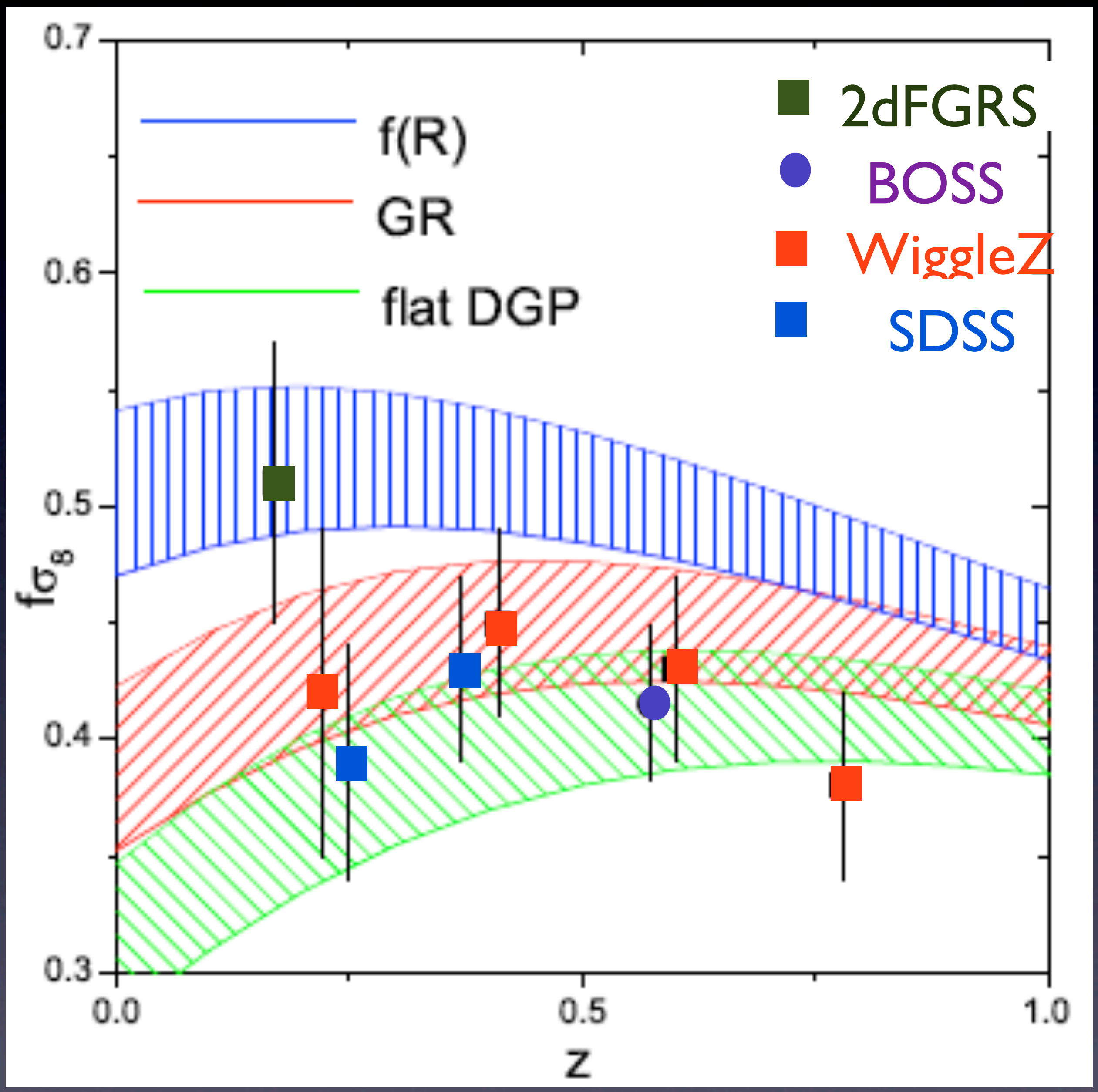
Anisotropic components

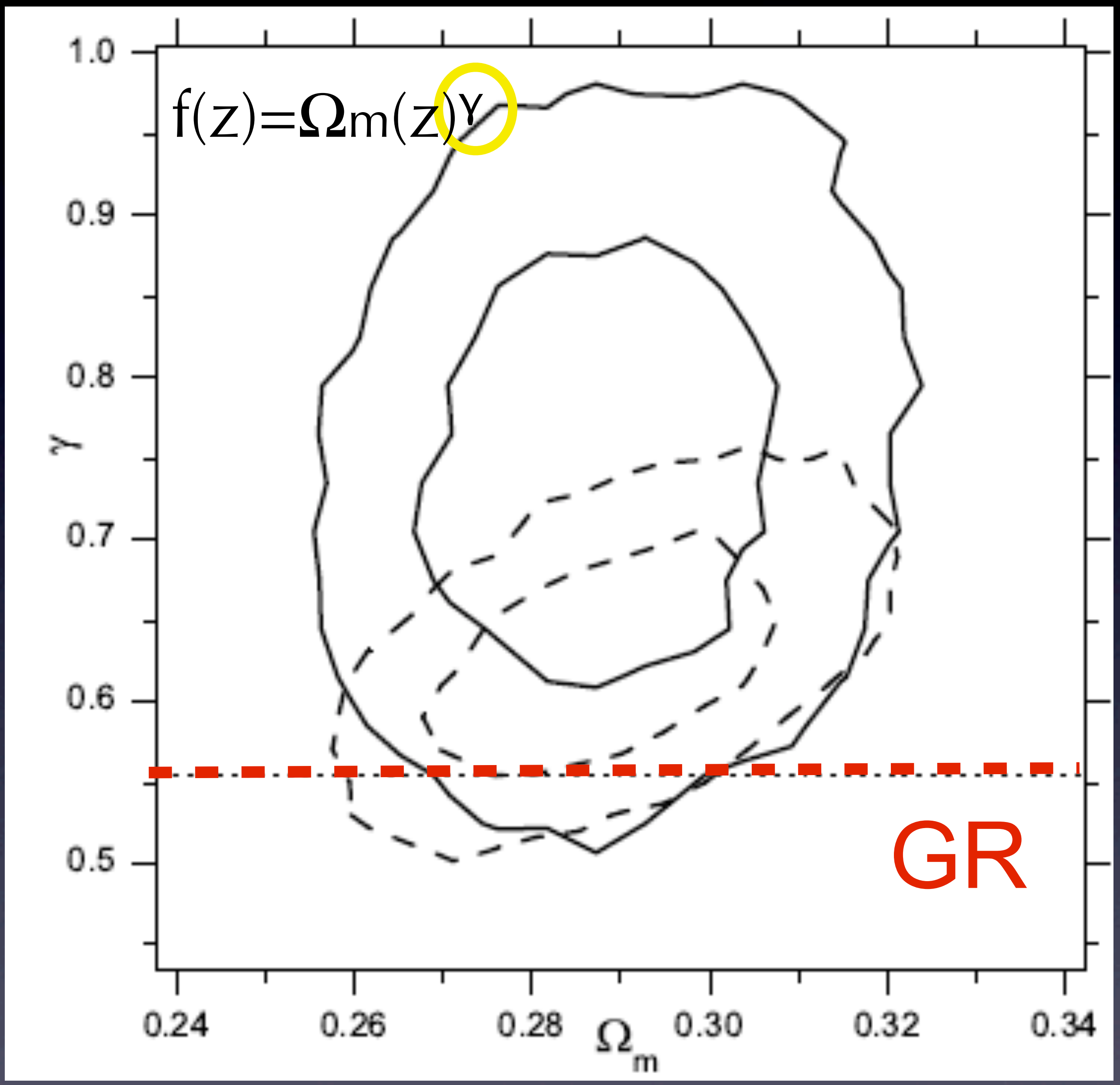
BOSS CMASS sample



Reid et al. 2012

Constraints on Growth rate

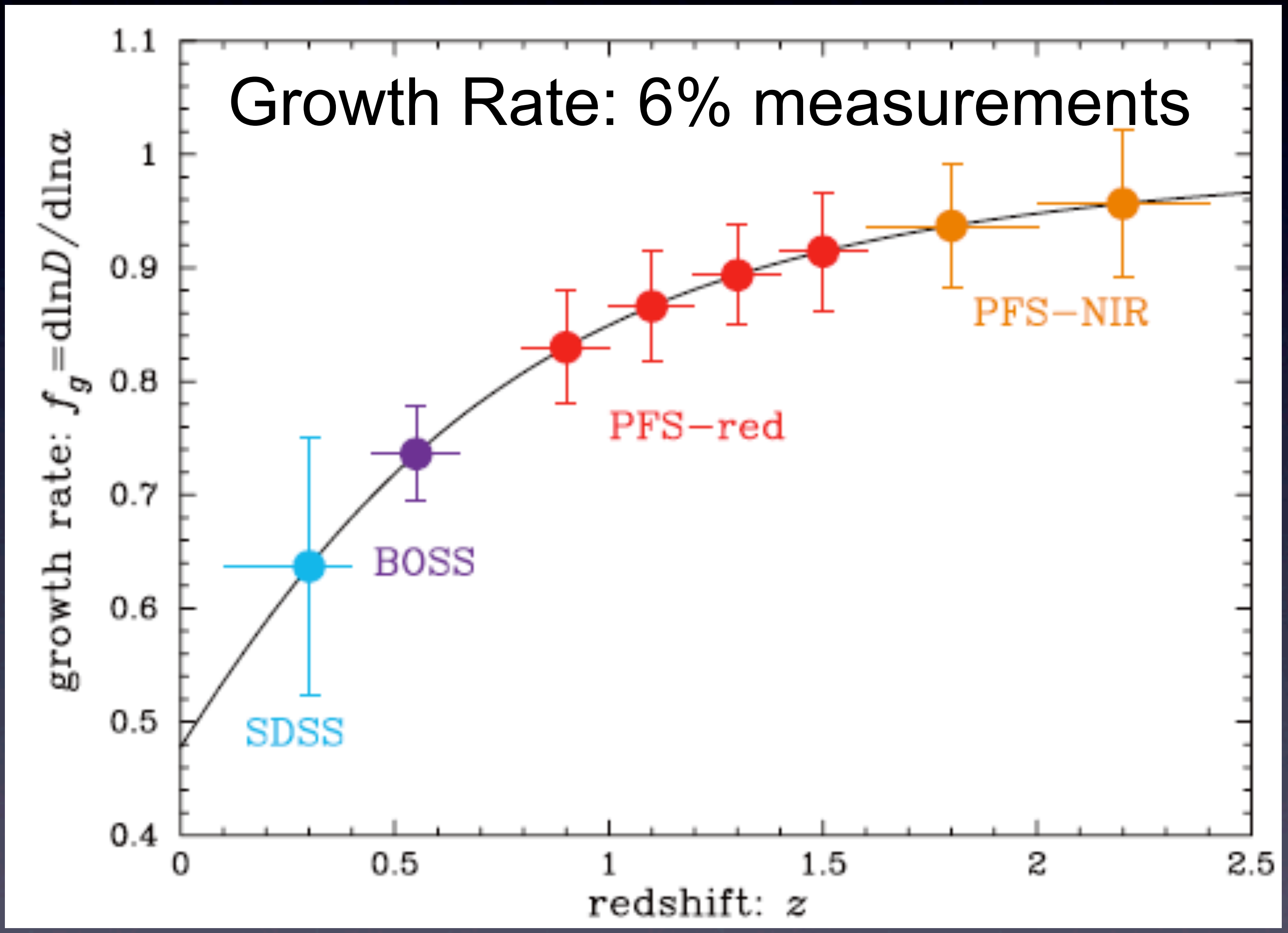




Samshia et al. 2012

Current observations are consistent with GR, but the measured values of growth rate are slightly smaller (γ is larger) than GR prediction

