Pseudo-spectrum analysis of galaxy-galaxy lensing

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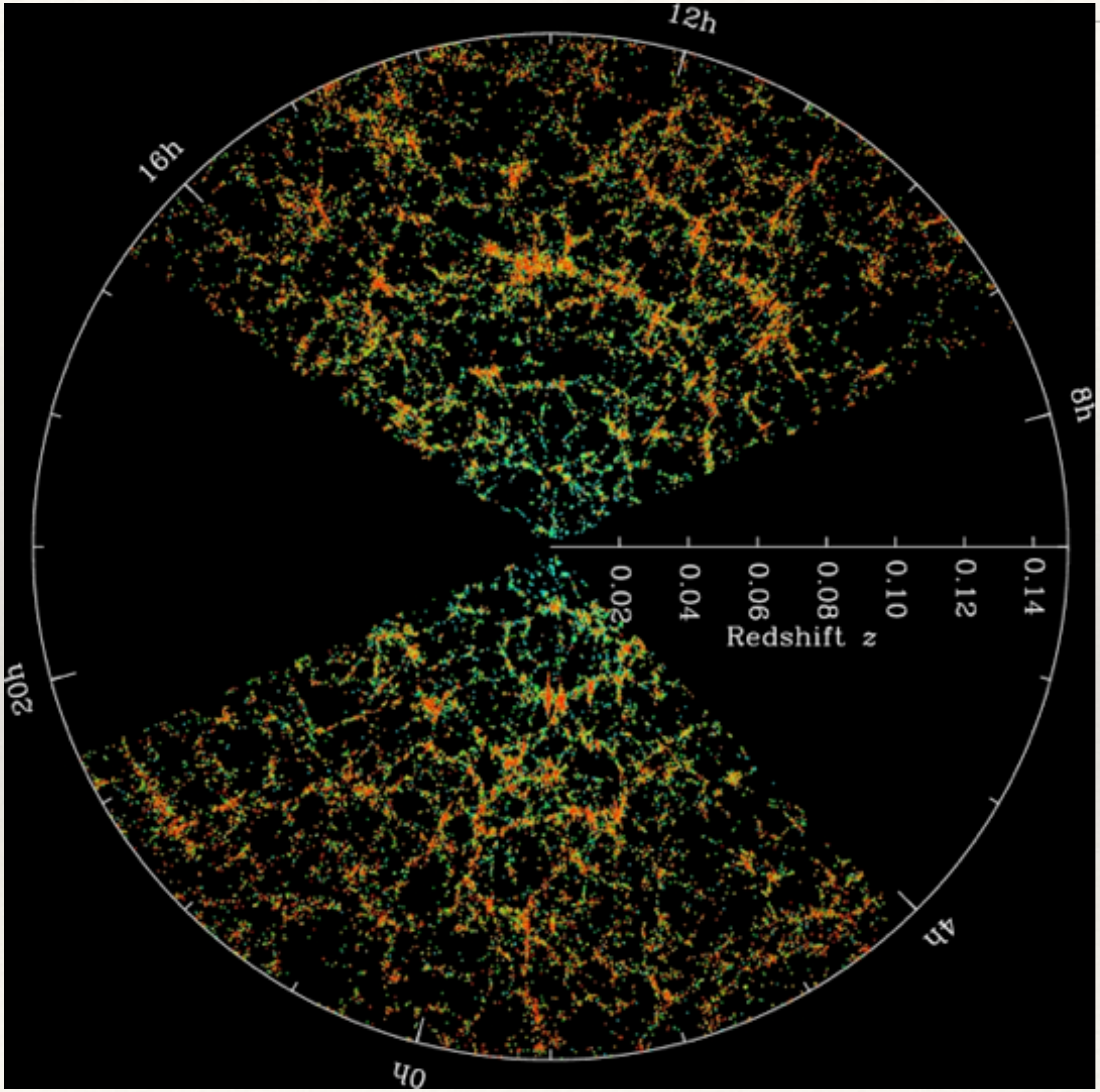
Galaxy redshift surveys



SDSS Collaboration

Science goals

- Dark energy
- Dark matter
- Neutrino mass
- Primordial Non-Gaussianity

Galaxy redshift surveys

- CfA, LCRS, 2dF, SDSS, BOSS, WiggleZ, VVDS, Vipers, FastSound
- PFS, HETDEX, eBOSS, Euclid, WFIRST

Uncertainty of galaxy biasing

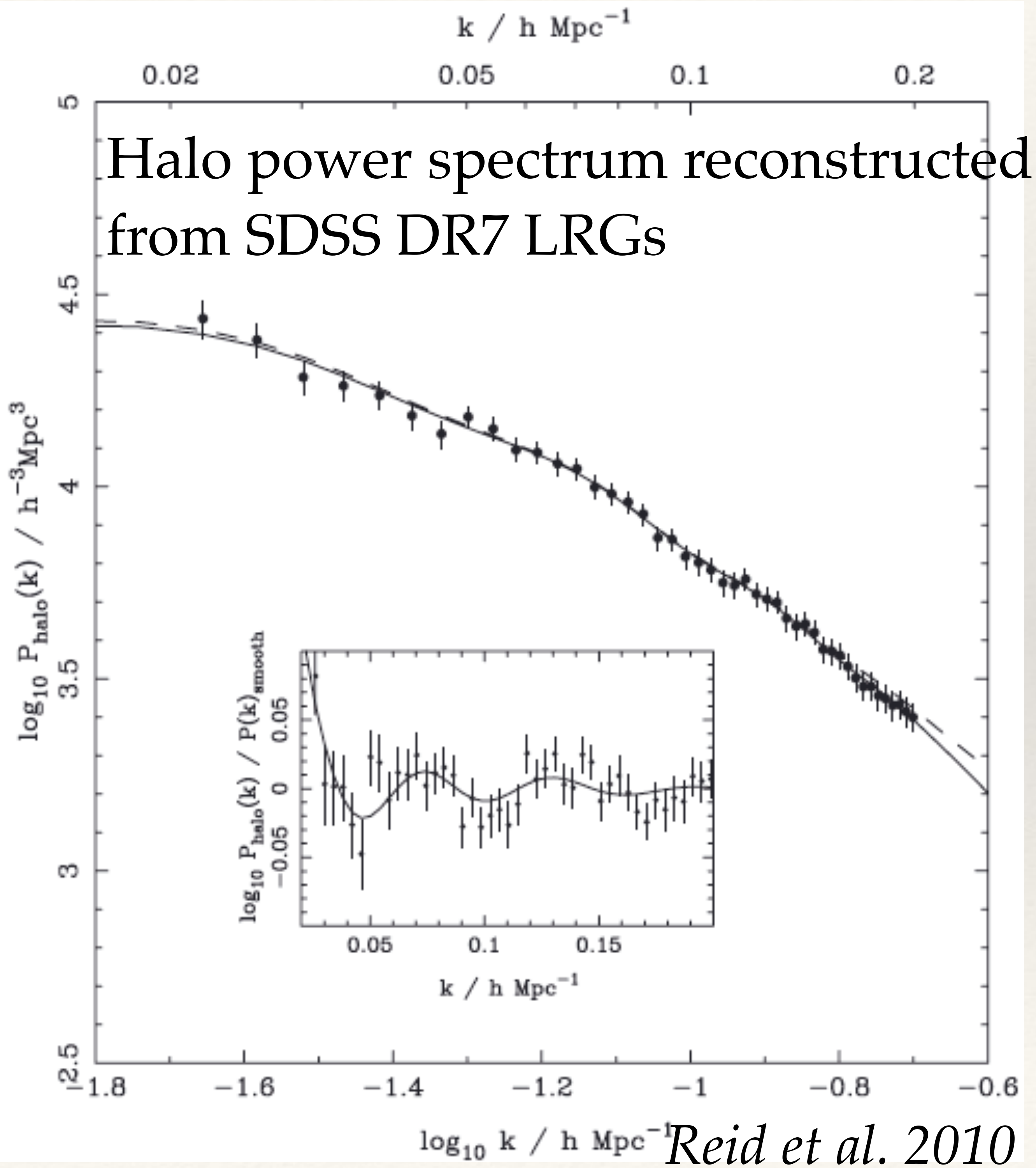
Relationship between galaxy number density field δ_g and mass density field δ_m

$$\delta_g(k) = b(k)\delta_m(k)$$

galaxy power spectrum:

$$P_{gg}(k) = b^2(k)P_{mm}(k)$$

galaxy biasing depends on scale, redshift, galaxy types,..

