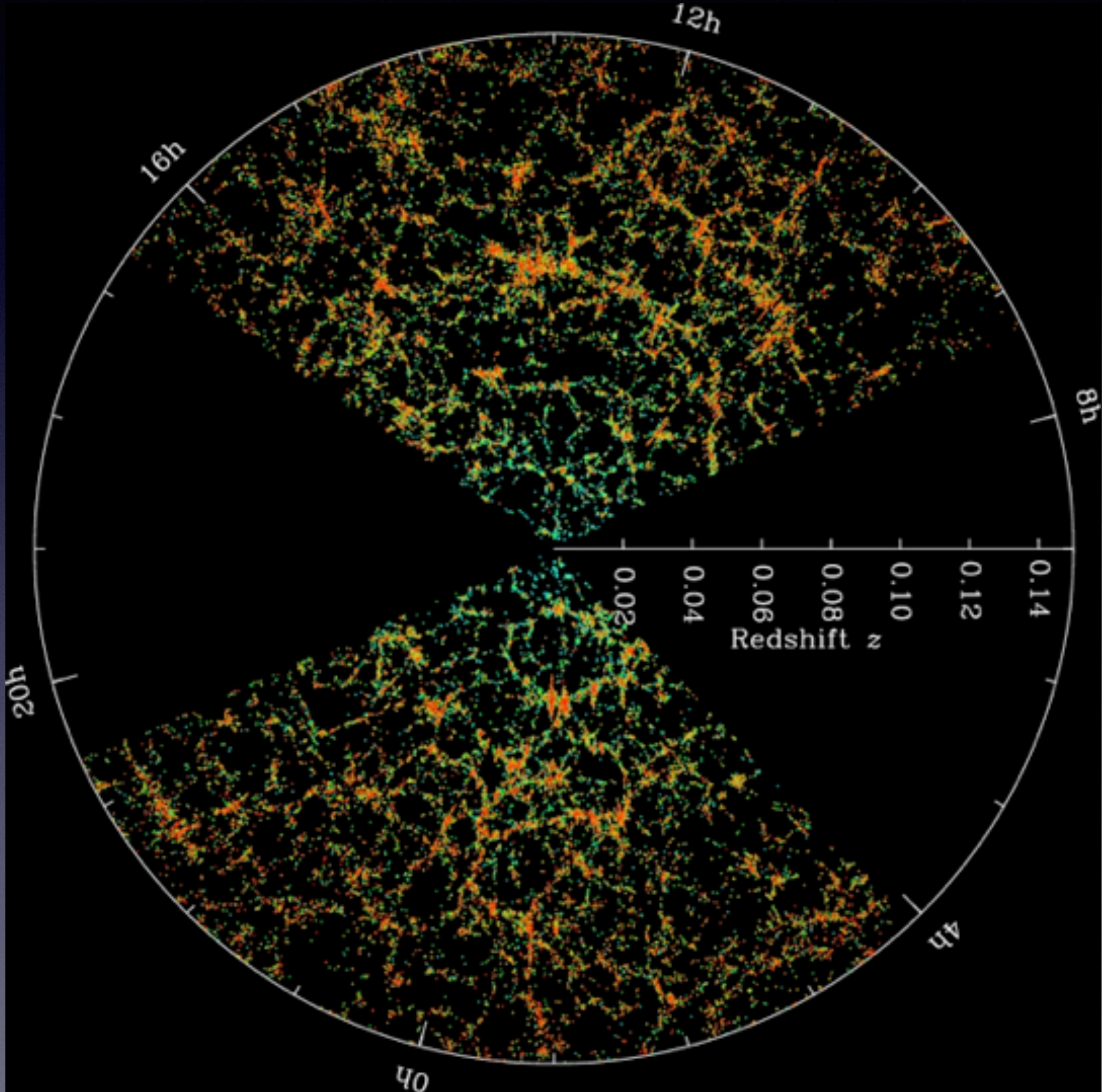
Impacts of satellite galaxies on the redshift-space distortion analysis

Chiaki HIKAGE (KMI, Nagoya U.）

Ref. C.H. , Kazuhiro Yamamoto, JCAP 08 (2013), 19
C.H., MNRAS Letter, 441 (2014) 21

Galaxy redshift surveys



SDSS Collaboration

What can we learn ?

- Dark energy
- Gravity test
- Neutrino mass
- Primordial Non-Gaussianity

previous/on-going surveys

- CfA, LCRS, 2dF, SDSS, BOSS, WiggleZ, VVDS, VIPERS, FastSound, …

planned survey

- PFS, HETDEX, DESI, Euclid, WFIRST, …

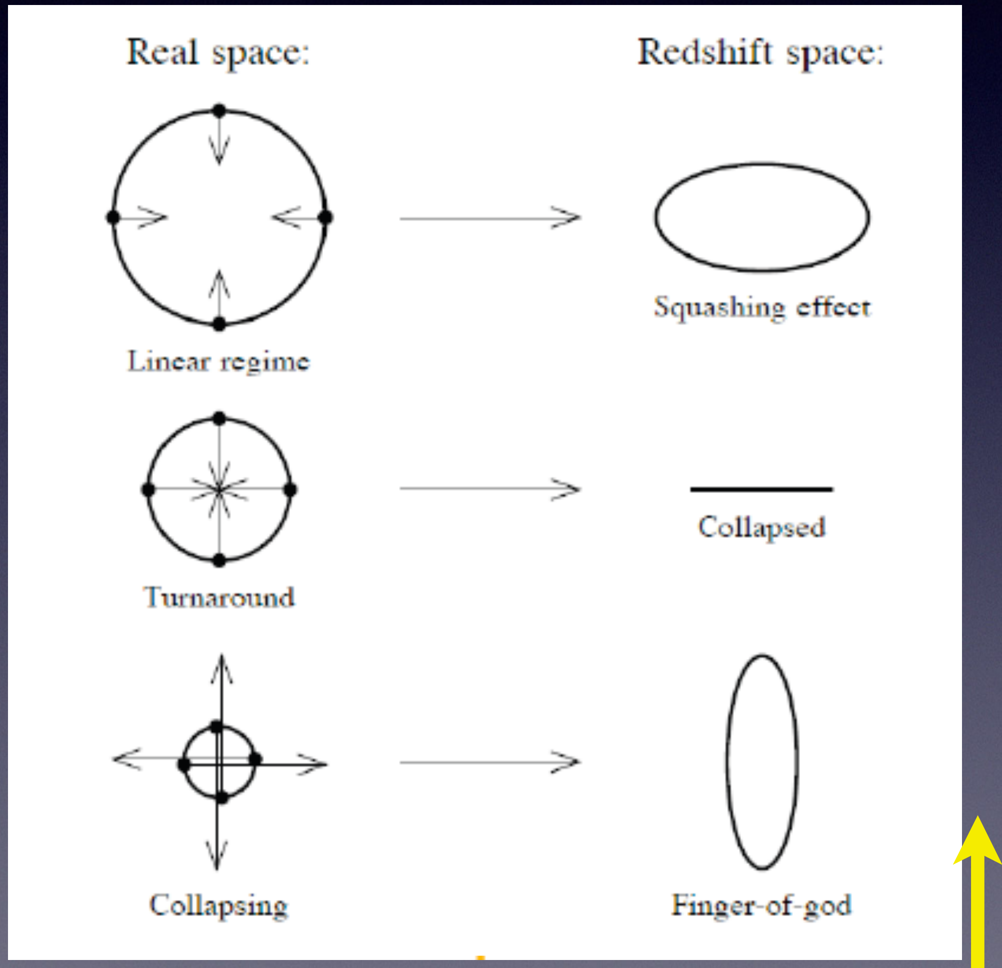
Redshift-space distortion (RSD)

Peculiar motion of galaxies distort the observed (redshift-space) galaxy distribution

$$z_{obs}=z_{true}+\delta v/c$$

<u>Linear regime</u>
Coherent bulk motion squashes the galaxy distribution along the LOS direction
"Kaiser effect"

<u>Nonlinear regime</u>
Random motion of galaxies elongate the galaxy distribution along the LOS direction
"Fingers-of-God effect"