Prime Focus Spectrograph (PFS)

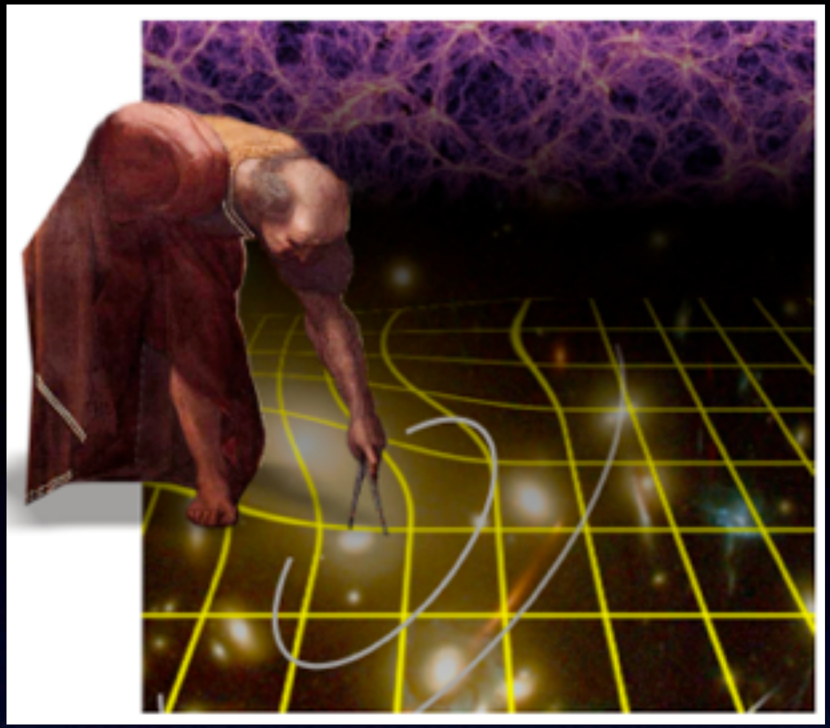


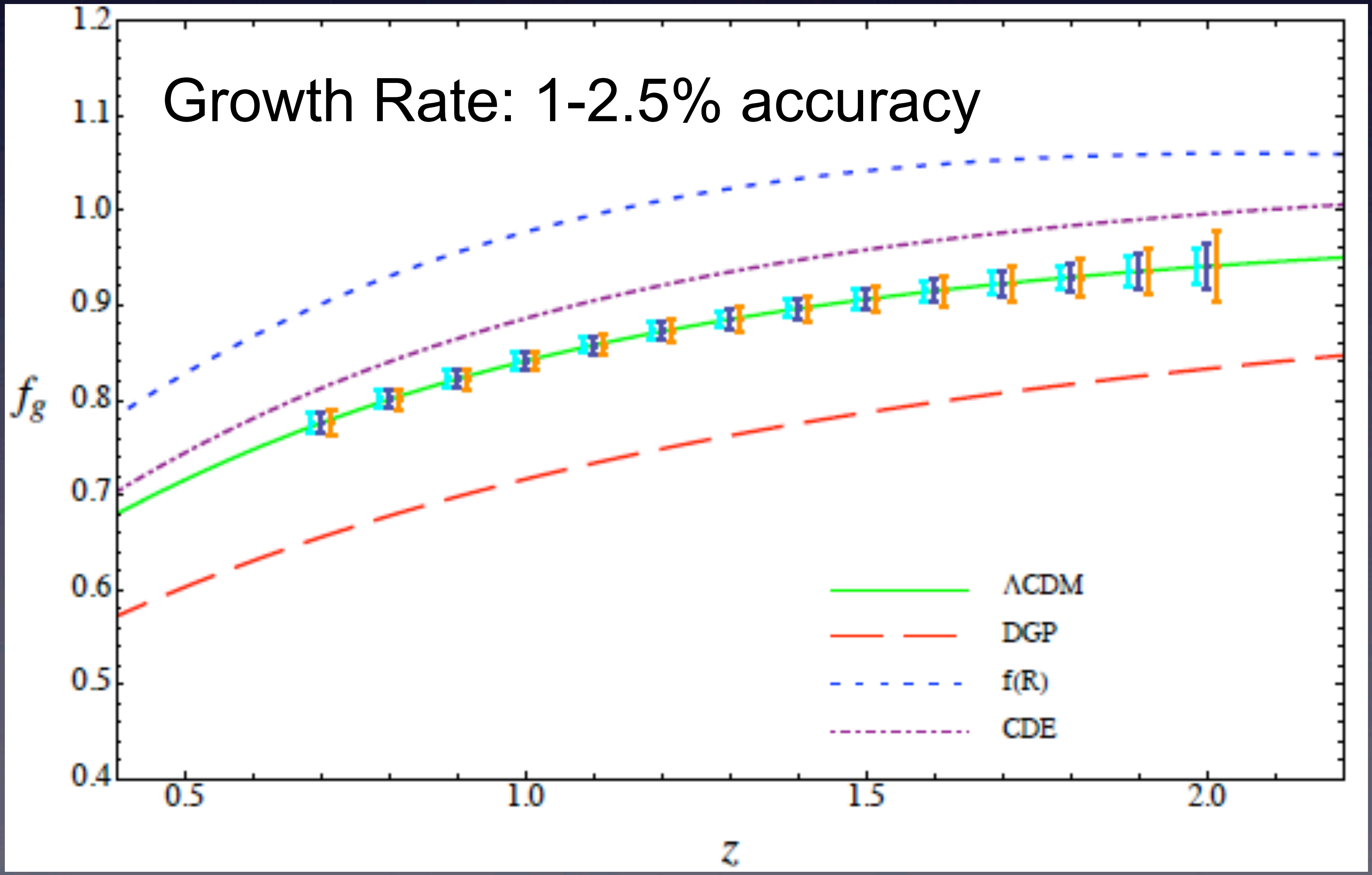
Ellis et al. 2012

- Redshift survey of the same sky as HSC
- Main target: LRGs, OII emitters
- 0.8<z<2.4 (9.3 Gpc/h^3)
- 2400 fibers, 380nm~1300nm
- 2019-2023 (planed)