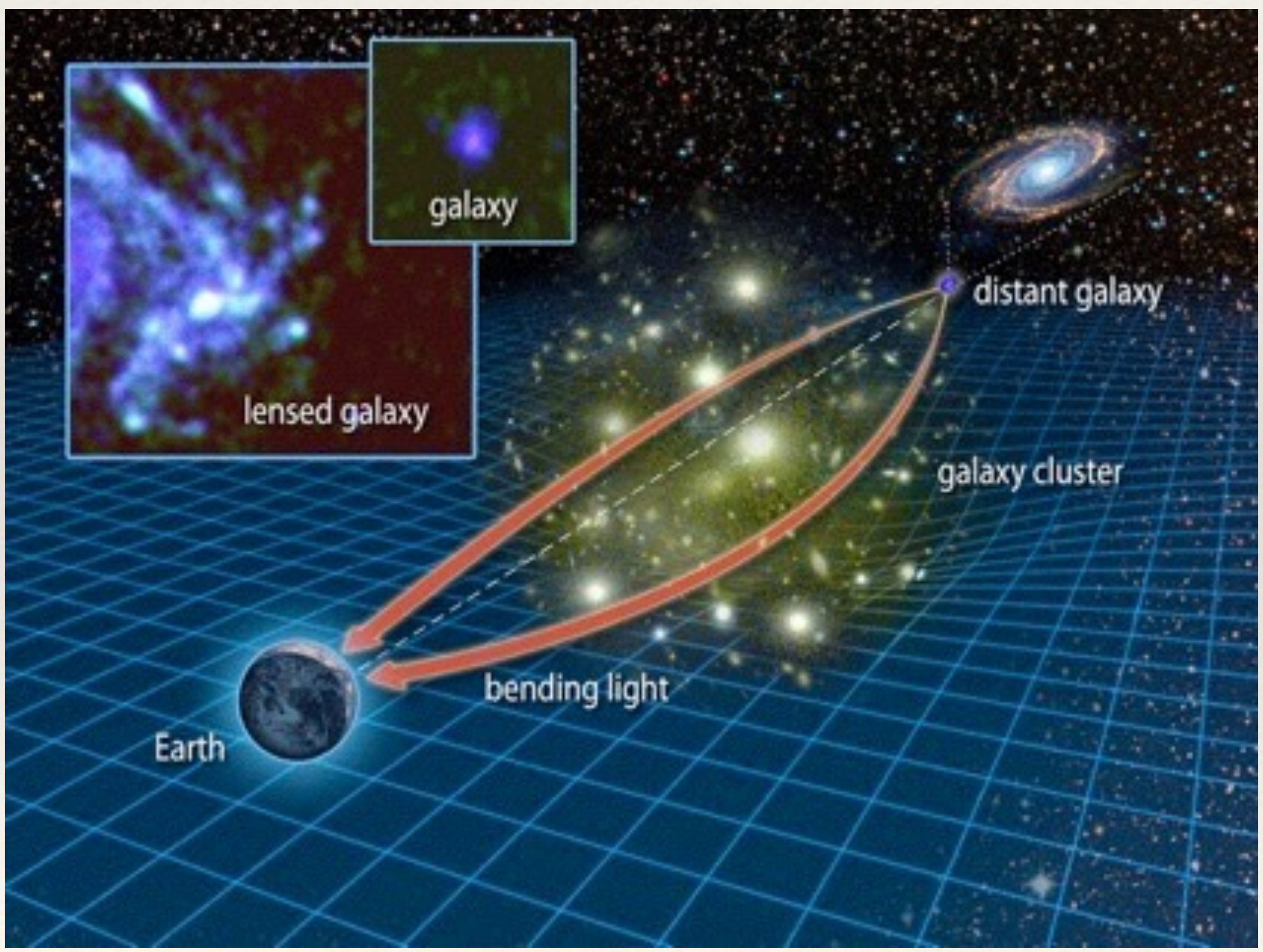


Halo power spectrum reconstructed from SDSS DR7 LRGs

Reid et al. 2010

galaxy-galaxy lensing

- Cross correlation between foreground galaxies and background galaxy image distortion



Credit: Karen Teramura, U Hawai IfA

galaxy-DM cross spectrum

$P_{gm}(k)=b(k)P_{mm}(k)$

Combination of P_{gg} and P_{gm} can reduce bias uncertainty

SUbaru Measurement of Images and REdshift

Joint Mission of Imaging and Redshift surveys using 8.2m Subaru Telescope

Hyper-Suprime Cam (HSC)

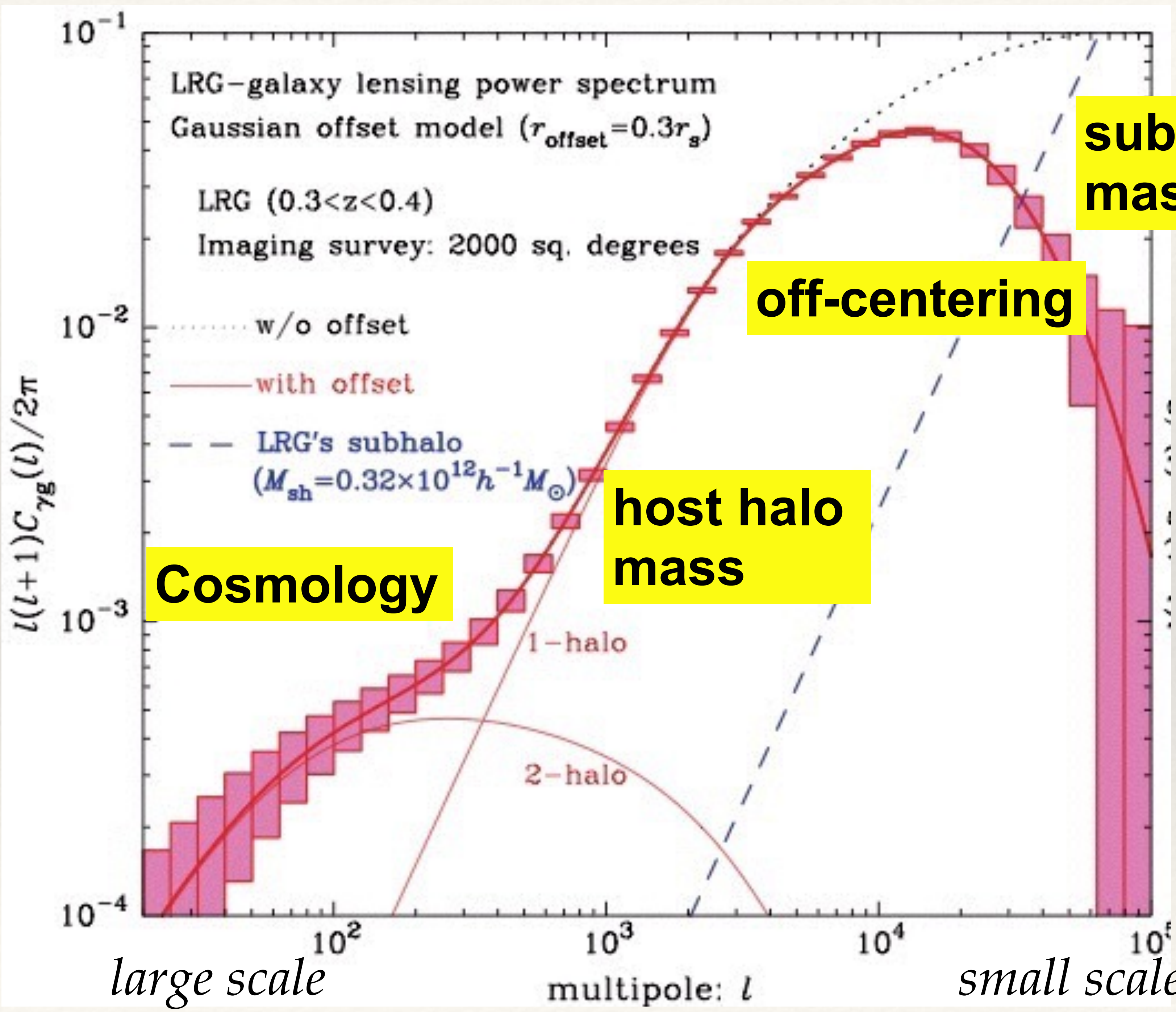
- 1300 deg^2 sky (overlap w/ ACT, BOSS)
- 30gals/arcmin^2, z_{mean}=1, i~26(5σ)
- 1.5 deg FoV, grizy band, 0.16"pix,
- 2014-2018

Prime Focus Spectrograph (PFS)

- 1300 deg^2 of sky (overlap w/ HSC)
- Redshift of LRGs + OII emitters at 0.8<z<2.4 (9.3 Gpc/h^3 comoving vol)
- 2400 fibers, 380~1300nm (R~3000)
- 2019-2023 (planed)