Hamilton 1992

Test of Gravity

Redshift-space galaxy power spectra in linear regime

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

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

f: growth rate

Growth rate is a key probe to test gravity

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

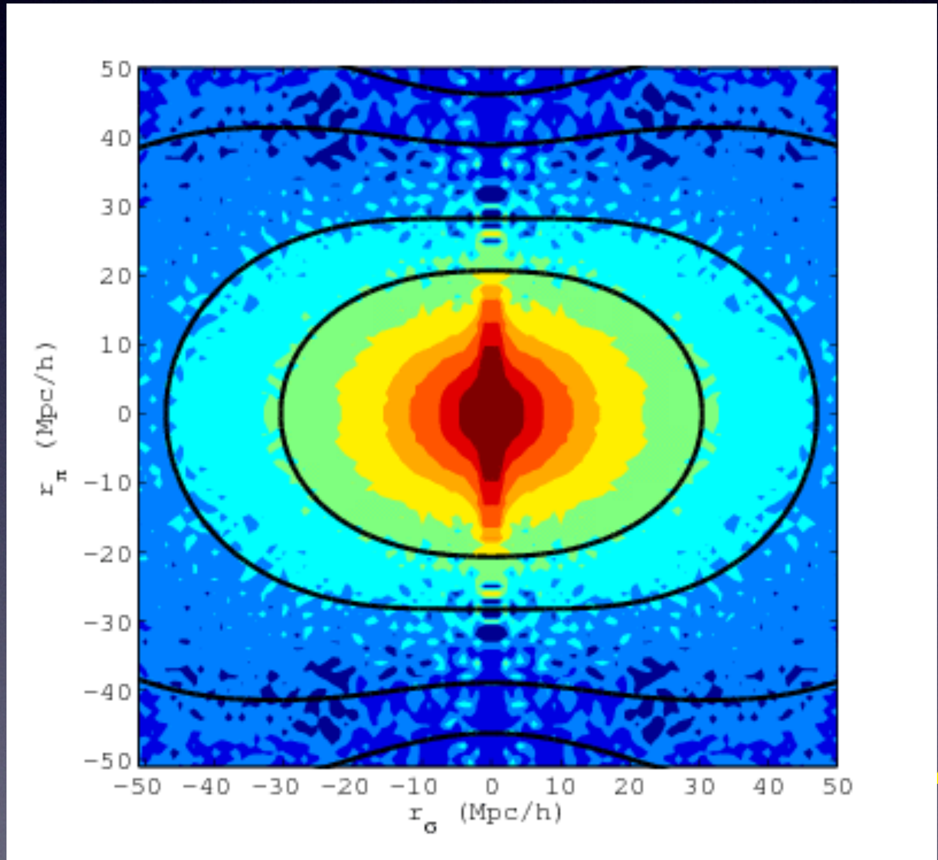
(Peebles 1976, Lahav et al. 1991)

$\gamma \simeq 0.55$ 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)

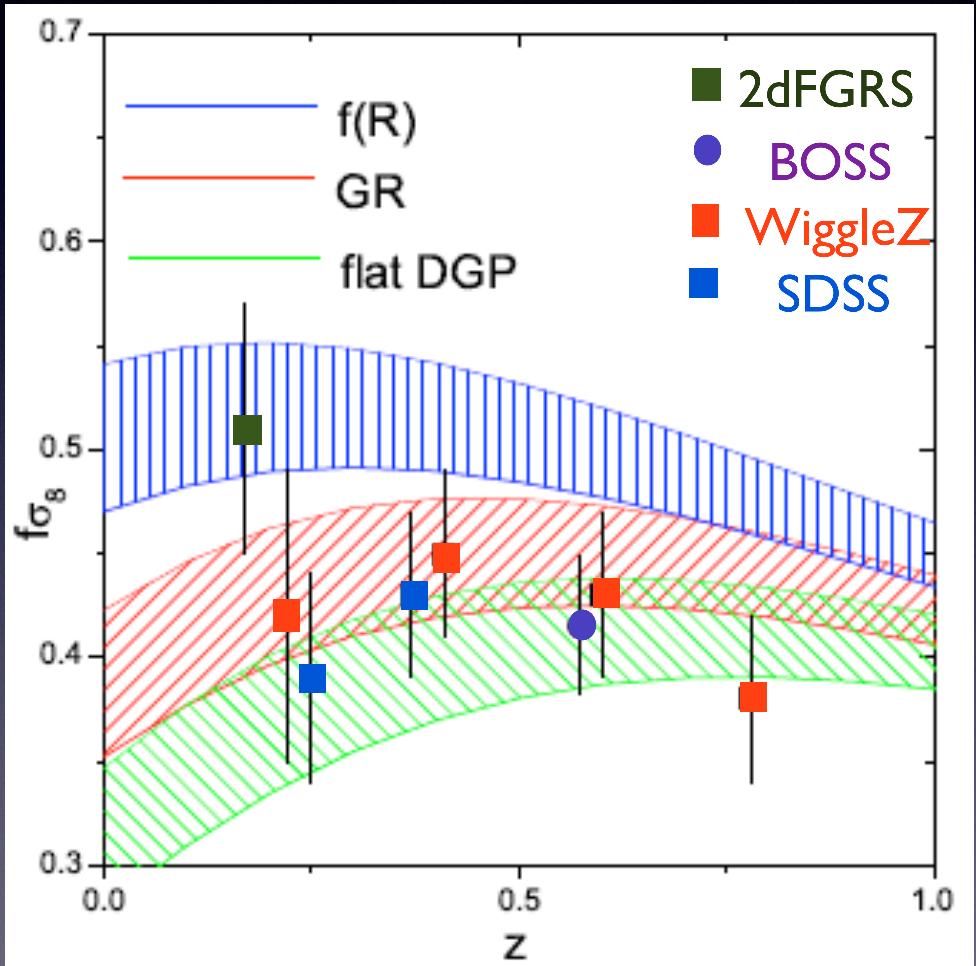
2-point correlation functions for BOSS CMASS samples $\xi(r_p, r_\pi)$