Euclid

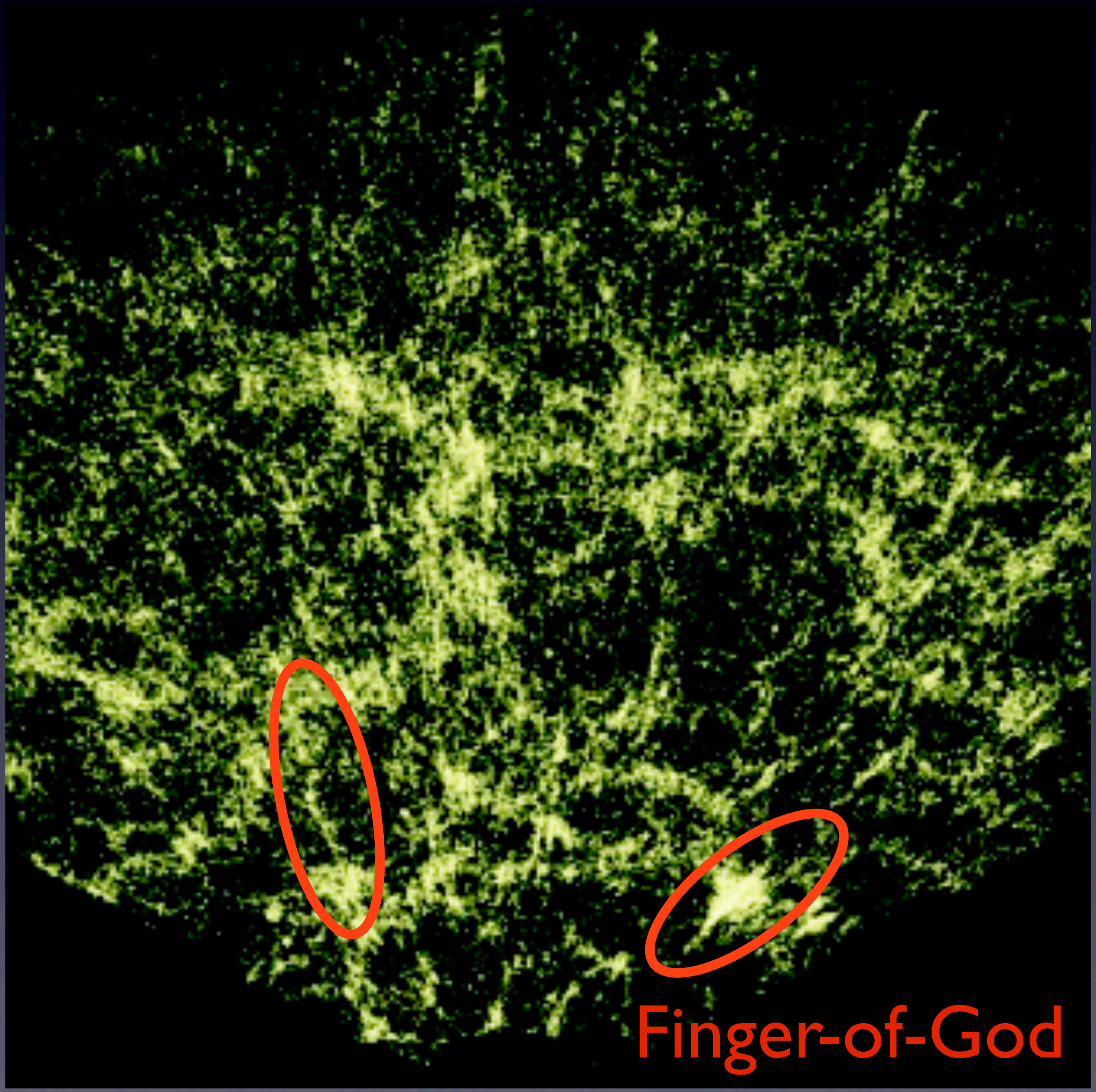
- Imaging 15,000 deg^2 sky, 40gals/arcmin^2
- Spectrum of 70M Hα emitters at 0.5<z<2
- 1.2m telescope
- FoV 0.5deg^2, rizYJH(550nm~1800nm)
- 0.2-0.3" pixel size
- 2023-2028 (planed)



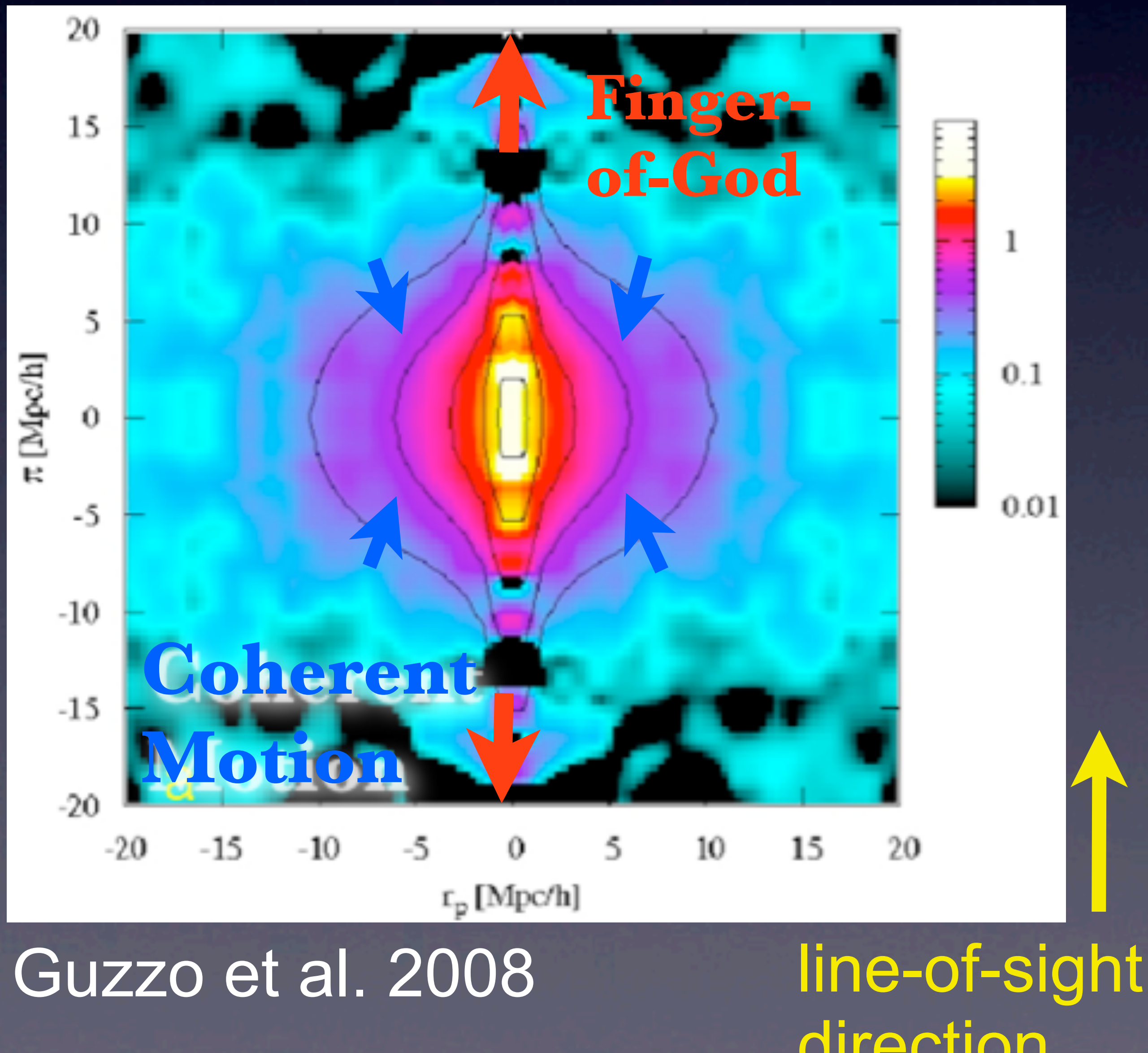


Finger-of-God (FoG) effect

Nonlinear redshift-space distortion due to random motion of galaxies inside their hosted halos



2-point correlation function of galaxies for VVDS survey(6000 gals, 0.6<z<1.2, 4deg^2)