Mauna Kea, Hawaii, 4139m alt., 0.6-0.7" seeing

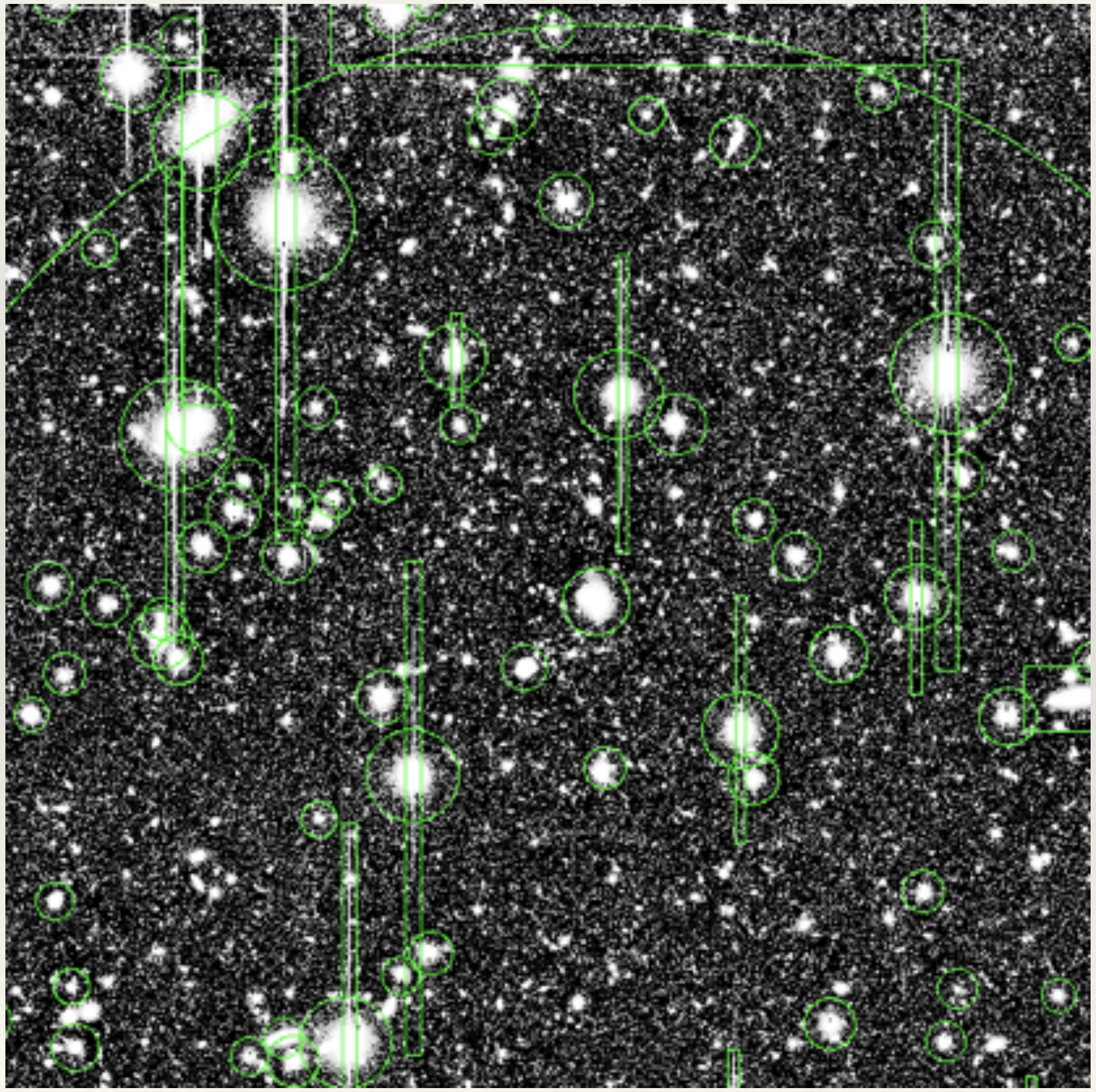
g-g lensing expected from HSC+LRG



CH, Takada, Spergel 2011

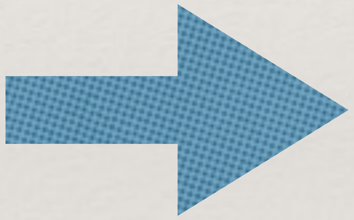
How can we measure lensing spectrum ?

20-30% of sky is masked by bright stars



Suprime Cam

?



lensing power spectrum

g-g lensing spectrum

Convolution of survey mask

obs | mask (weight) | true

$$\tilde{\gamma}_1(\mathbf{n}) \pm i\tilde{\gamma}_2(\mathbf{n}) = W(\mathbf{n})\left[\gamma_1(\mathbf{n}) \pm i\gamma_2(\mathbf{n})\right] \qquad W(\mathbf{n}) : \text{mask field}$$

$$\tilde{E}_{\mathbf{k}} \pm i\tilde{B}_{\mathbf{k}} = \sum_{\mathbf{n}} \left[\tilde{\gamma}_1(\mathbf{n}) \pm i\tilde{\gamma}_2(\mathbf{n})\right] \exp\left(-i\mathbf{k}\cdot\mathbf{n} \pm 2\varphi_{\mathbf{k}}\right)$$

$$= \sum_{\mathbf{k}'} \left[E_{\mathbf{k}'} \pm iB_{\mathbf{k}'}\right] W_{\mathbf{k}-\mathbf{k}'} \exp\left(\pm 2(\varphi_{\mathbf{k}'} - \varphi_{\mathbf{k}})\right)$$

E-mode and B-mode power spectrum

$$\begin{pmatrix} \tilde{C}^{EE}_{\mathbf{k}} \\ \tilde{C}^{BB}_{\mathbf{k}} \end{pmatrix} = \sum_{\mathbf{k}'} \mathrm{W}_{\mathbf{k}-\mathbf{k}'} \begin{pmatrix} \cos^2 2\varphi_{\mathbf{k}'\mathbf{k}} & \sin^2 2\varphi_{\mathbf{k}'\mathbf{k}} \\ \sin^2 2\varphi_{\mathbf{k}'\mathbf{k}} & \cos^2 2\varphi_{\mathbf{k}'\mathbf{k}} \end{pmatrix} \begin{pmatrix} C^{EE}_{\mathbf{k}'} \\ C^{BB}_{\mathbf{k}'} \end{pmatrix} + \begin{pmatrix} \tilde{N}_{\mathbf{k}} \\ \tilde{N}_{\mathbf{k}} \end{pmatrix}$$

E-B mode mixing due to mask

$$\cos\varphi_{\mathbf{k}'\mathbf{k}} = \mathbf{k}'\cdot\mathbf{k} / k' k$$

Reconstruction of power spectrum

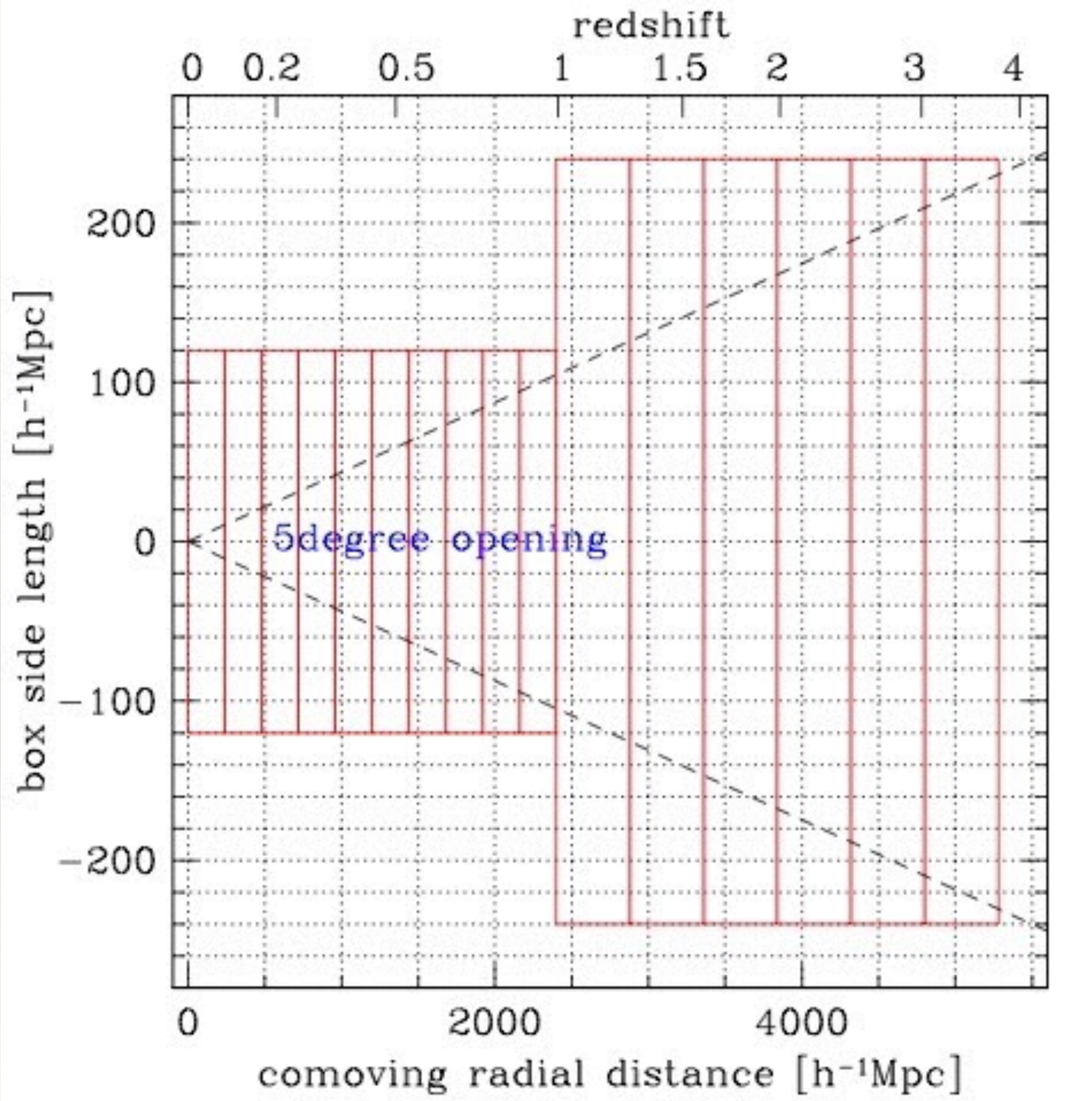
true mask obs noise

$$\mathcal{C}_b = \mathbf{M}_{bb'}^{-1} \sum_{\mathbf{k}}^{k \in k'_b} P_{b'k}(\tilde{\mathbf{C}}_{\mathbf{k}} - \langle \tilde{\mathbf{N}}_k \rangle_{\mathrm{MC}}),$$

- Commonly used to reconstruct CMB temperature/ polarization spectrum (e.g., Hivon et al. 2002)
  - Analogy to CMB polarization (Q,U) ⇔(γ_1,γ_2)
- Noise spectrum is estimated by randomly rotating shapes

Ray-Tracing Simulations (Sato et al. 2009)