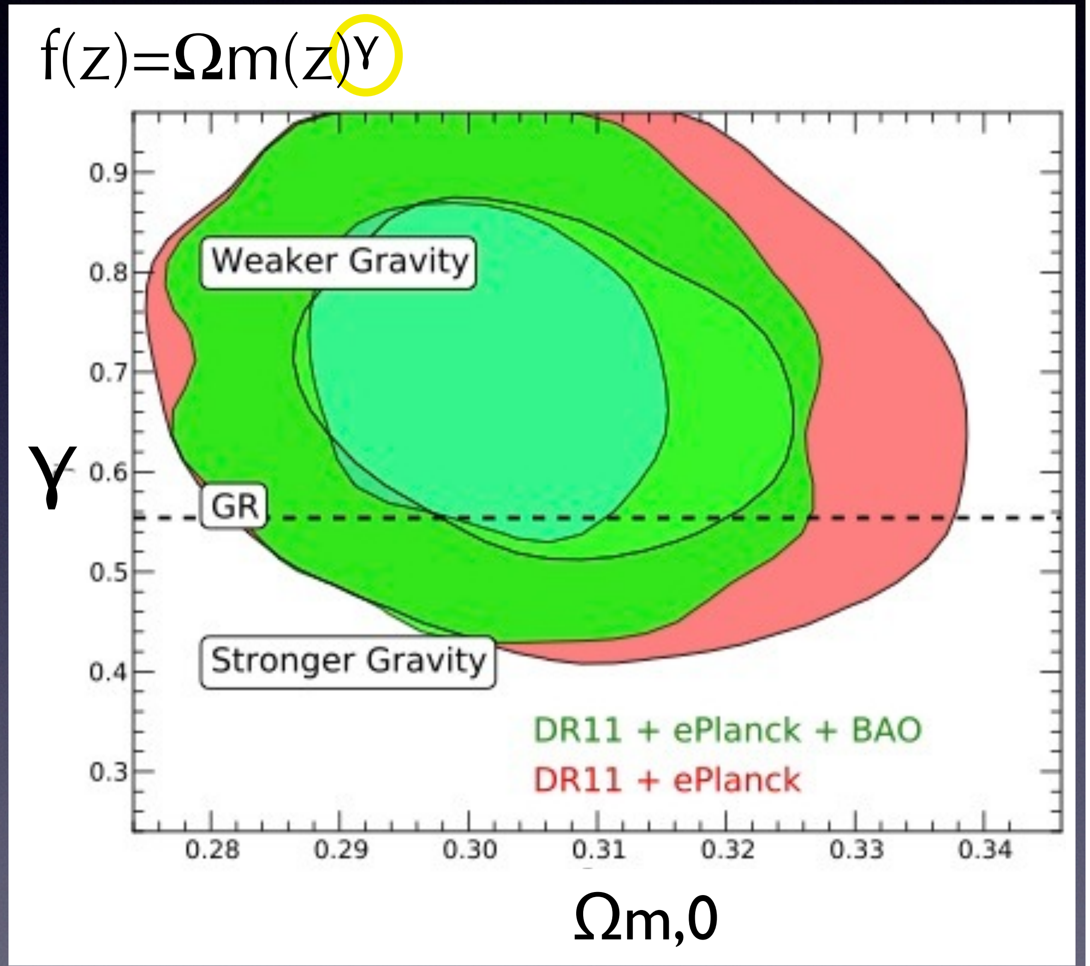


Reid et al. 2012

line-of-sight direction

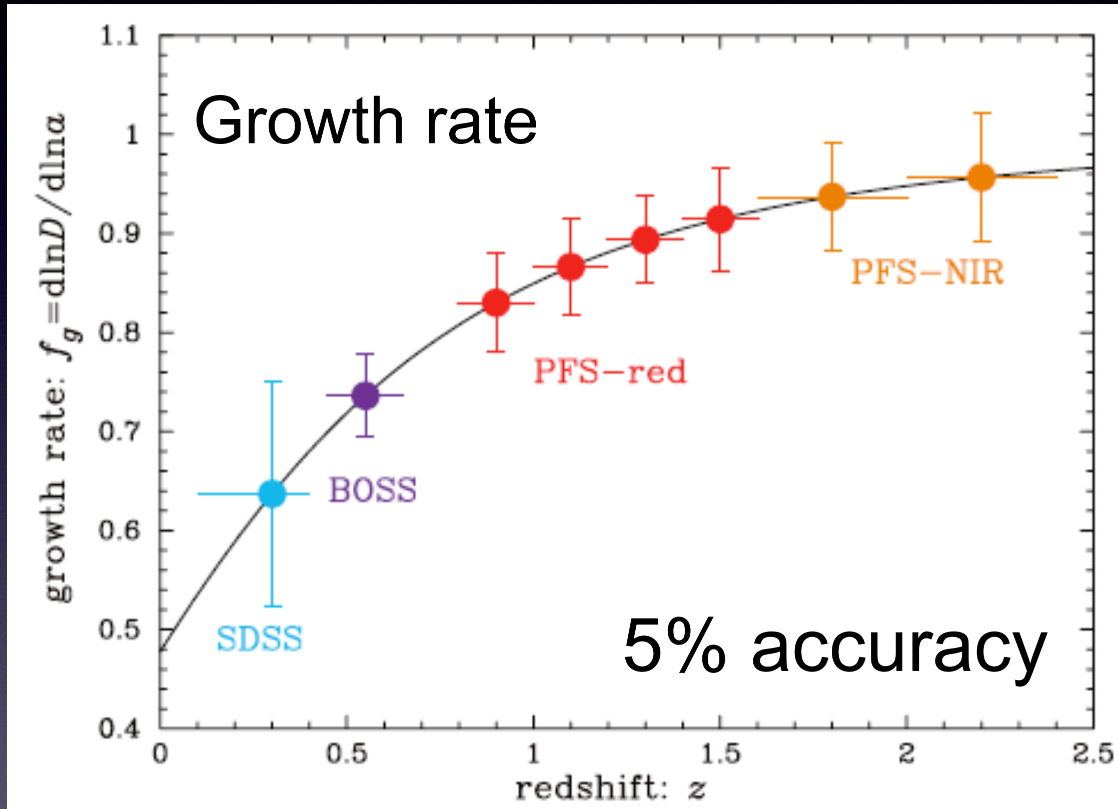
Constraints on Growth rate





Samshia et al. 2014

Subaru/PFS cosmology survey

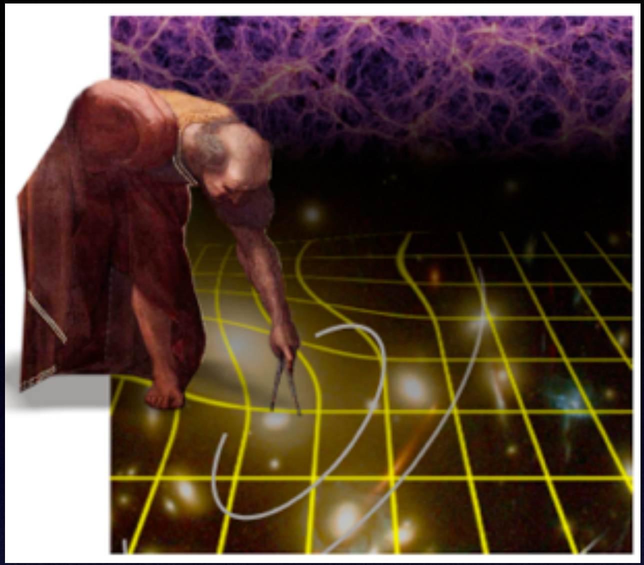


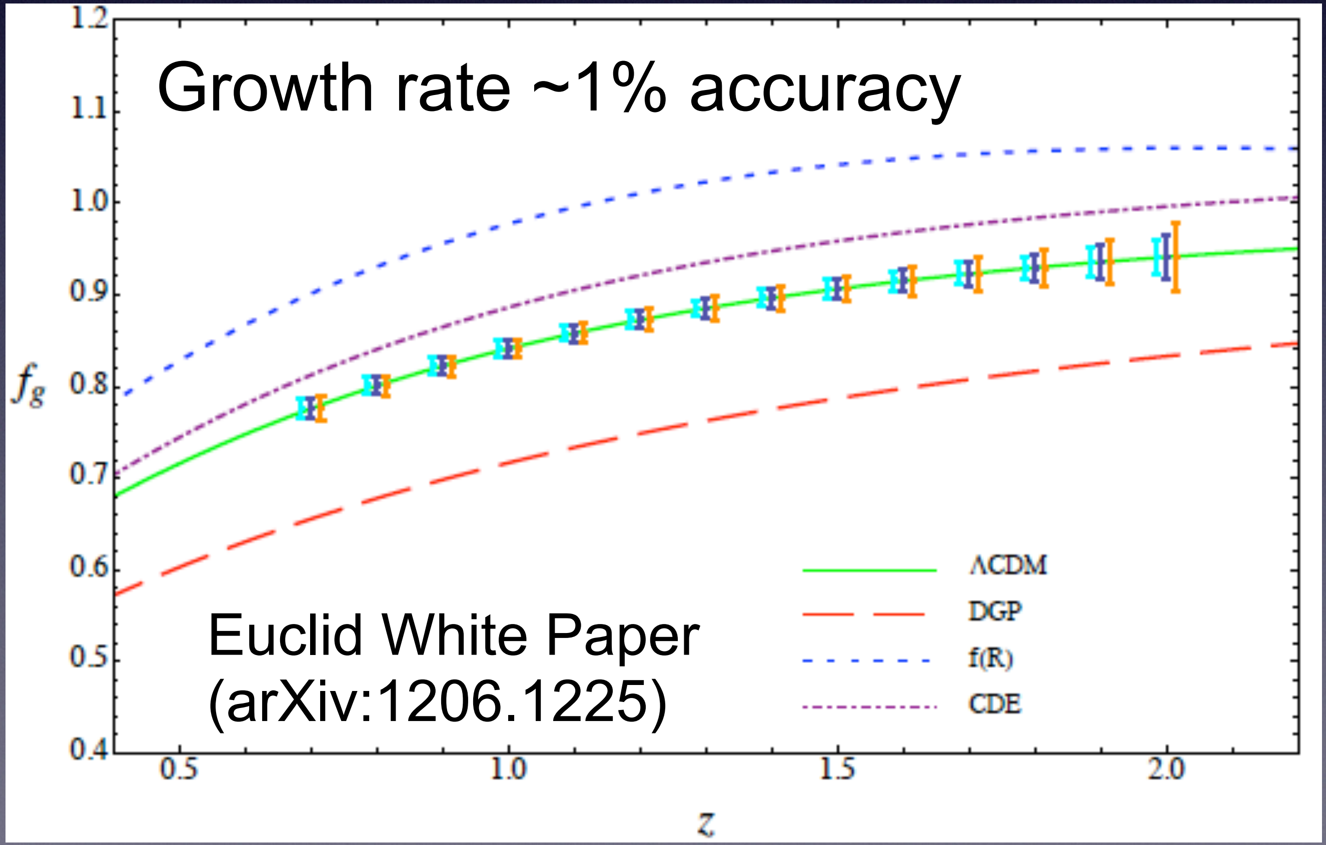
Takada et al. 2013

- Subaru 8.2m telescope
- same sky coverage as HSC (1500deg^2)
- Target: 4M LRGs, ELGs (OII)
- $0.8<z<2.4$ (9.3 Gpc/h^3)
- Err. of $D_A(z)$, $H(z)$ ~3% (Ω_k ~7%), f_z ~5% in 6 bins , Ω_k~0.3%
- 2019-2023 (planed)

Euclid

- 1.2m space telescope
- Imaging 15,000 deg^2 sky, 40gals/arcmin^2
- Spectrum of 50M Hα emitters at 0.5<z<2
- FoV 0.5deg^2, rizYJH(550nm~1800nm)
- 2021~





Systematics

In order to achieve these goals, we have to control systematics at percent-level accuracy