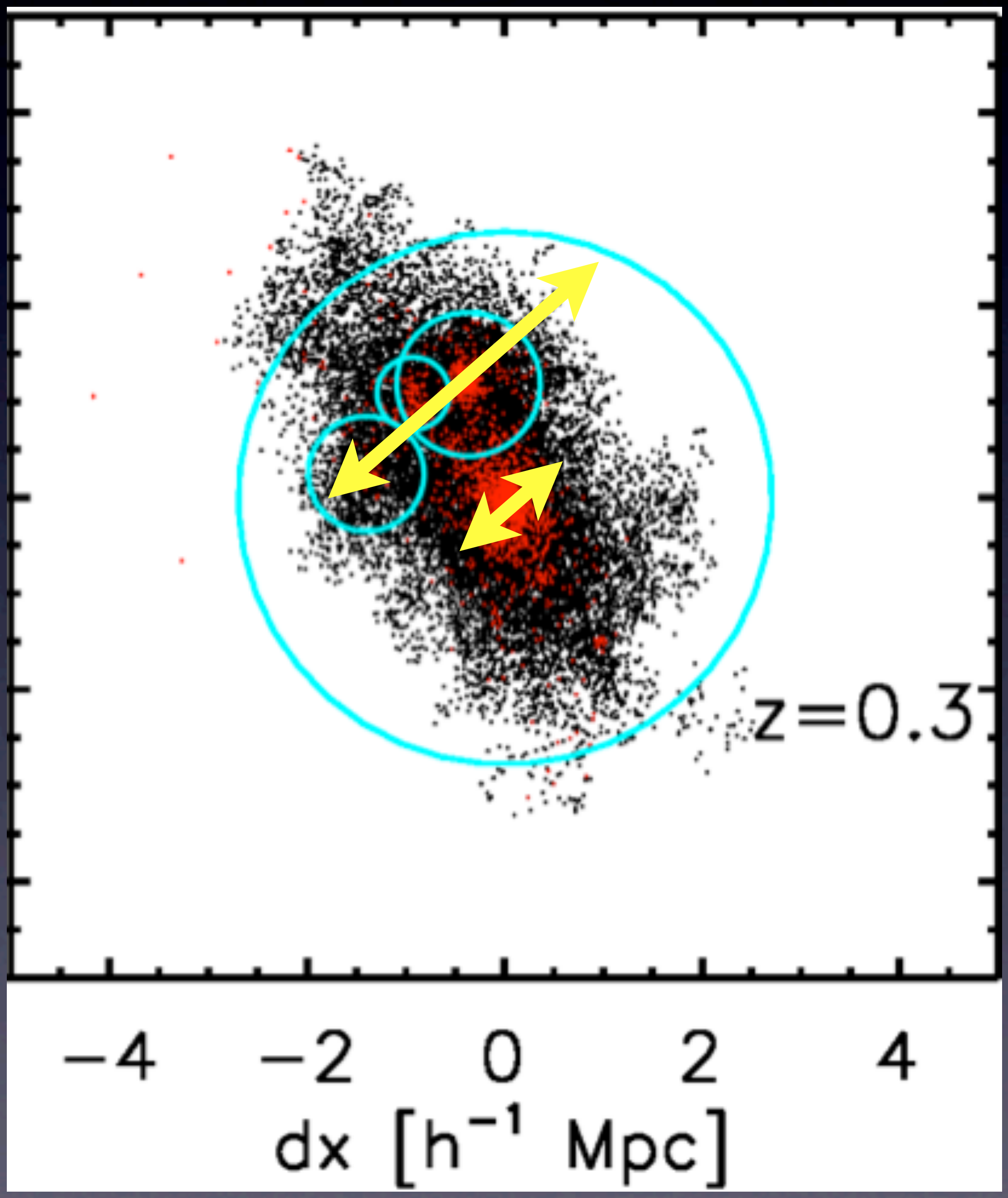
Guzzo et al. 2008

Central galaxy and Satellite galaxy

Central galaxy, which locates on the halo mass center, has small internal motion

Satellite galaxies have larger internal motions
→ main source of Fingers-of-God

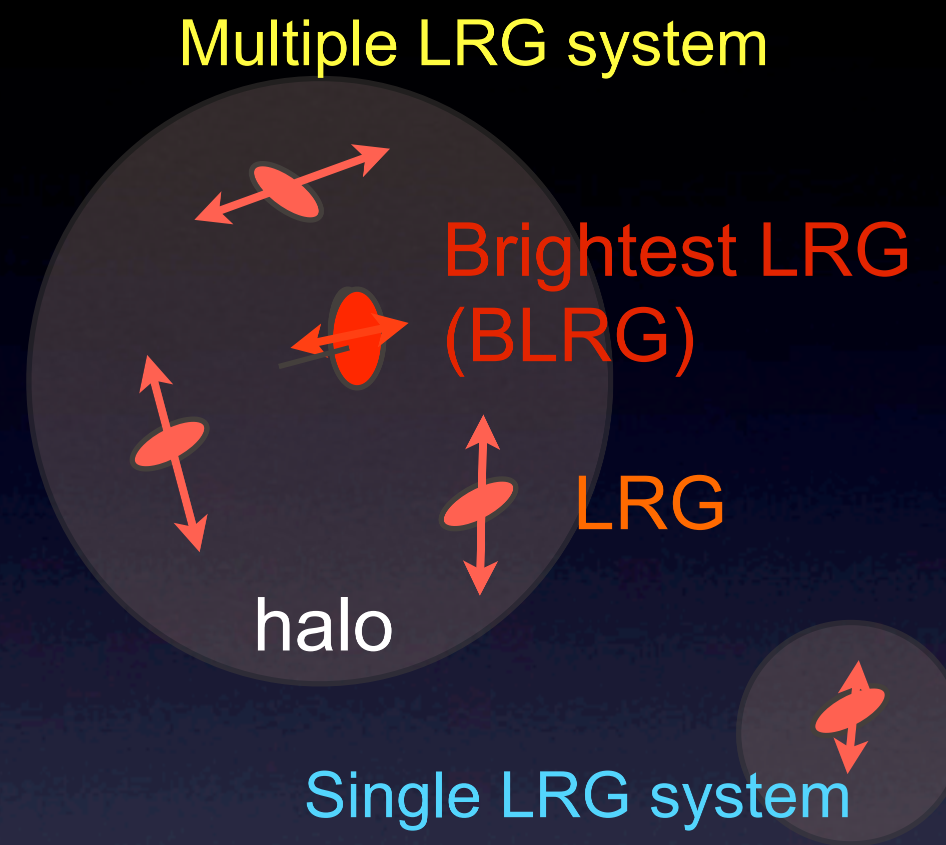
LRG-subhalo simulation



Masaki et al. 2013

Reconstruction of Halo samples

SDSS DR7 LRG sample (Kazin et al. 2010)
$-23.2<Mg<-21.2$, $0.16<z<0.47$



Reconstruct halo samples by grouping clos LRGs (Reid & Spergel 2010):

$\Delta z/(1+z)<0.006$, $\Delta r_{\perp} <0.8h^{-1}$Mpc/h

Multiplicity function

$N_{\rm LRG}$	Number of LRG FoF groups
1	87889 (95.5 per cent)
2	3713
3	358
4	65
5	14
6	6
7	1
Total	92046 (100 per cent)

Single LRG is dominated

Let's see the differences of FoG effect on power spectrum in the following samples:

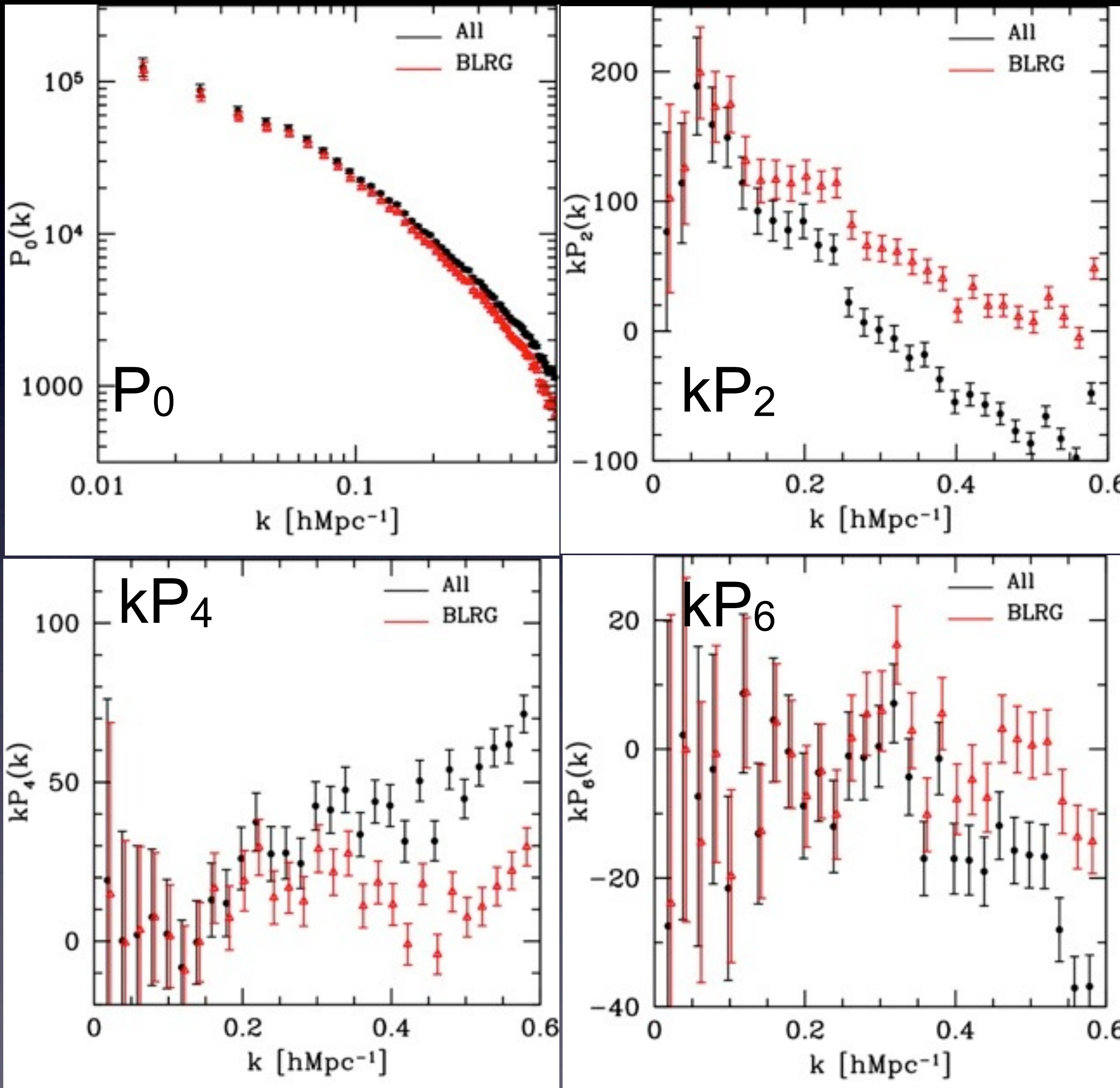
1) **ALL** : All LRGs

2) **BLRG** : Brightest LRG in each group (Single LRG systems are included)

3) **Single** : Single LRG systems only

Difference among the samples is just ～5%

Impact of Satellite Galaxies

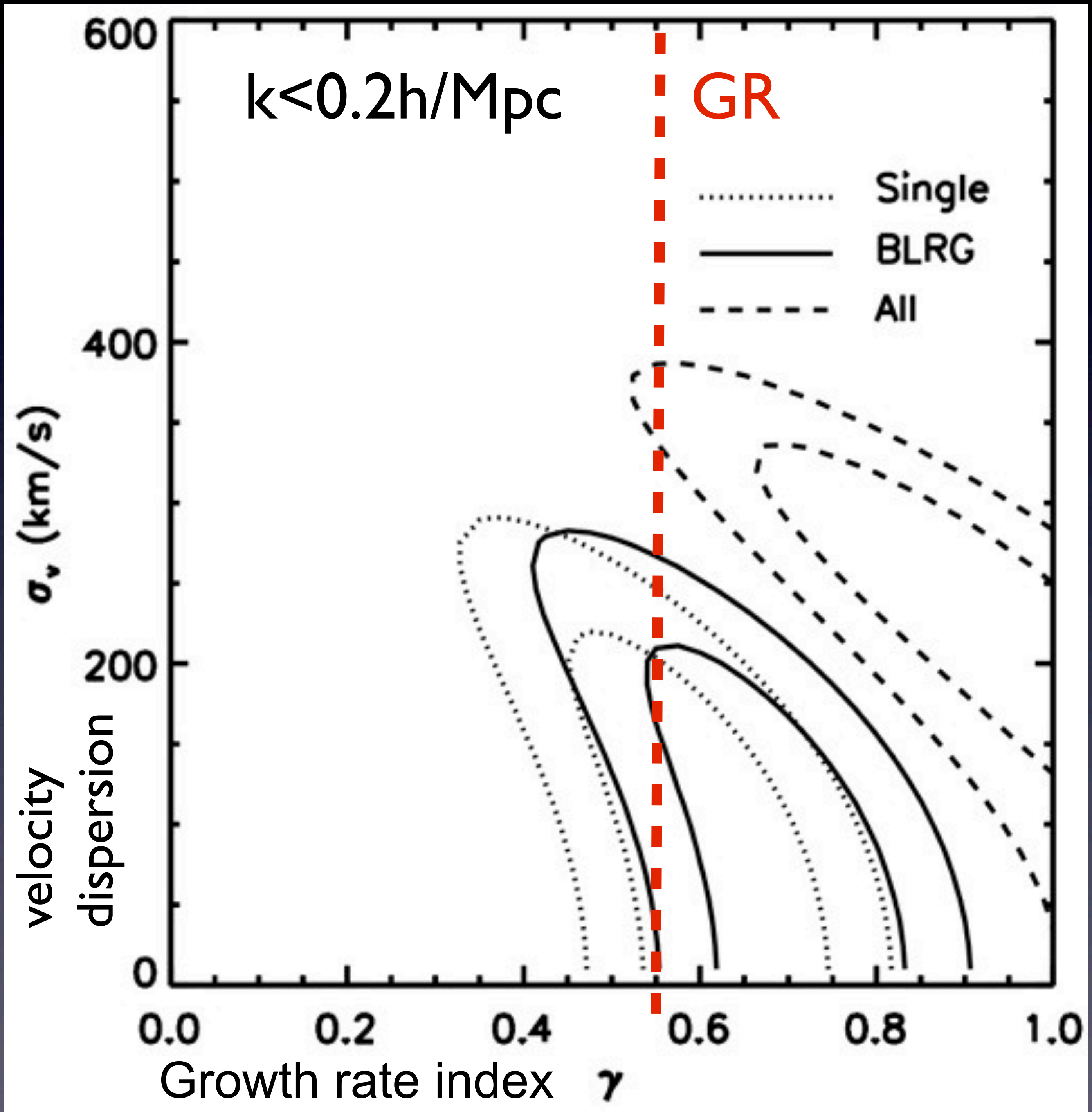


Comparison of multipole power spectra for ALL (black) and BLRG (red)

Impact of satellite galaxies, most of which are removed in BLRG, is large at small scale (large k)

Note that the sample difference is only ~5%

Systematic effect on Growth Rate measurement



Estimate growth rate by fitting Kaiser+FoG model

$$P(k,\mu) = (b(k) + f\mu^2)^2 P_{\rm m}^{\rm NL}(k)\mathcal{D}[k\mu\widetilde{\sigma}_v],$$

FoG damping assuming Lorentzian form (velocity dispersion σ_v is free)

Systematic effects on the growth rate measurement is very large for All sample

$f(z) = \Omega_{\rm m}(z)^\gamma$

Cosmology is fixed to WMAP9

Halo model

$$P_{\rm LRG}(k,\mu) = P^{\rm 1h}(k,\mu) + P^{\rm 2h}(k,\mu).$$

One-halo term

Central-Satellite pairs

$$P^{\rm 1h}(k,\mu) = \frac{1}{\bar{n}^2}\int dM\,\frac{dn}{dM}\Big[2\langle N_{\rm cen}\rangle\langle N_{\rm sat}\rangle\tilde{p}_{\rm cs}(k,\mu;M)$$

satellite-satellite pairs

$$+\langle N_{\rm sat}(N_{\rm sat}-1)\rangle\tilde{p}_{\rm ss}(k,\mu;M)\Big]$$

Satellite galaxy distribution inside halo

$$\tilde{p}_{\rm cs}(k,\mu,M) = \tilde{u}_{\rm NFW}(k;M)\exp\left[-\frac{\sigma^2_{v,\rm off}(M)k^2\mu^2}{2a^2H^2(z)}\right],$$