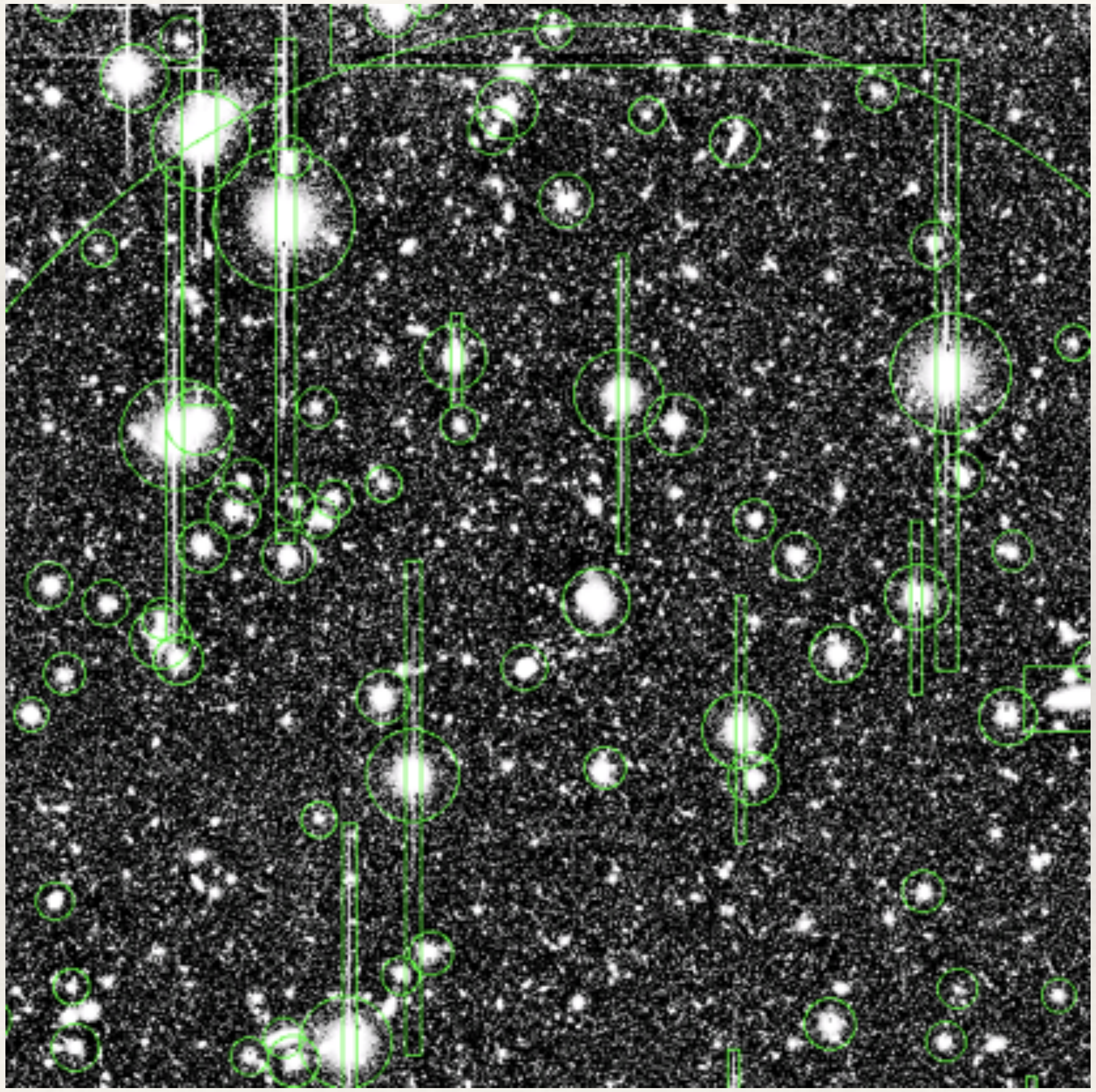
- N-body simulations
  - Gadget 2 at z_{init}=50
  - 200 realizations with L_{box}=240 and 480Mpc/h
  - ΛCDM based on WMAP 3
- Ray-Tracing simulations
  - 5° x 5°, 2048^2 grids (grid size: 0.15′)
  - Multiple lens plane algorithm (Jain et al. 2000)
  - Lens plane width $\Delta\chi$=120Mpc/h, z=0 – 3.5
  - 1000 realizations