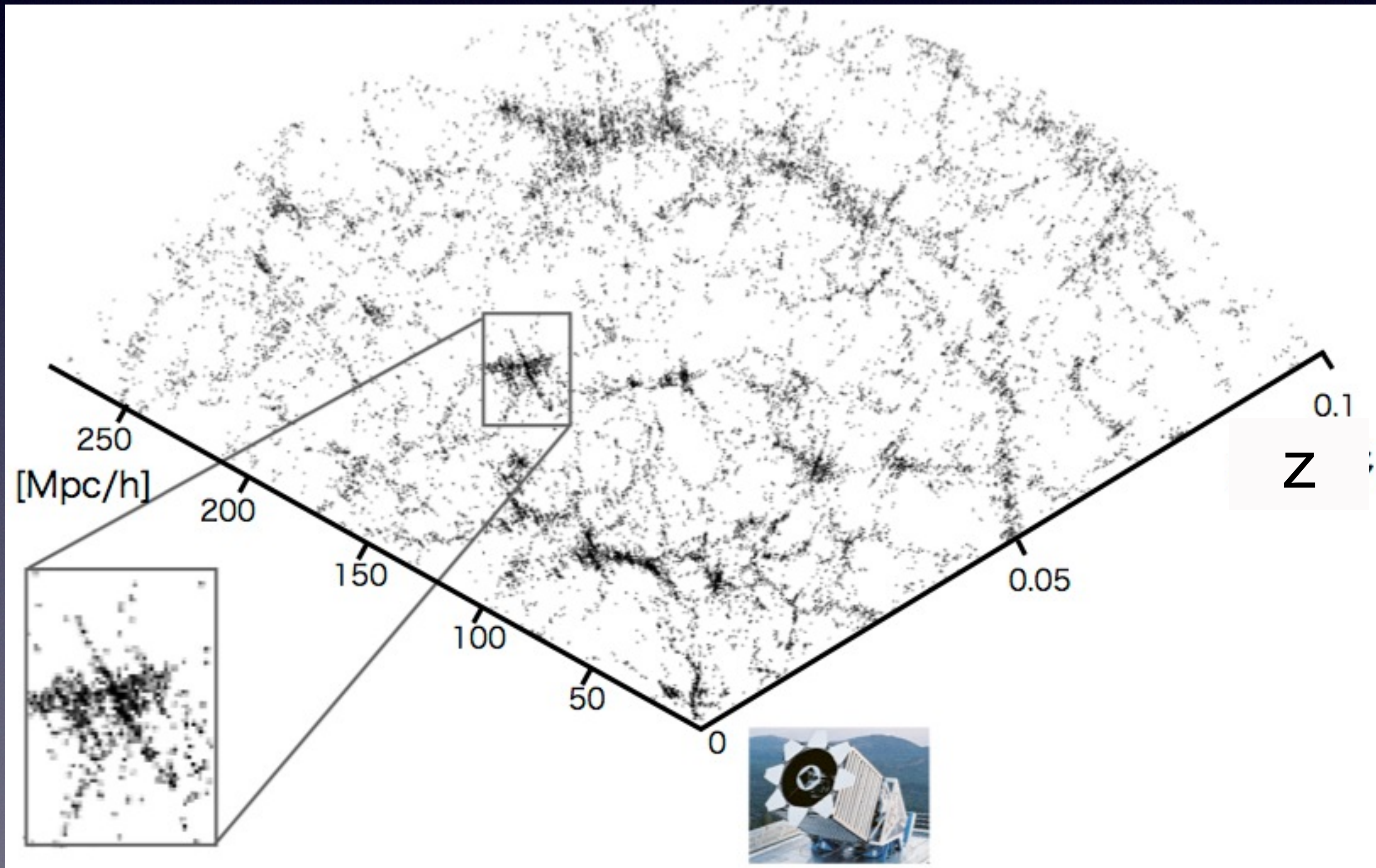
1. Nonlinear Gravity

2. Relationship between galaxy and DM halo
 a) Galaxy biasing

 b) Non-linear redshift-space distortion (i.e., Fingers-of-God)

Fingers-of-God (FoG) effect

Nonlinear redshift-space distortion due to internal motion of galaxies in the host halos

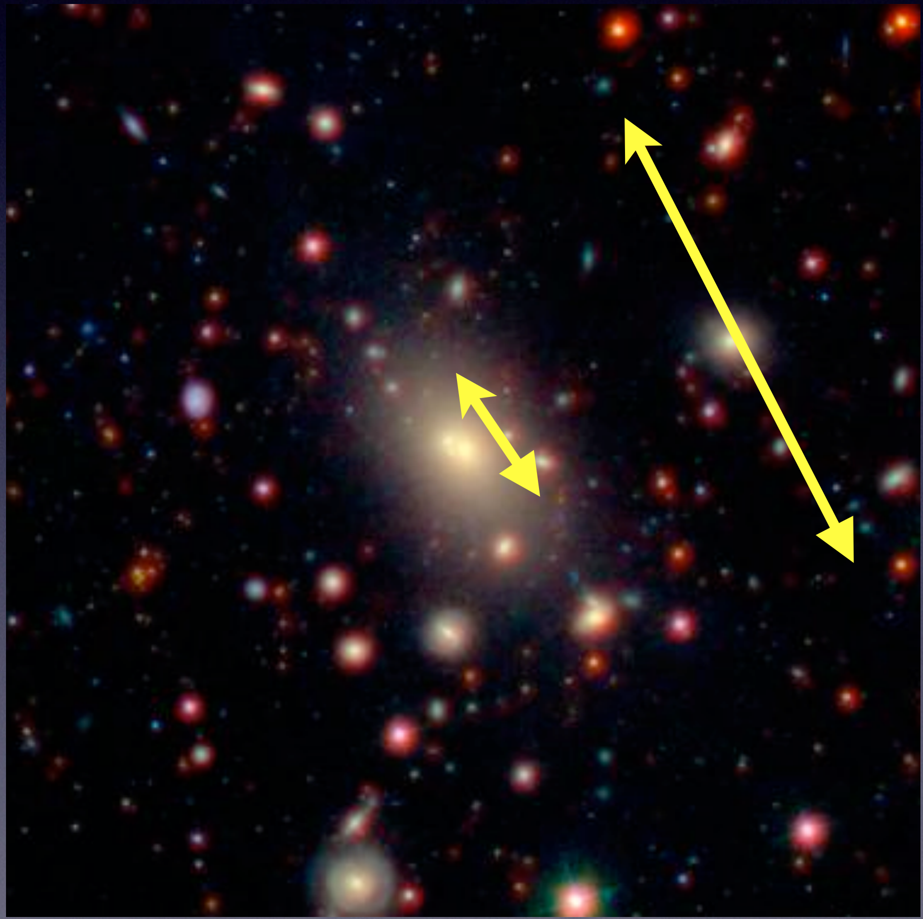


Central and Satellite galaxies

Central galaxies, which locate around the halo mass center, has small internal motion

Satellite galaxies have larger internal motion

Main source of FoG

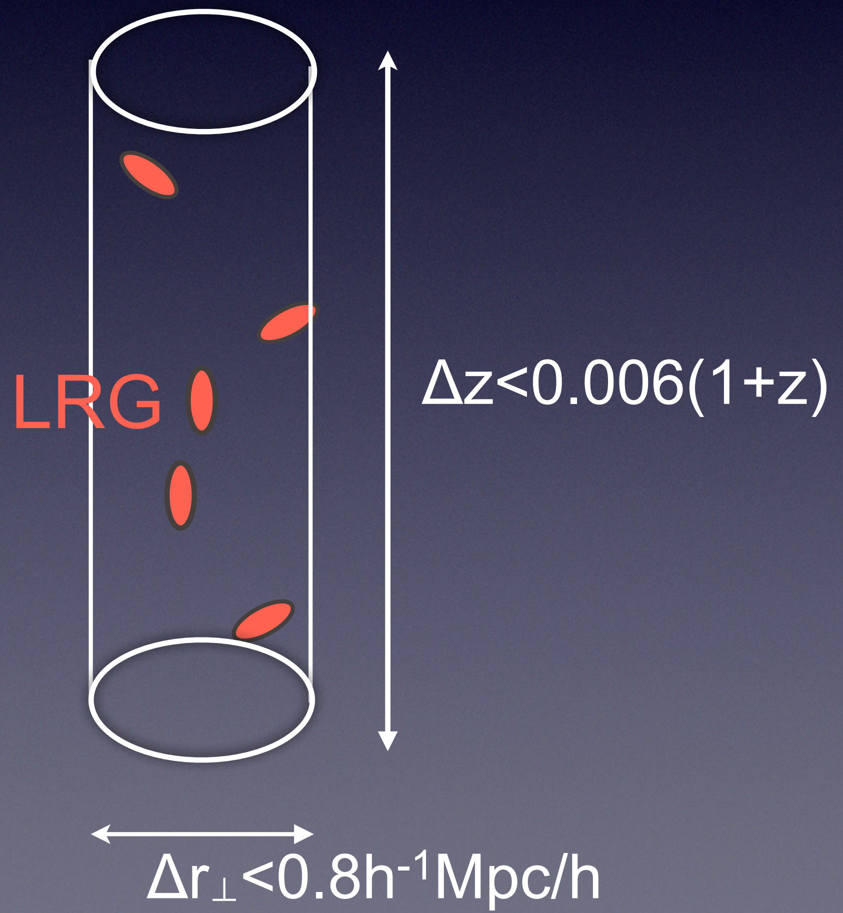


credit: NASA/JPL-Caltech/SDSS/NOAO

Reconstruction of halo catalogs

SDSS DR7 Luminous Red Galaxy sample (0.16<z<0.47)