$$\tilde{p}_{\rm ss}(k,\mu,M) = \tilde{p}^2_{\rm cs}(k,\mu,M).$$

Finger-of-God

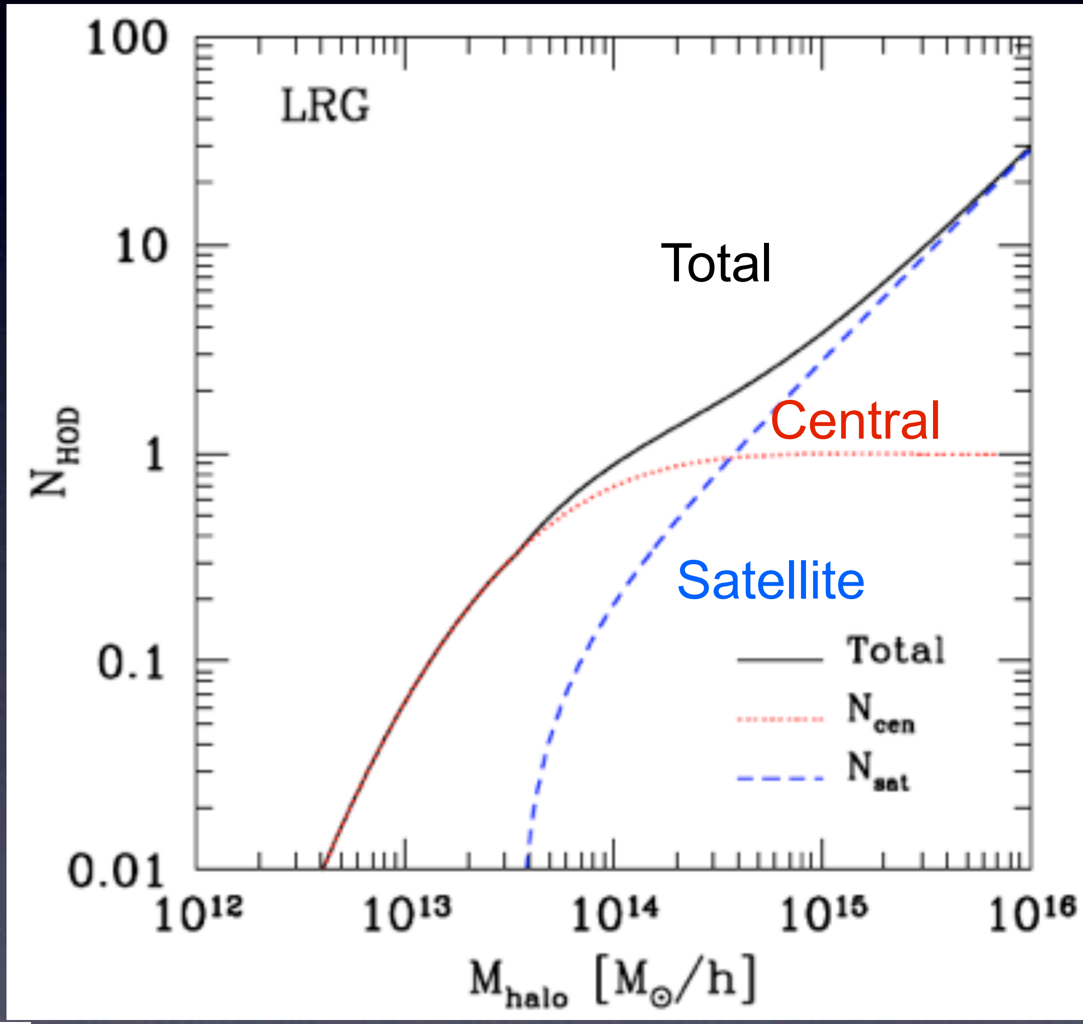
Two-halo term

$$P^{\rm 2h}(k,\mu) = \Big[\frac{1}{\bar{n}}\int dM\,\frac{dn}{dM}(b(M)+f\mu^2)\langle N_{\rm cen}\rangle$$

volume exclusion effect

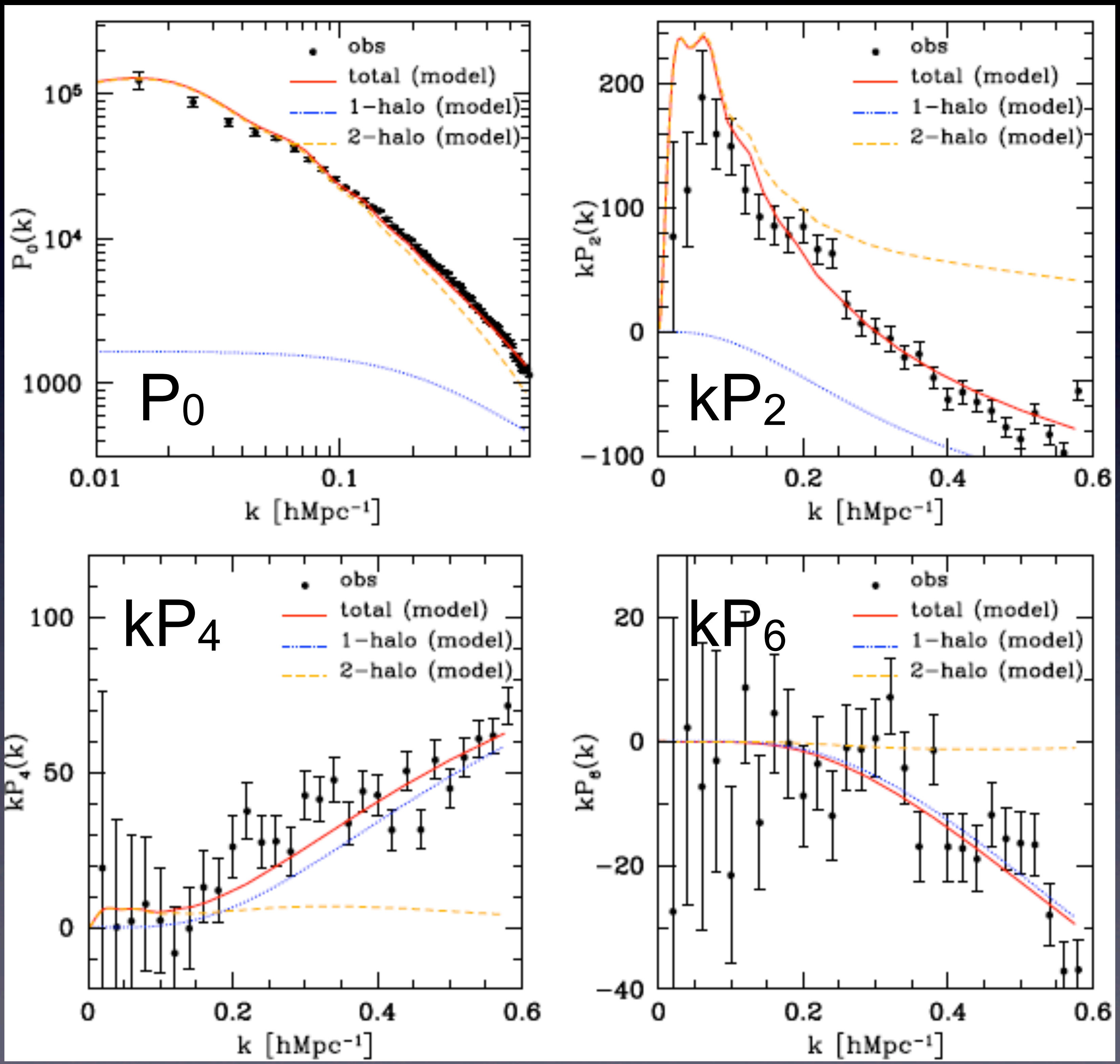
$$\times(1+\langle N_{\rm sat}\rangle\tilde{p}_{\rm cs}(k,\mu;M))\tilde{u}_{\rm vol}(k;M)\Big]^2 P^{\rm NL}_{\rm m}(k),$$

HOD (Average number of central and satellite galaxies in halo with mass $M_{\rm halo}$)