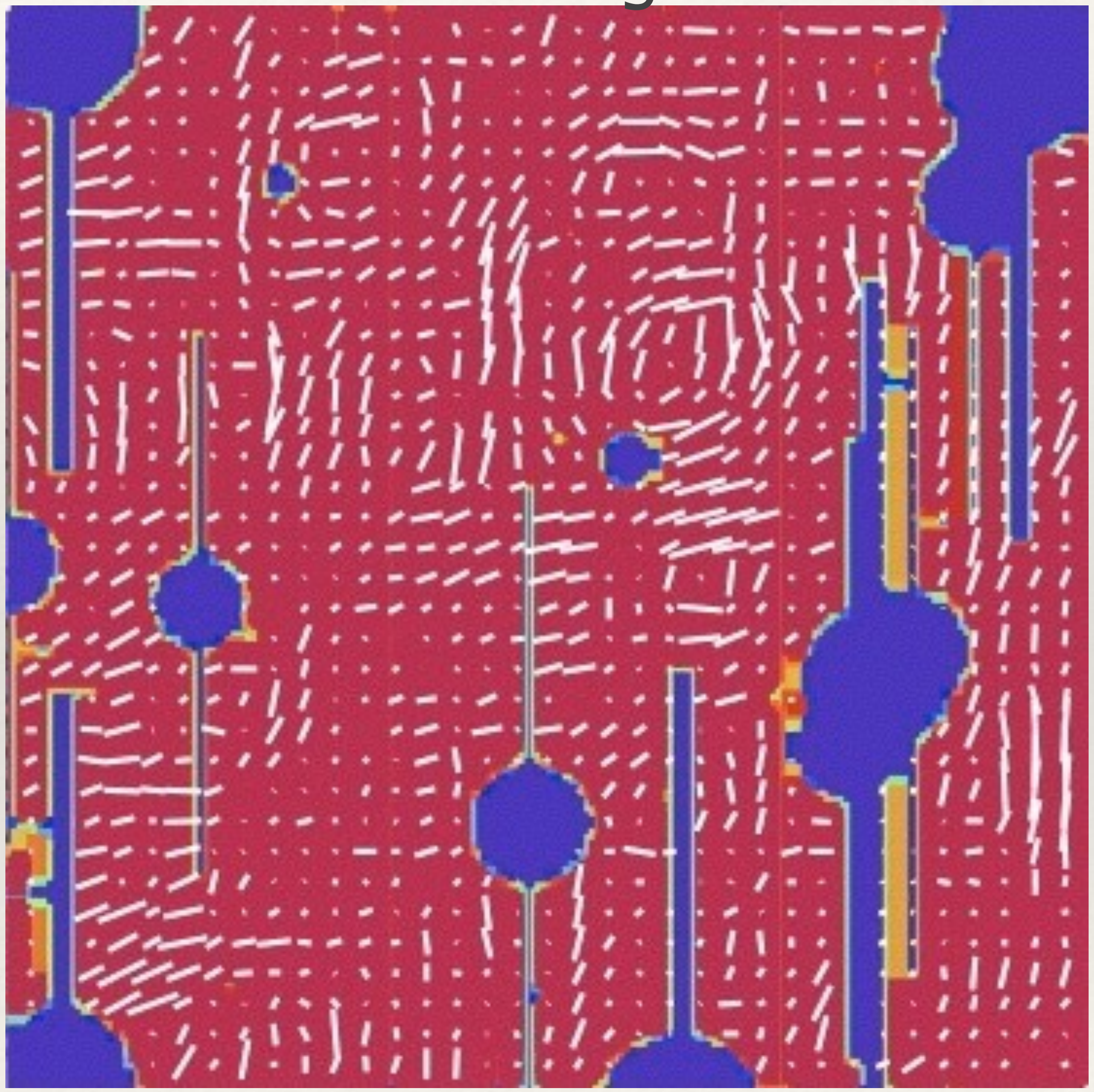
Sato et al. 2009

Mock star mask

side length: 20 arcmin



Suprime Cam

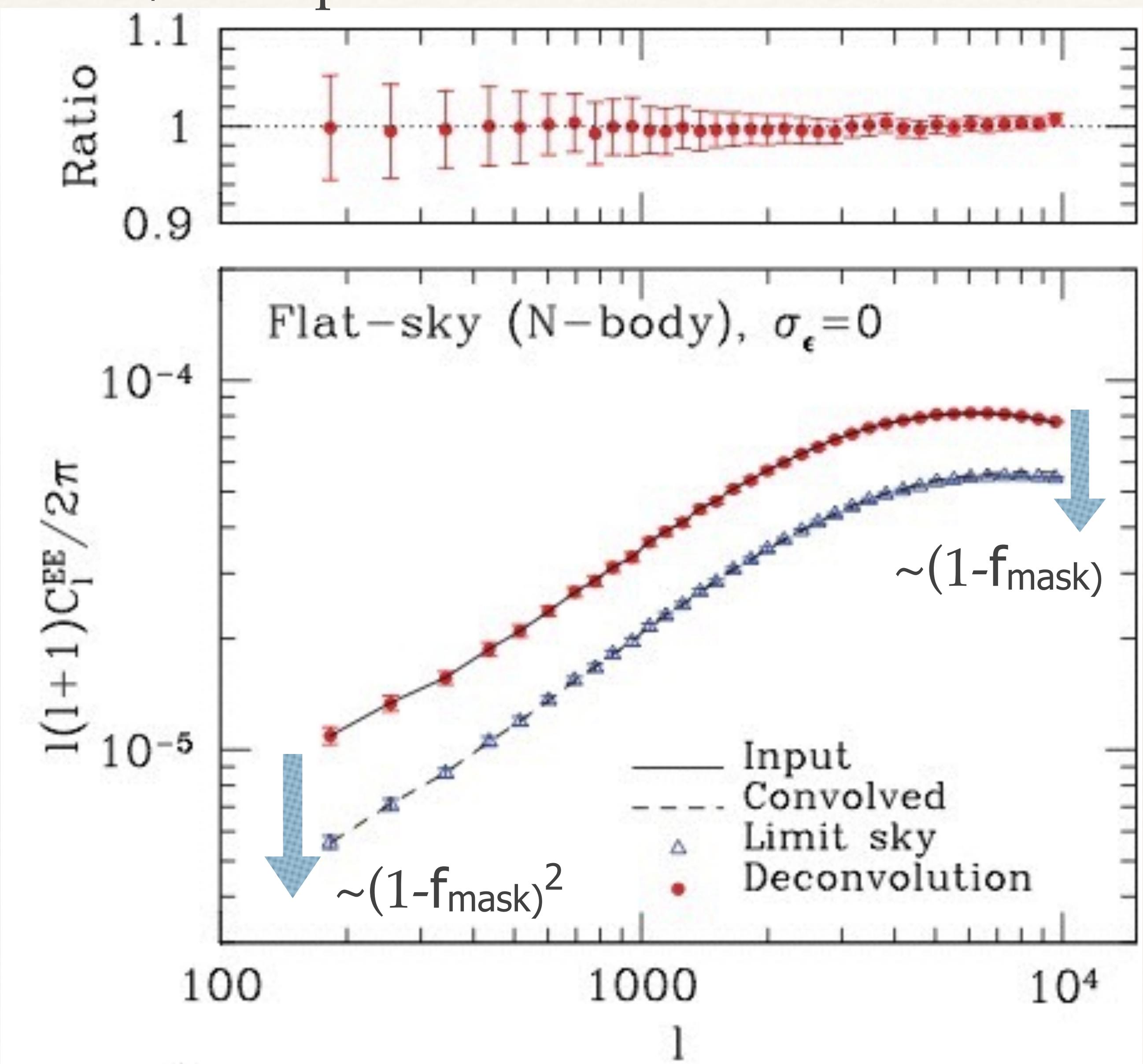


CH, Takada, Hamana, Spergel 2009

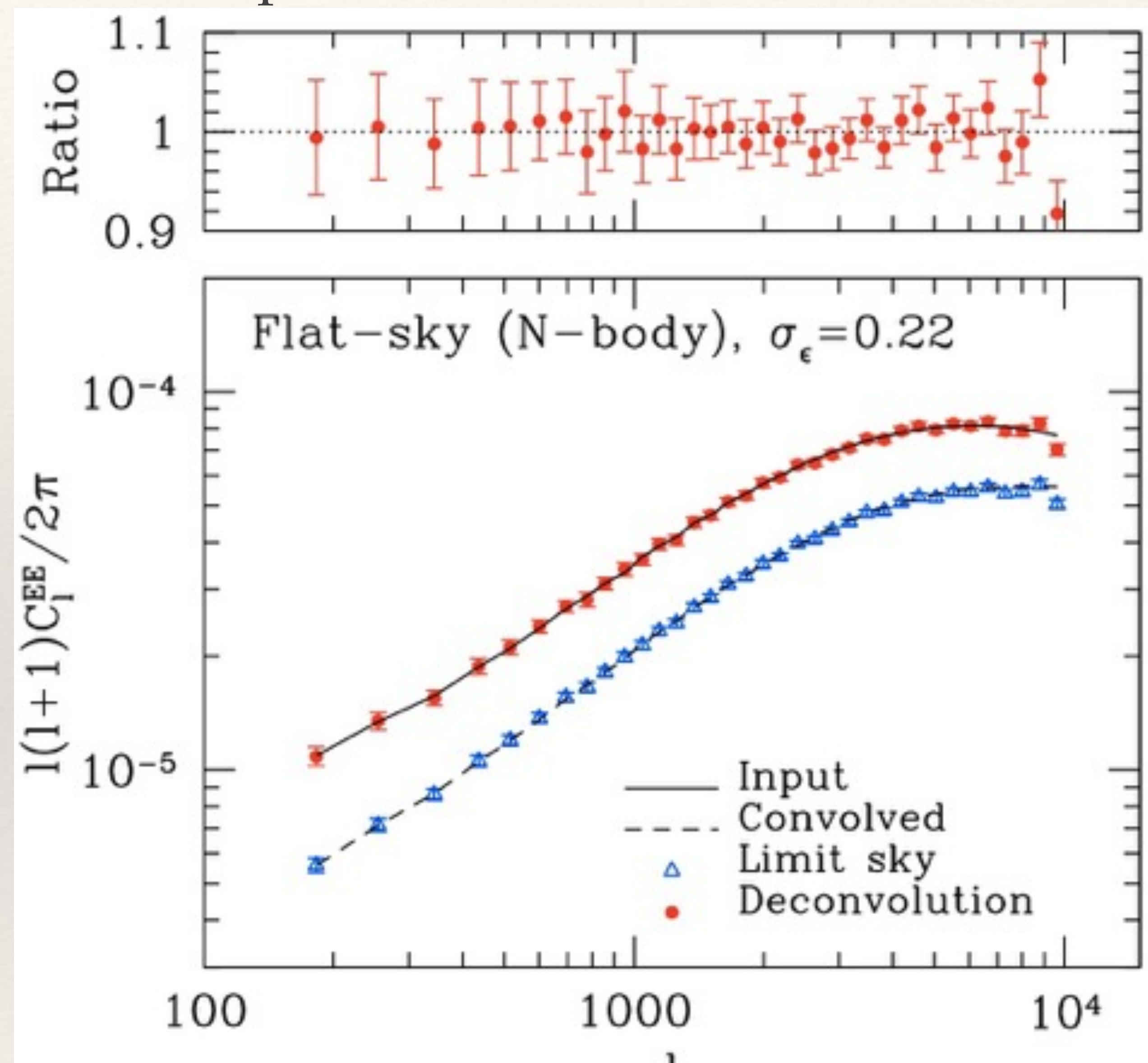
25% field is masked

Reconstruction of lensing power spectrum

w/o shape noise



w/ shape noise (σ_{noi}=0.22)