Counts-in-Cylinder group finding method (Reid & Spergel 2010):



LRG Multiplicity function

N_{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)

Brightest LRG catalog

We compare the power spectra of following 3 samples to see the impact of satellite galaxies

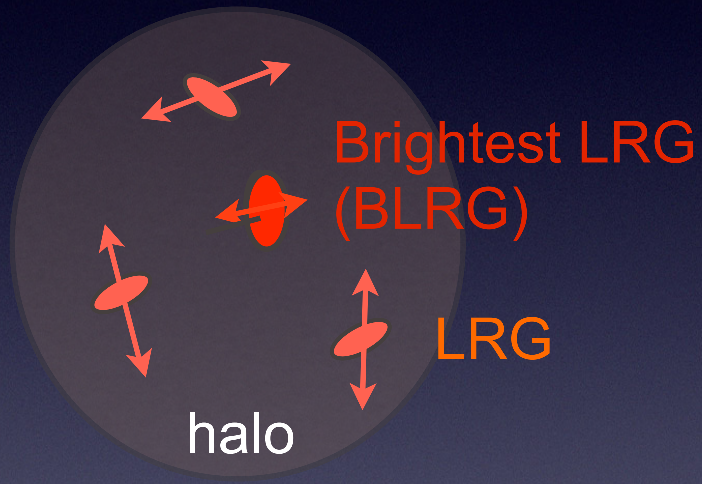
1) **ALL** : All LRGs

2) **BLRG** : Brightest LRG in each group

(BLRGs are not always centrals, but many satellites are removed in this catalog)

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

Multiple LRG system



Single LRG system

Difference among the samples is just ～5% LRGs

Multipole expansion of galaxy power spectrum

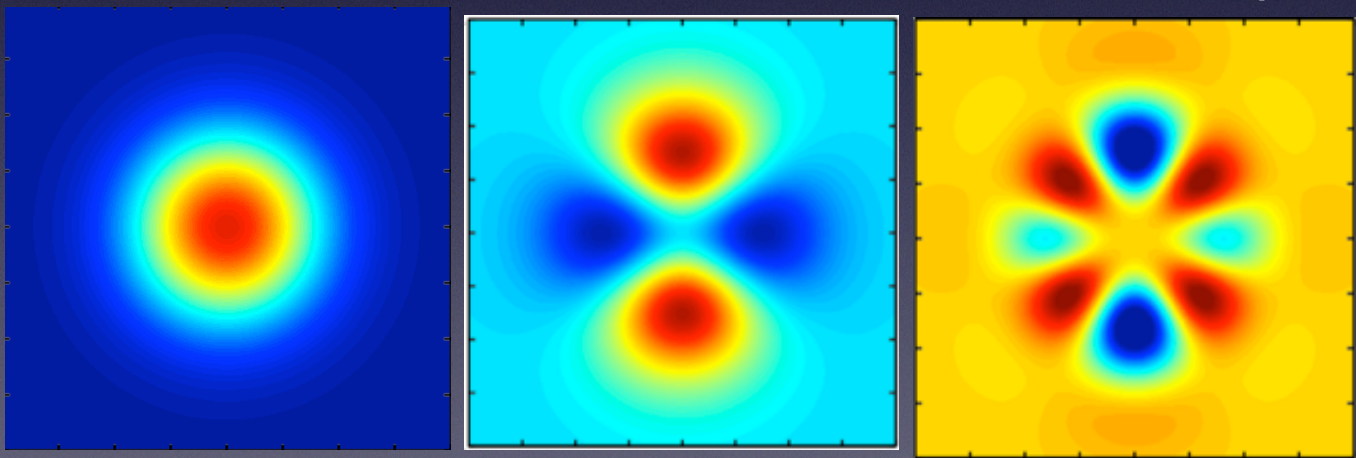
Clustering anisotropy is described with the multipole power spectra

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

$\mathcal{L}_l$:Legendre polynomials

$\mu=k_{||}/k$: cosine angle against the line-of-sight direction

P_0: monopole P_2: quadrupole P_4: hexadecapole



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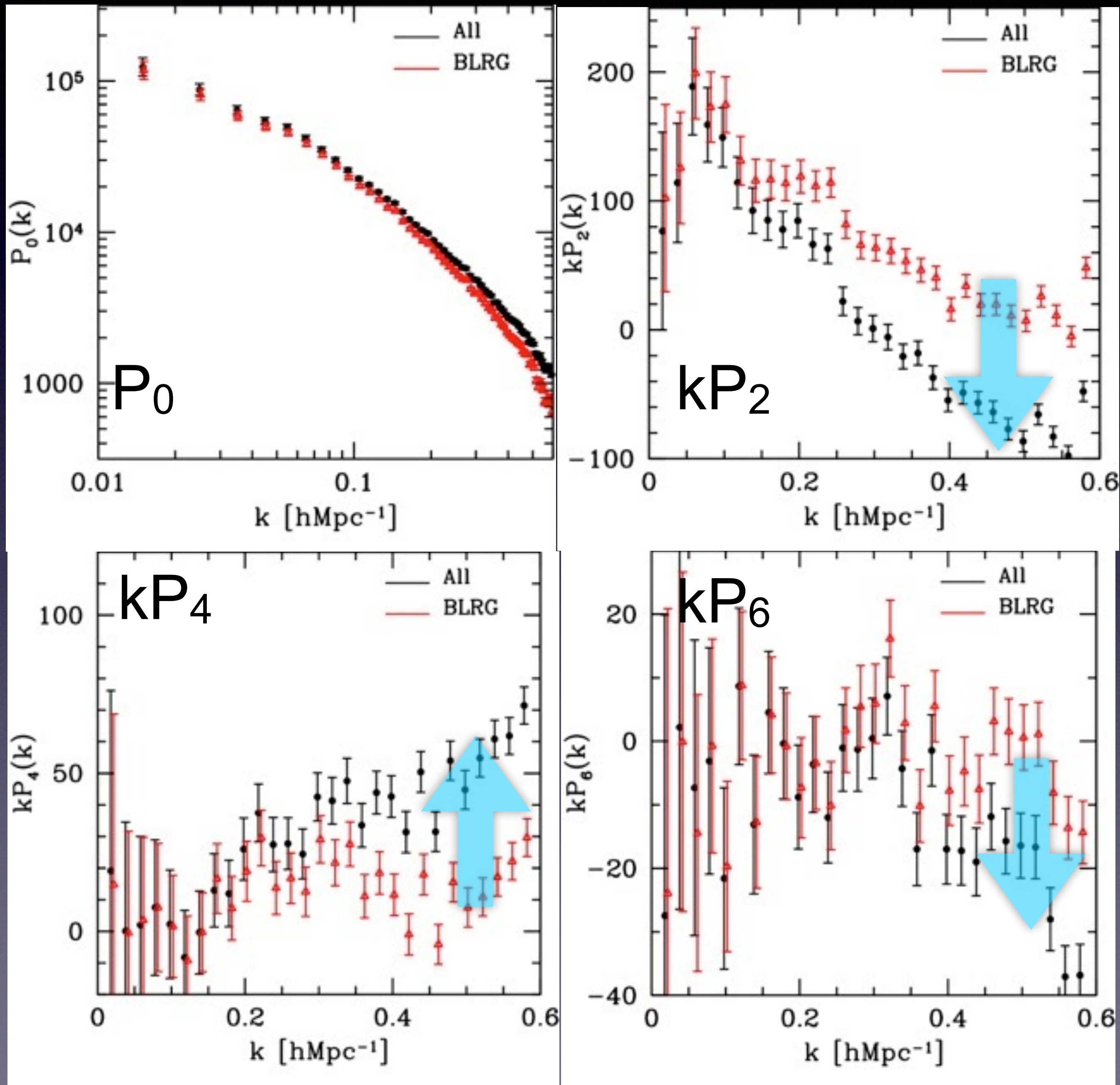
Kaiser effect mainly generates quadrupole anisotropy (l=2)

Fingers-of-God affects higher-l multipole anisotropy (l=2, 4, …)