Reid & Spergel 2009

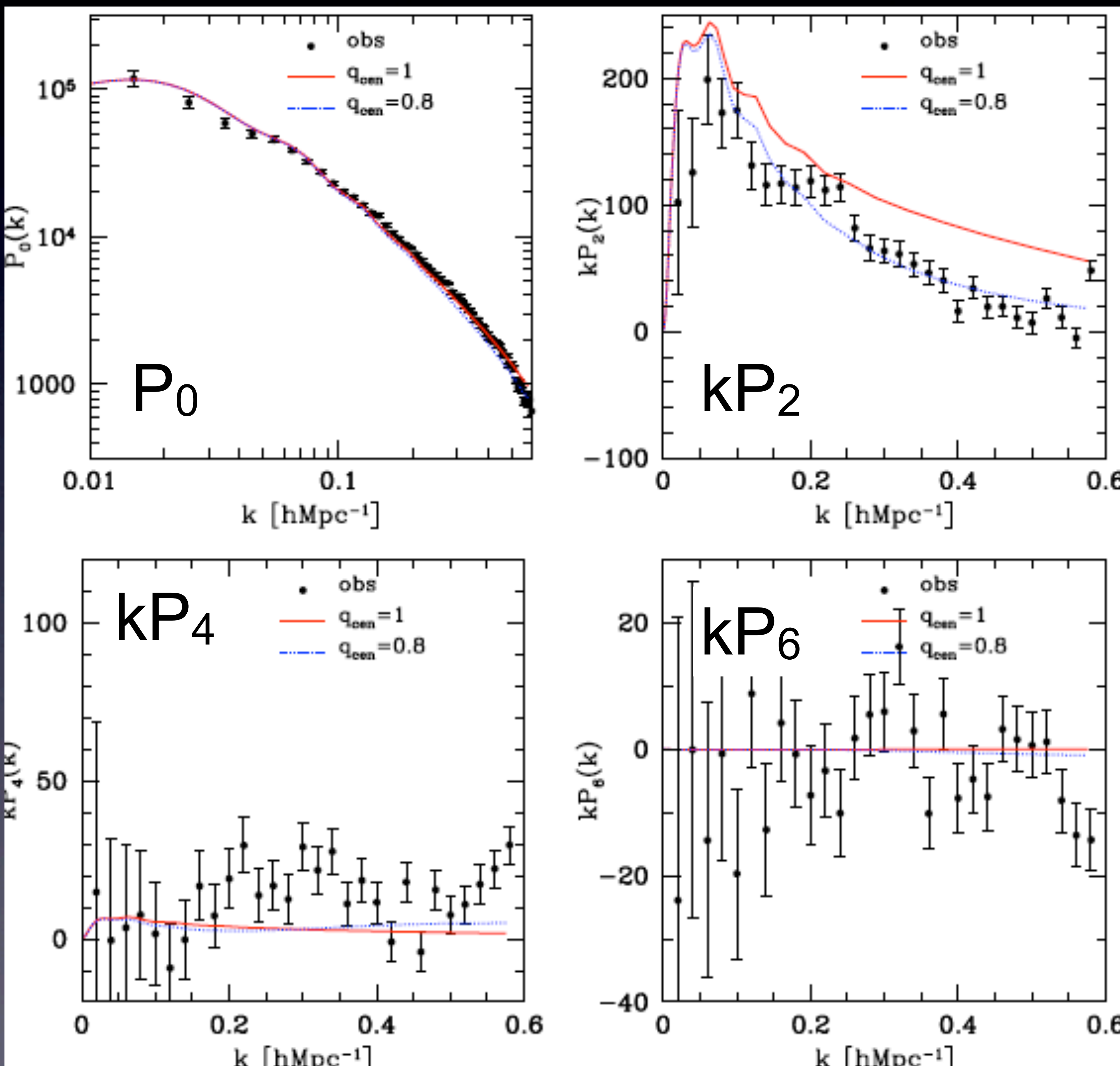
All LRG power spectrum



Power spectra are well described upto small scale by including one-halo term (blue line)

In multipole power spectra with l≧4, one-halo term (correlation between central and satellite galaxies within same halos) is dominated

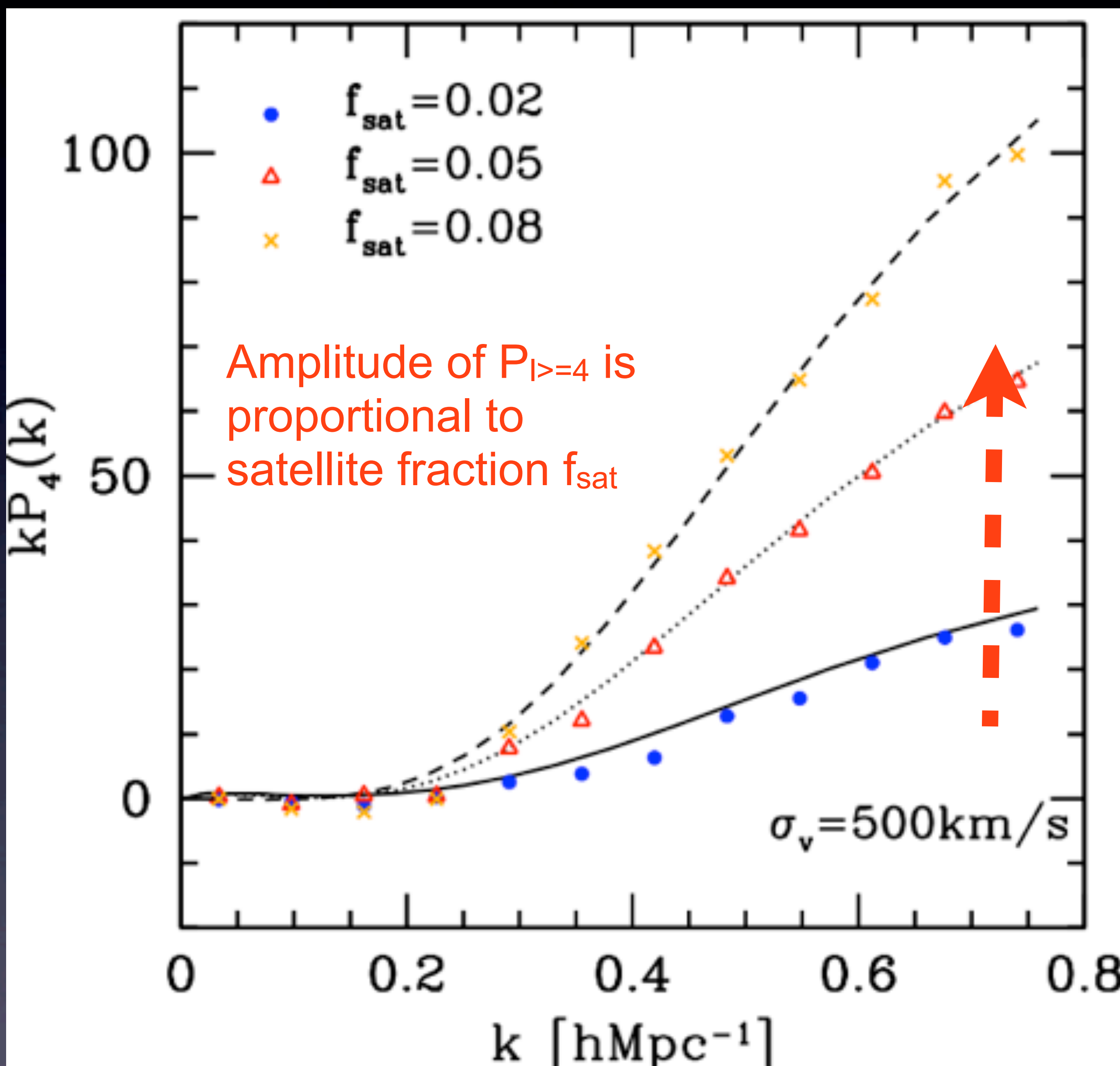
Brightest LRG power spectrum

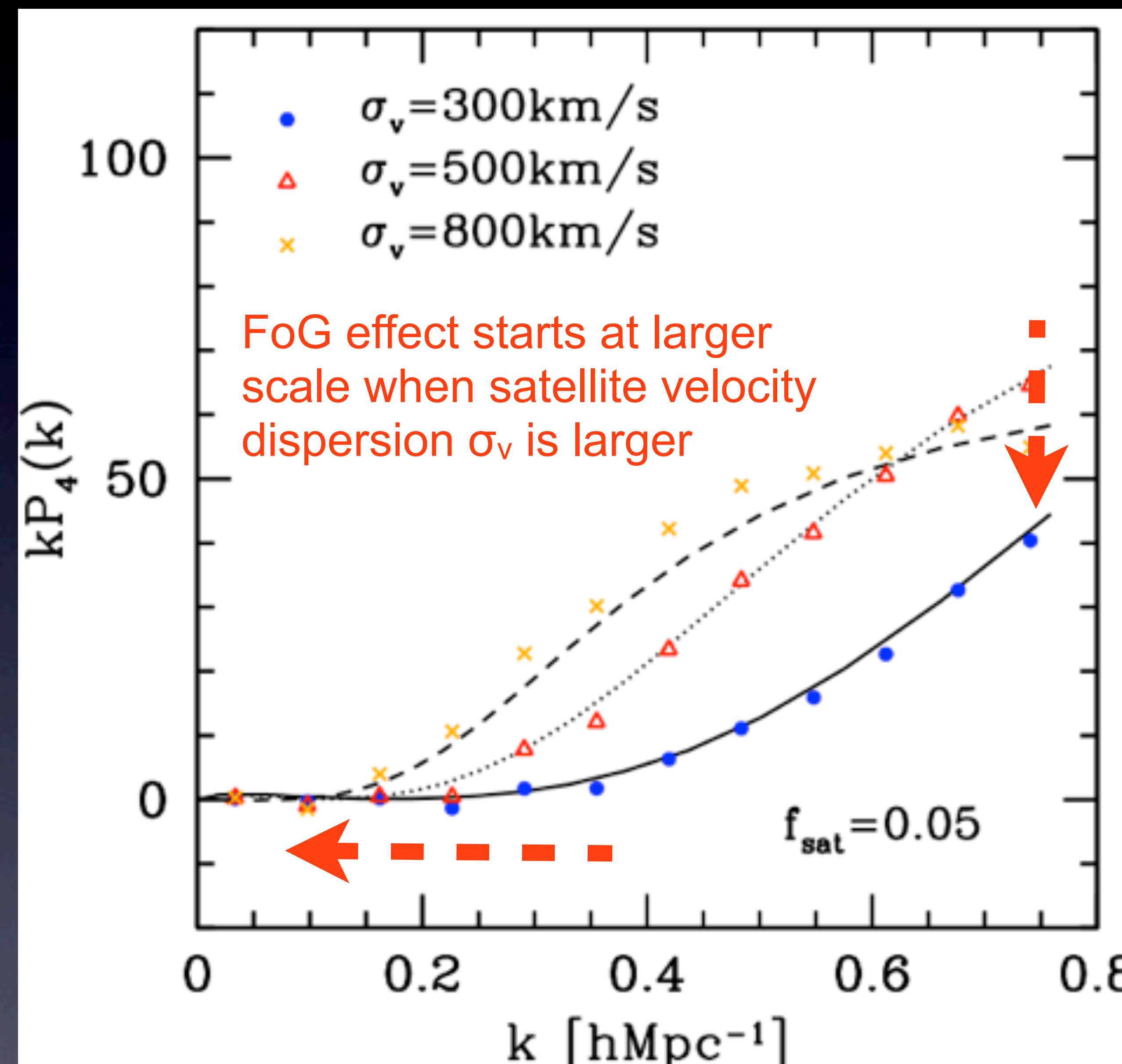


Brightest LRG, where many satellites are removed, is well described with 2-halo term only（P_4 and P_6 are consistent with 0）