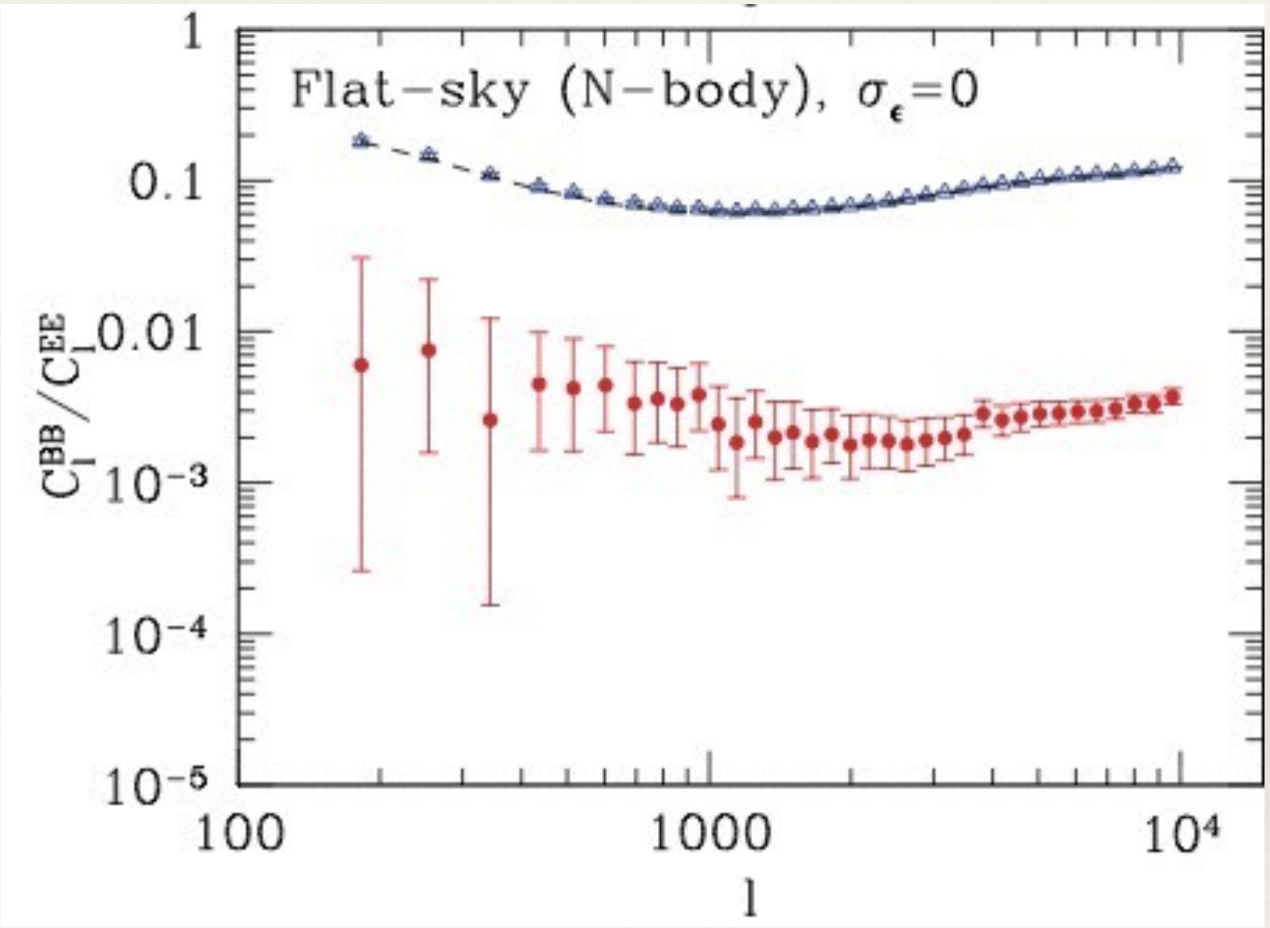


CH, Takada, Hamana, Spergel 2009

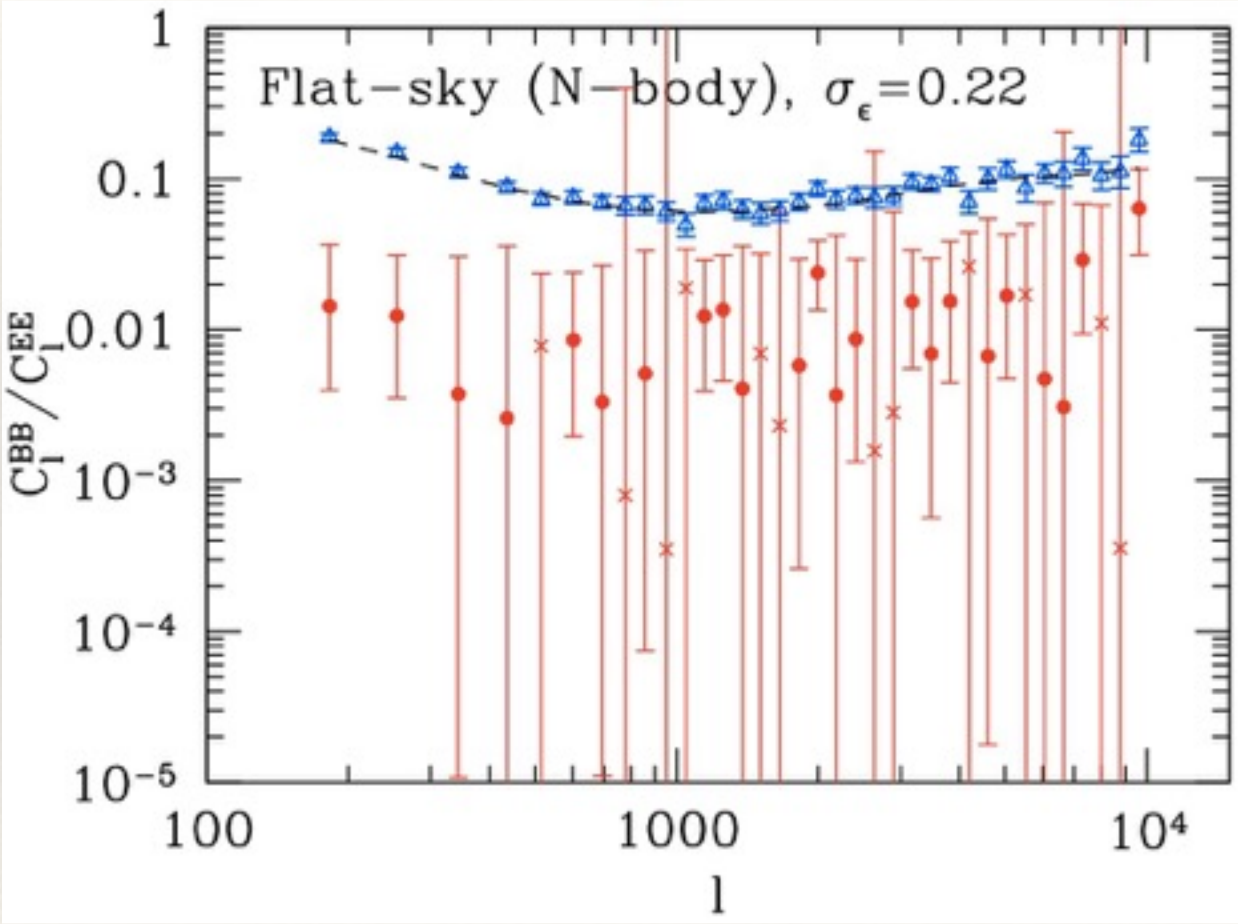
Input lensing power spectrum is successfully reconstructed

B-mode contamination

w/o shape noise



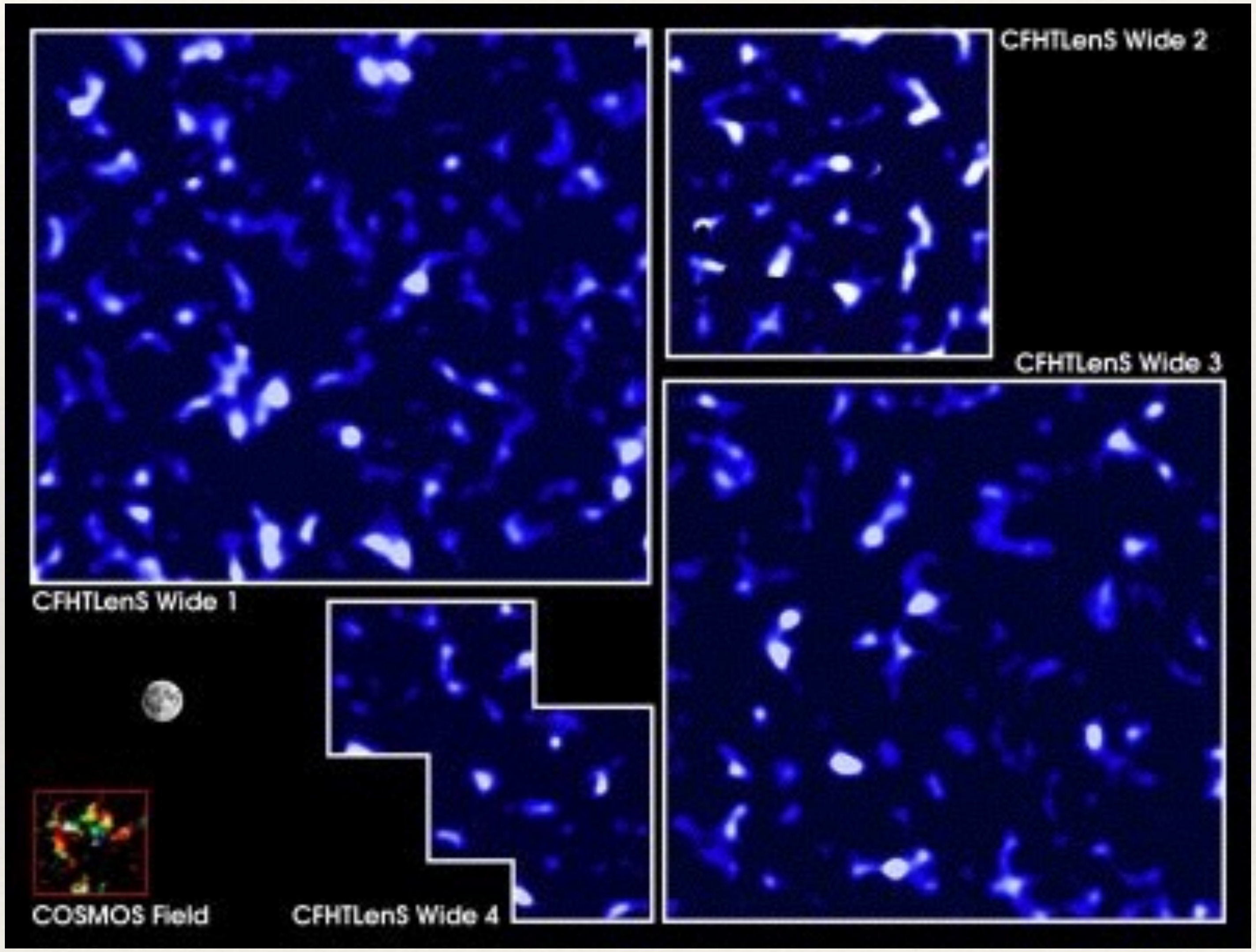
w/ shape noise



Residual B-mode is suppressed below a percent of E-mode

CFHTLenS public data

- Ω_{sky}=154 deg^2 for 4 CFHTLS fields (W1 – W4)
- n_{gal}=17arcmin^2, z_{mean}=0.75
- 5-year data taken in Hawaii
- Lensfit: Bayesian model fitting method of shape measurement
- Bayesian Photometric Redshift Code (BPZ)



Credit: Van Waerbeke, C. Heymans

CFHTLenS power spectrum

Preliminary results of CFHTLenS lensing power spectrum

Error: sample variance estimated from 4 CFHTLS fields

B-mode is consistent with zero up to l<4000

pseudo-spectrum for galaxy-galaxy lensing

shear field

$$\tilde{\gamma}(\mathbf{n}) = W_\gamma(\mathbf{n})\gamma(\mathbf{n})$$

weight for shear field: source numbers, shape noise, intrinsic noise

2D galaxy number density field

$$\tilde{\delta}_g(\mathbf{n}) = W_g(\mathbf{n})\delta_g(\mathbf{n})$$

weight for density field: angular selection function, redshift failure, fiber collision

galaxy-galaxy lensing spectrum

$$\tilde{C}_{\mathbf{l}}^{\mathrm{gE(B)}} = \frac{1}{L^2}\sum_{\mathbf{l}'} C_{\mathbf{l}'}^{\mathrm{gE(B)}} \mathcal{W}_{\mathbf{l}-\mathbf{l}'}^{g\gamma} \cos(2\varphi_{\mathbf{l}\mathbf{l}'})$$