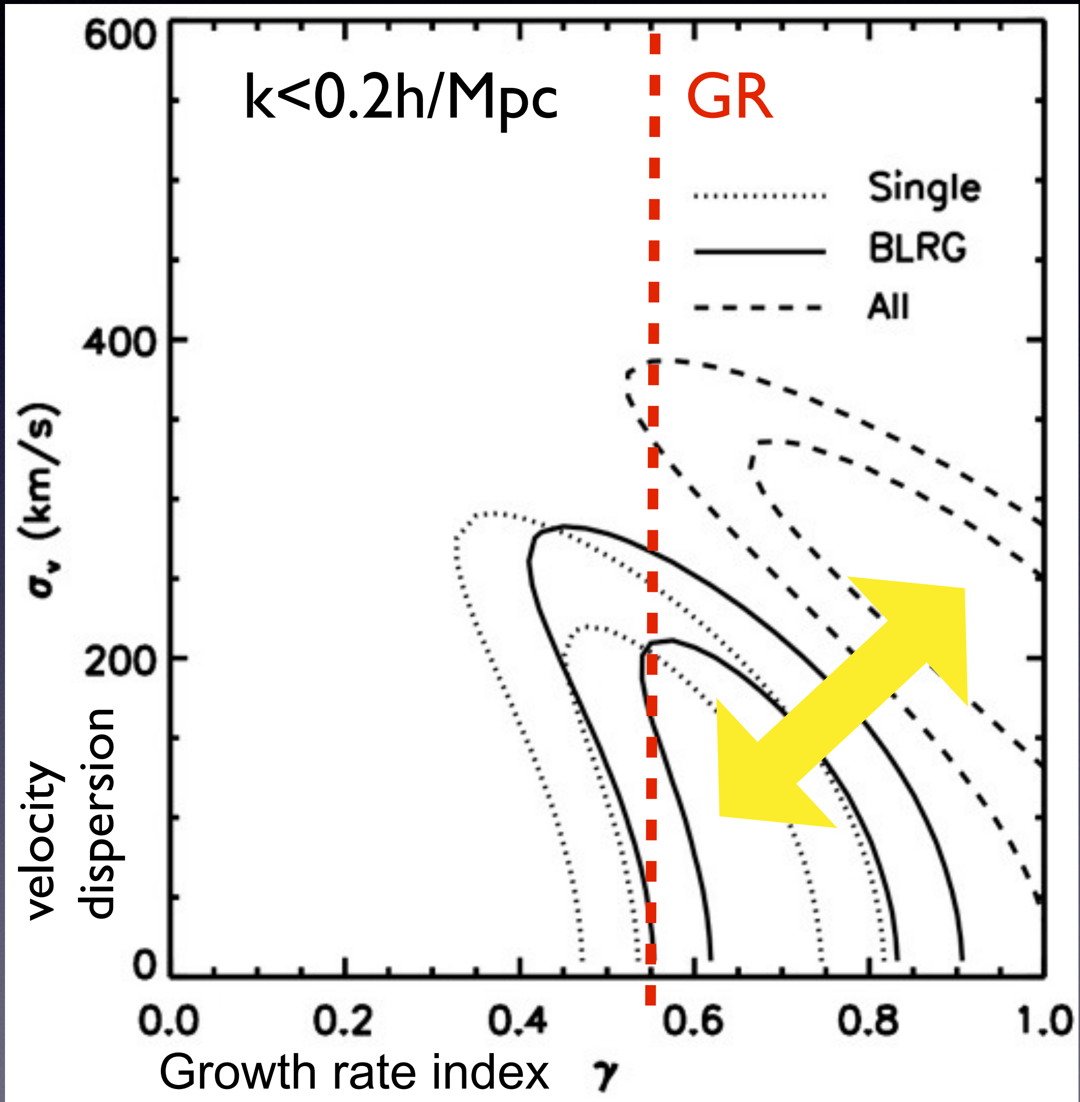
All LRG vs Brightest LRG



Sample difference is just ~5% satellites

Impact of satellites is significantly large even at k~0.2Mpc/h

Impact on Growth Rate measurement



Cosmology is fixed to WMAP9

Estimate growth rate by fitting monopole and quadrupole with 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 difference between ALL and BLRG/Single samples

Halo Model

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

1-halo term

central-satellite pair

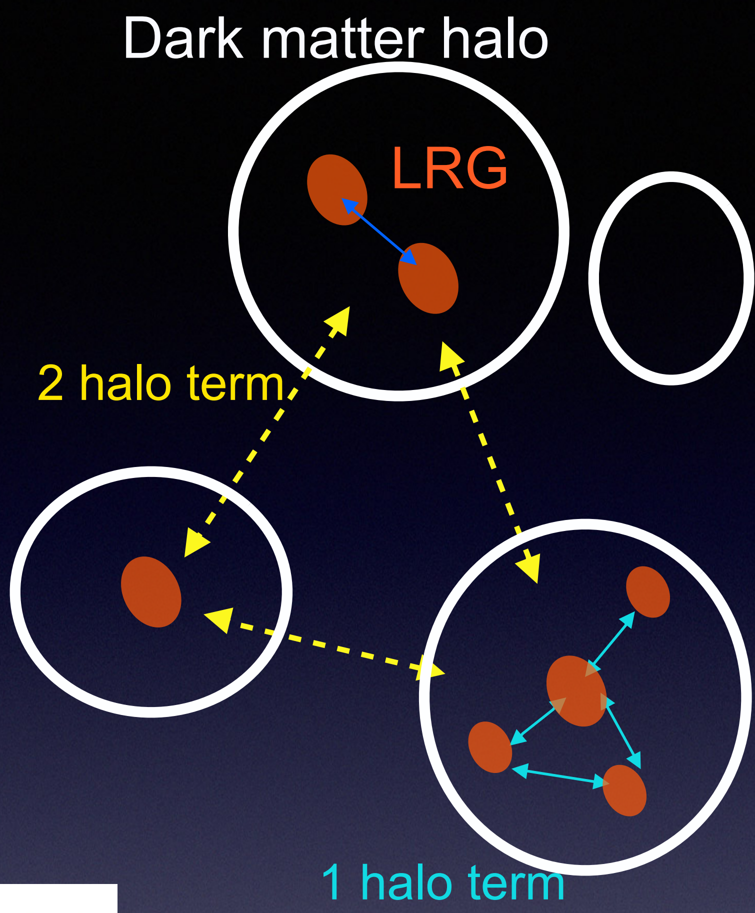
$$P^{\rm 1h}(k,\mu) = \frac{1}{\bar{n}_{\rm tot}^2}\int dM \frac{dn_{\rm h}}{dM}\left[2\langle N_{\rm cen}\rangle\langle N_{\rm sat}\rangle\tilde{p}_{\rm sat}(k,\mu;M) + \langle N_{\rm sat}(N_{\rm sat}-1)\rangle\tilde{p}_{\rm sat}^2(k,\mu;M)\right]$$

satellite-satellite pair

2-halo term

$$P^{\rm 2h}(k,\mu) = \frac{1}{\bar{n}_{\rm tot}^2}\int dM \frac{dn_{\rm h}}{dM}\int dM' \frac{dn_{\rm h}}{dM'}\left[\langle N_{\rm cen}\rangle(1+\langle N_{\rm sat}\rangle\tilde{p}_{\rm sat}(k,\mu;M))\right] \times \left[\langle N_{\rm cen}\rangle(1+\langle N_{\rm sat}\rangle\tilde{p}_{\rm sat}(k,\mu;M'))\right] P_{\rm hh}(k,\mu;M,M'),$$