Quadrupole P_2 is described better when 20% of Brightest LRG is satellite（blue lines）

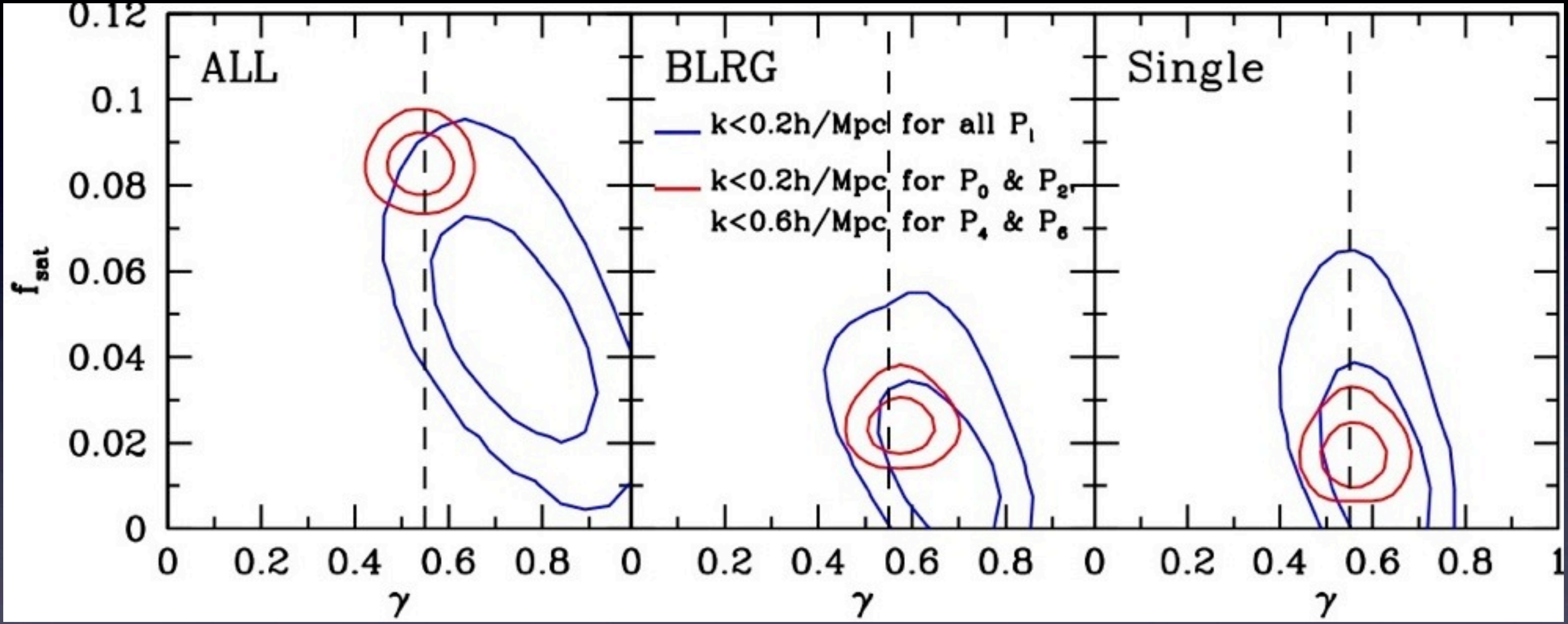
P_4 as a probe of satellite fraction





Multipole power spectra with l≧4 are good probes of satellite fraction and velocity dispersions (or HOD)

Improvement of growth rate measurement using P_4 & P_6



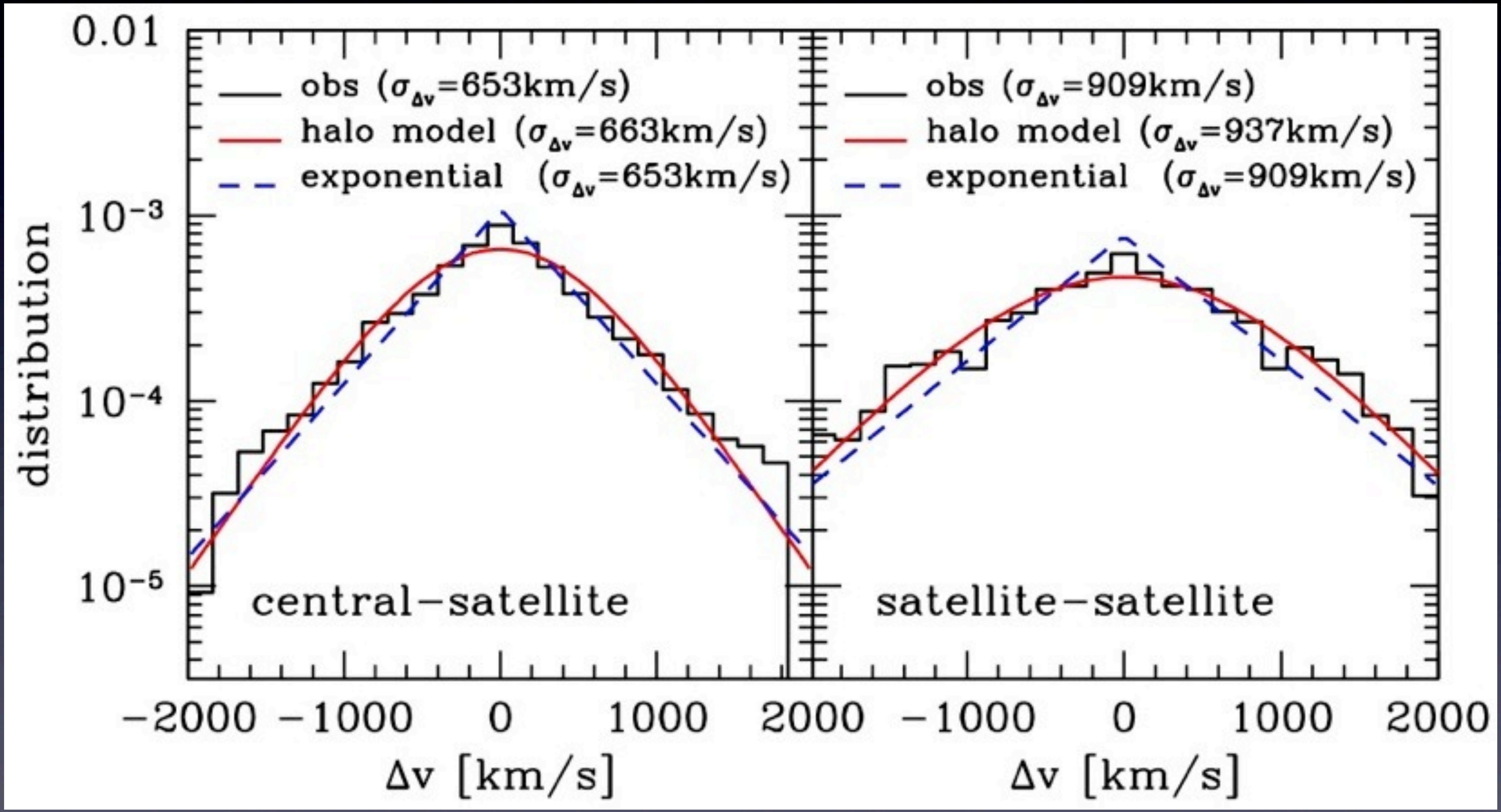
fitting parameter: γ, f_{sat}, $\sigma_{v,sat}$, b_0, b_1

Multipole power spectra (l≧4) breaks the degeneracy between growth rate and satellite FoGs

Summary

- We study the impact of satellite Fingers-of-God on the measurement of cosmic growth rate using SDSS DR7 LRG sample
- Although the fraction of satellite galaxies is small (~5%), we find that the effect on the growth rate is significantly large
- We point out that 1-halo term (central-satellite pair contribution within the same halo) is necessary to describe Fingers-of-God effect. We detect the non-zero signature of multipole power spectra with $l \geqq 4$, which comes from Fingers-of-God in 1-halo term
- Information of $P_{l \geqq 4}$ are good probe of satellite properties and then improves the accuracy of growth rate measurement significantly

Satellite velocity distribution



Halo Model vs Observations