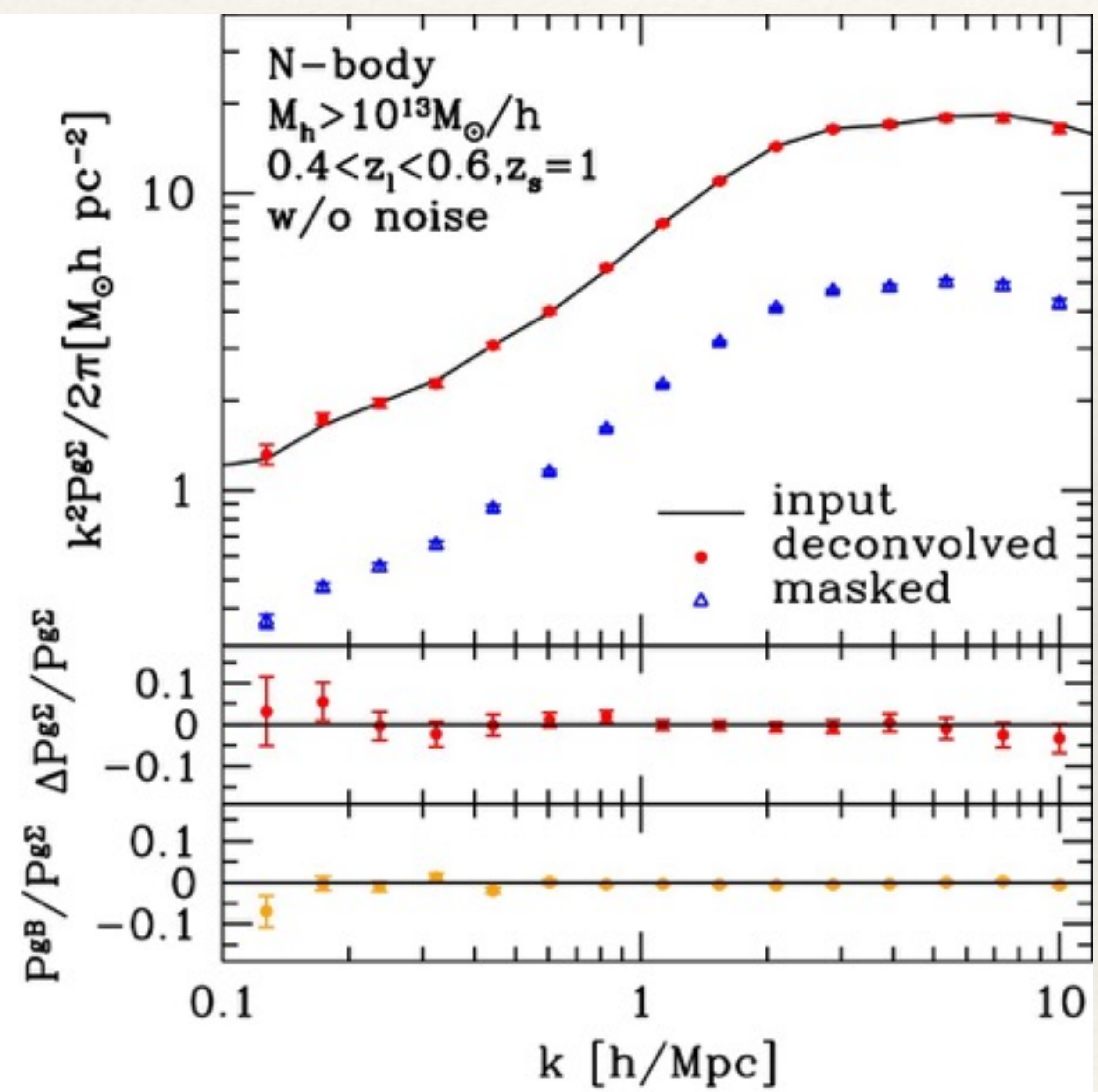
cross spectrum of the two weight fields

$$\langle W_{\mathbf{l}}^{g} W_{\mathbf{l}'}^{\gamma *}\rangle = L^2 \delta_{\mathbf{l}-\mathbf{l}'}^{\mathrm{W}} \mathcal{W}_{\mathbf{l}}^{g\gamma}$$

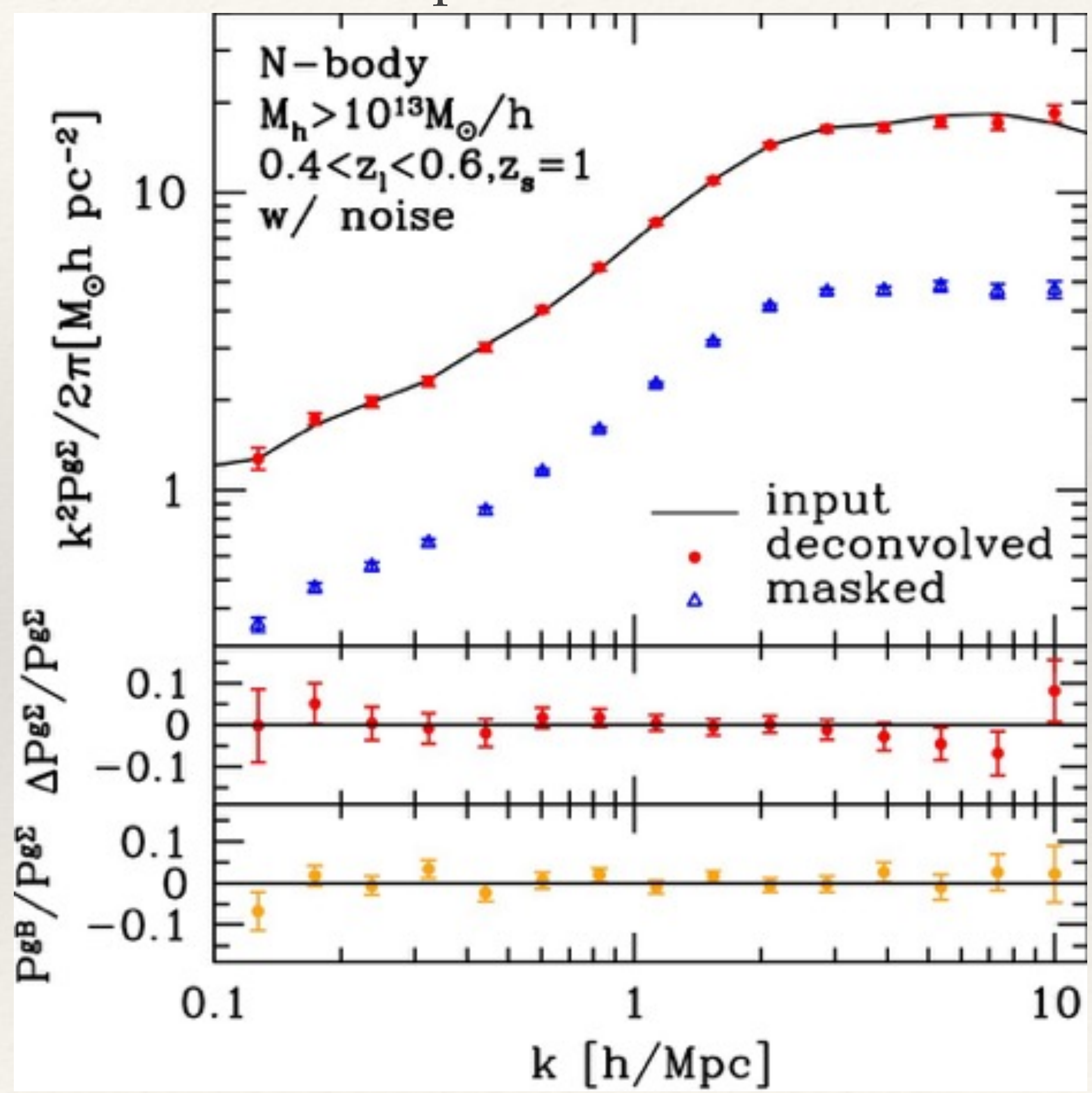
Pseudo-spectrum method can be applied for g-g lensing spectrum

Reconstruction of galaxy (halo) lensing spectrum

w/o shape noise n_s=20 [arcmin^{-2}]