halo auto- (cross-) power spectra



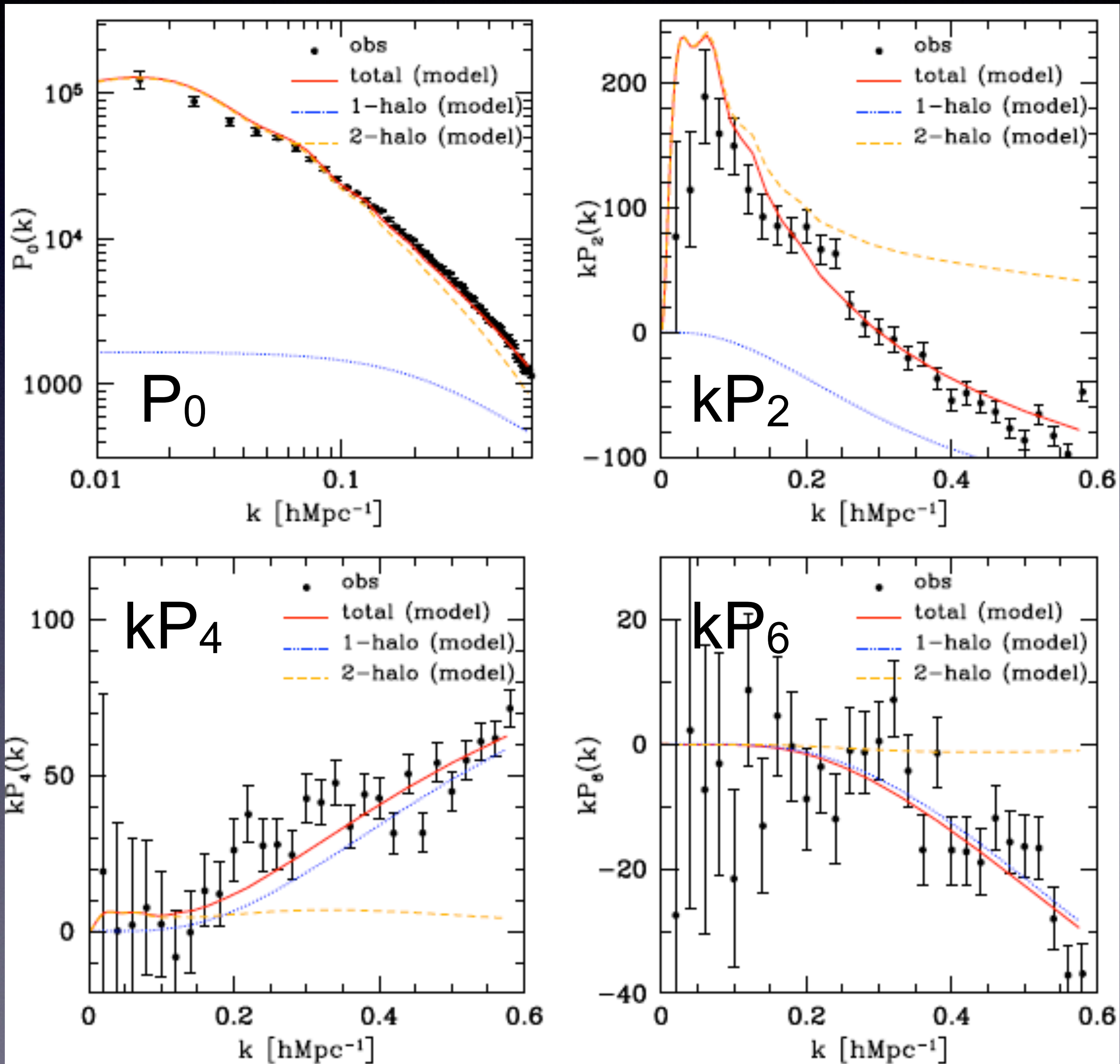
Satellite galaxy distribution inside their host halos

$$\tilde{p}_{\rm sat}(k,\mu,M) = \tilde{u}_{\rm NFW}^{\rm 3D}(k;M)\exp\left[-\frac{\sigma_v^{(\rm sat)2}(M)k^2\mu^2}{2a^2H^2(z)}\right]$$

$$\sigma_v^{(\rm sat)}(M) = \left(\frac{GM}{2r_{\rm vir}}\right)^{1/2}$$

Assuming satellite velocity distribution is Gaussian with Virial velocity dispersion

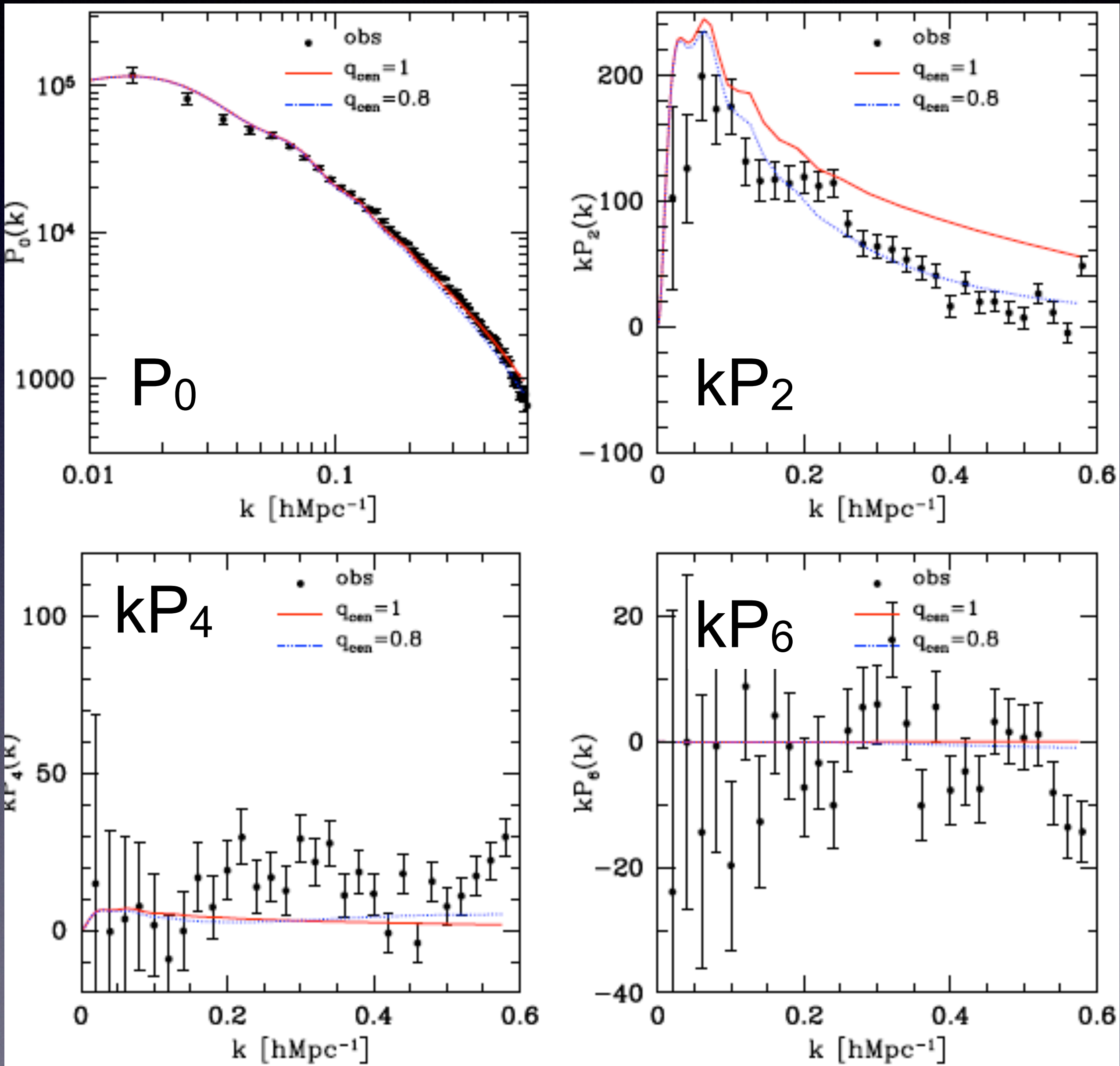
All LRG power spectrum



One halo term (blue line) is necessary to describe ALL LRG power spectra

One-halo term is dominated for P_l ($l \geqq 4$)

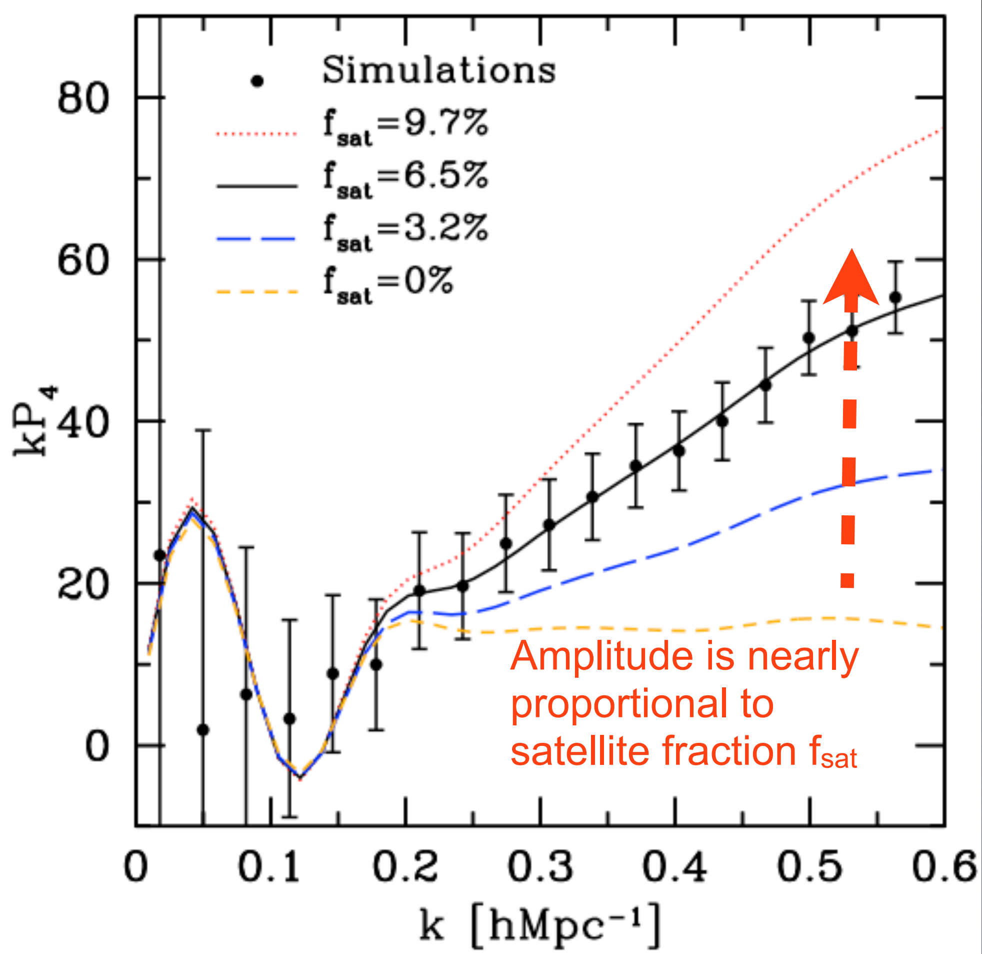
Brightest LRG power spectrum

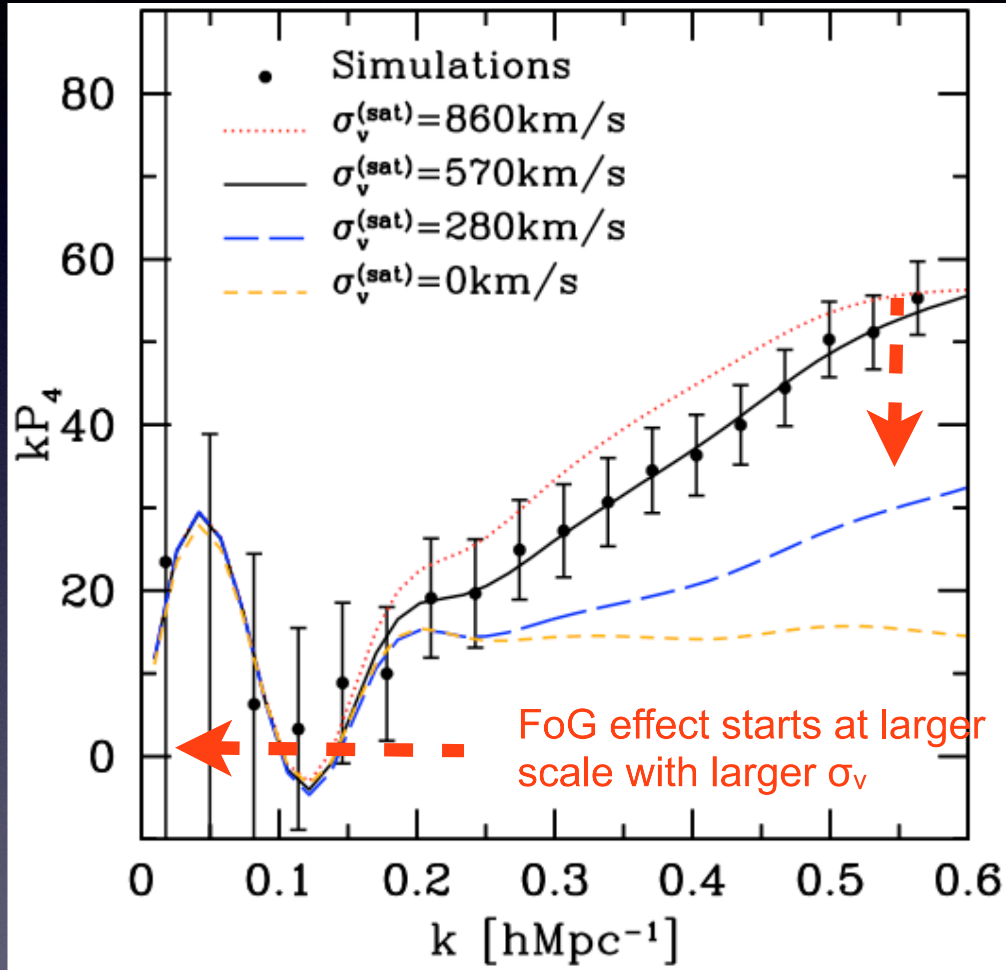


BLRG power spectra can be described only with 2-halo term (P_4 & P_6 are consistent with 0)

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

P_4 as a probe of satellite properties

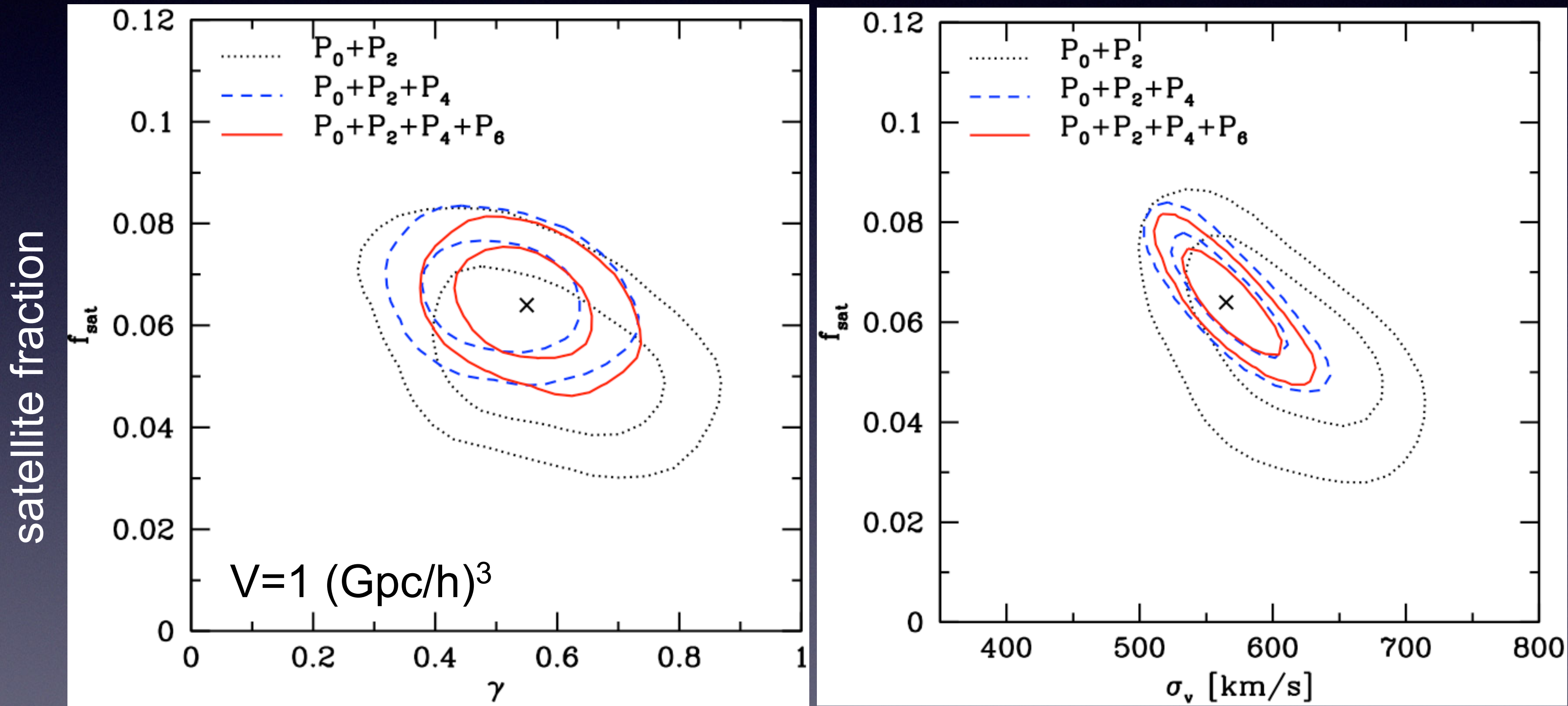




High l multipole power spectra (l≧4) are good probes of satellite fraction and velocity dispersions (or HOD)

Expected constraints on growth rate and satellite fractions/velocity : w/o P_4 vs w/ P_4

fitting parameters: HOD (M_{min}, σ_{logM}, M_{cut}, M_1, α) + growth rate (Cosmology is fixed)



Growth rate index

Velocity dispersion of satellite galaxies

High-l multipole components are useful for breaking the degeneracy between satellite FoG and growth rate

Summary

- Galaxy redshift surveys have a huge potential to provide a key insight on the nature of gravity
- Major difficulty in this analysis comes from the systematic uncertainty due to Fingers-of-God effect
- Even just 5% fraction of satellite galaxies has large impact on the redshift-space galaxy clustering
- High-l ($l \geqq 4$) multipole power spectrum provides a good probe of satellite fraction and kinematics
- High-l multipole information significantly improves the accuracy of both HOD and growth rate measurement