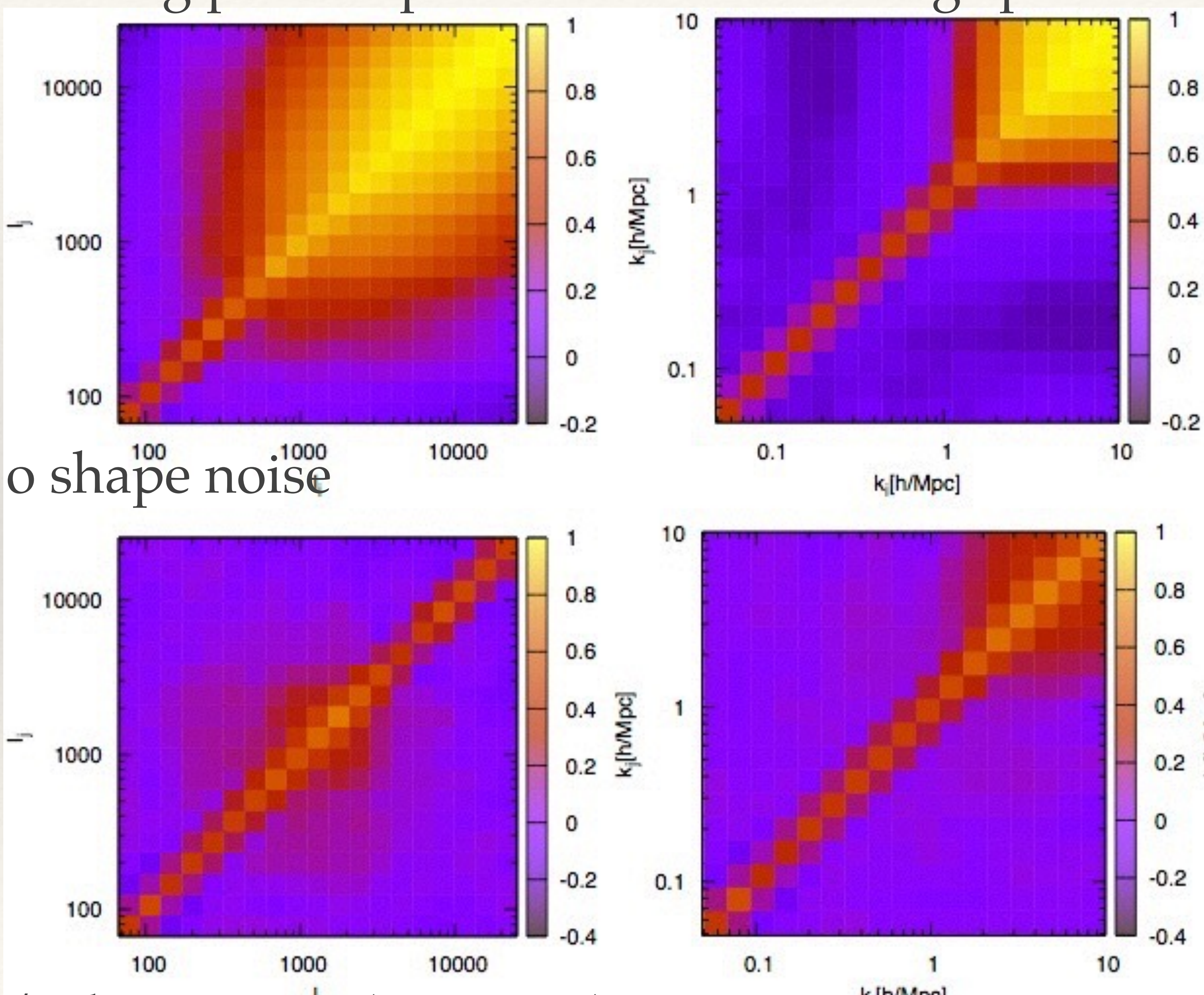
w/ shape noise (σ_{noi}=0.22)



Input halo lensing spectrum is successfully reconstructed

Covariance matrix

lensing power spectrum   halo lensing spectrum



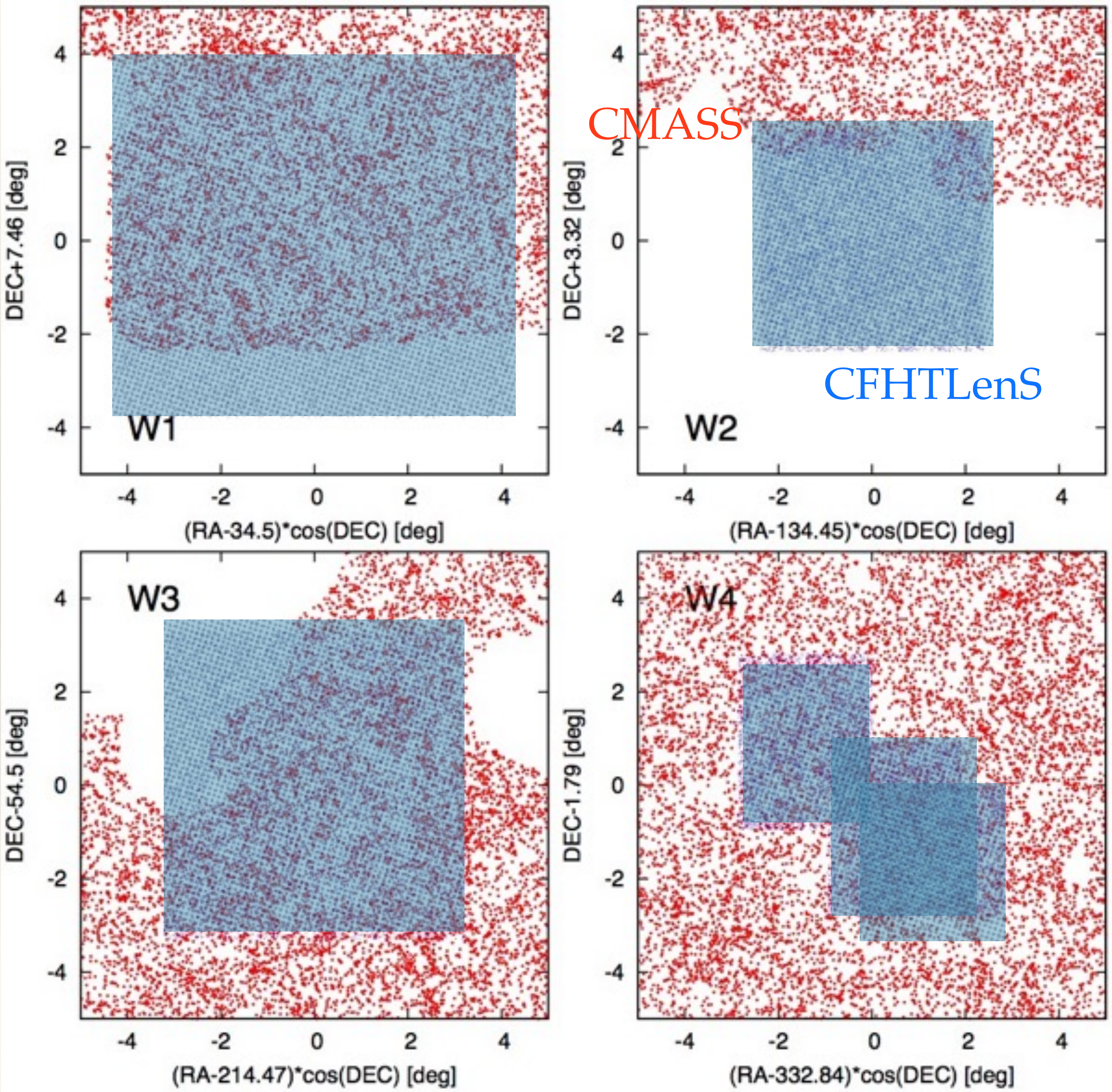
w/o shape noise

w/ shape noise (σ_{noi}=0.22)

source:
z_s=1
n_{gal}=20arcmin^{-2}

halo:
M_h>10^{13}Msun/h
0.4<z<0.6

CFHTLenS + SDSS



Overlapped area for CMASS galaxies ~100 deg^2

3 spectroscopic samples

- SDSS DR7 LRG
  (0.16<z<0.33) : N_g=445
- BOSS LOWZ
  (0.16<z<0.33) : N_g=2396
- BOSS CMASS
  (0.47<z<0.59) : N_g=5415

observed g-g lensing spectrum

Preliminary results of g-g lensing

Residuals systematics of shape measurement is subtracted

Error includes Poisson error and sample variance estimated from 4 CFHTLS fields

We use source galaxies with $P(z_{BPZ} > z_{l,max}) > 0.84$

Halo model

$$P_{g\kappa} = P_{g\kappa}^{1h} + P_{g\kappa}^{2h}$$

1-halo term

HOD parameters

$$P_{g\kappa}^{1h}(k) = \int d\chi \left(\frac{W_g(z) W_\kappa(z)}{\chi^2(z)} \right) \int dM \frac{dn}{dM} \frac{M}{\bar{\rho}_m} \tilde{u}_{\rm NFW}(k; M, z) [\langle N_{\rm cen} \rangle + \langle N_{\rm sat} \rangle \tilde{p}_{\rm sat}(k; M)]$$

off-centering profile of satellites

$$\tilde{p}_{\rm sat}(k; M) = \exp(-k^2 R_{\rm vir}^2(M)/2)$$

2-halo term

$$P_{g\kappa}^{2h}(k) = \int d\chi \left(\frac{W_g(z) W_\kappa(z)}{\chi^2(z)} \right) \left[\int dM \frac{dn}{dM} (\langle N_{\rm cen} \rangle + \langle N_{\rm sat} \rangle \tilde{p}_{\rm sat}(k; M)) P_{\rm hm}(k, z; M) \right]$$

halo matter power spectrum

$$P_{hm}(k, z; M) = b(M, z) P_{mm}^{(\rm lin)}(k, z)$$

linear bias (Tinker et al. 2010)

Comparison with halo model: LRG

HOD for LRGs: Reid, Spergel 2009

Preliminary results of LRG-galaxy lensing

LRG lensing spectrum is consistent with halo model predictions

Summary

- We apply pseudo-spectrum analysis to measure lensing power spectrum and galaxy-galaxy lensing
- We find that observed g-g lensing spectrum using CFHTLenS and SDSS LRG, BOSS CMASS, LOWZ samples are consistent with halo model predictions
- The measurements can be used for the analysis of cosmology and galaxy-DM relation (e.g., stellar mass-halo mass relation)