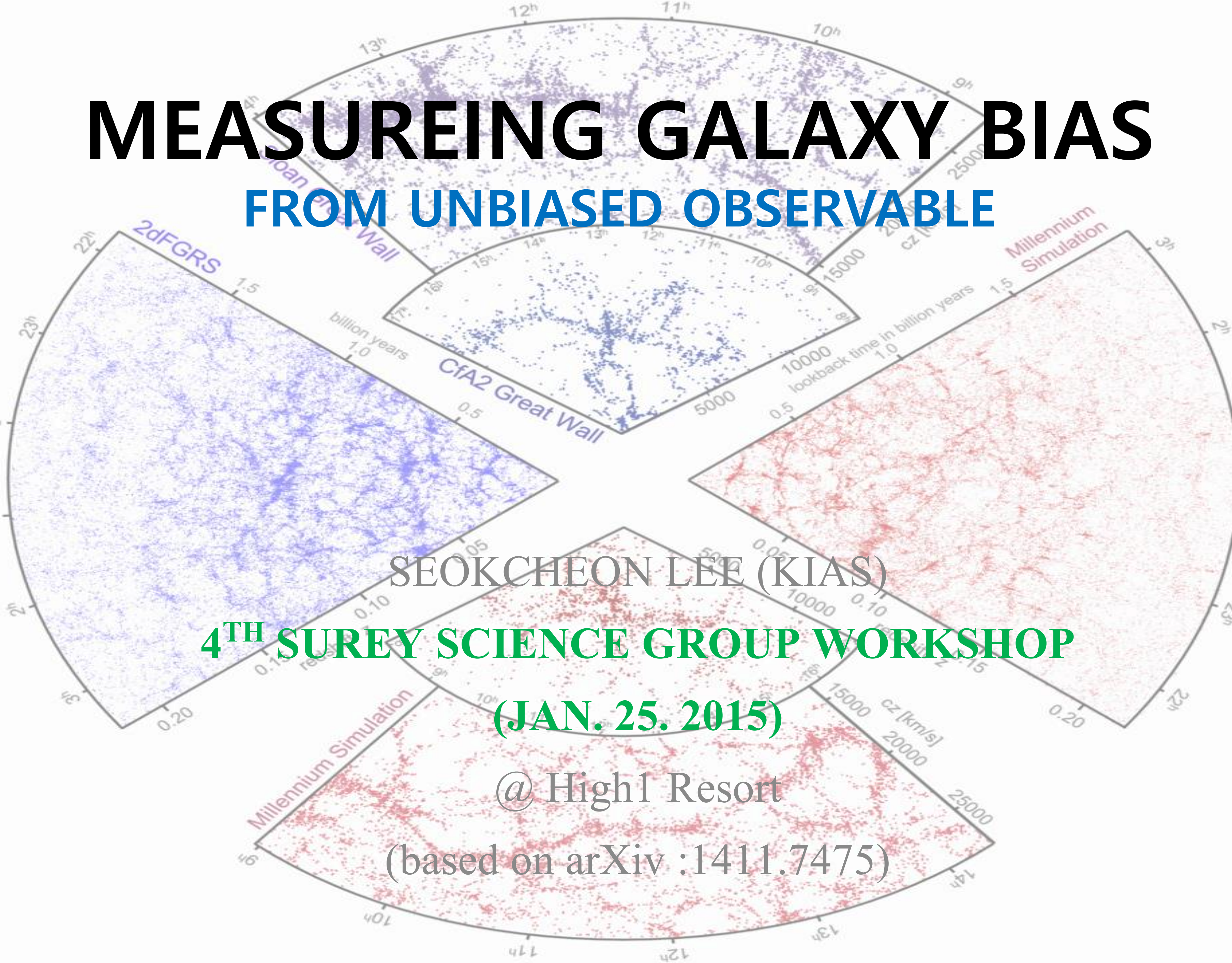
MEASUREING GALAXY BIAS

FROM UNBIASED OBSERVABLE



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4TH SUREY SCIENCE GROUP WORKSHOP

(JAN. 25. 2015)

@ High1 Resort

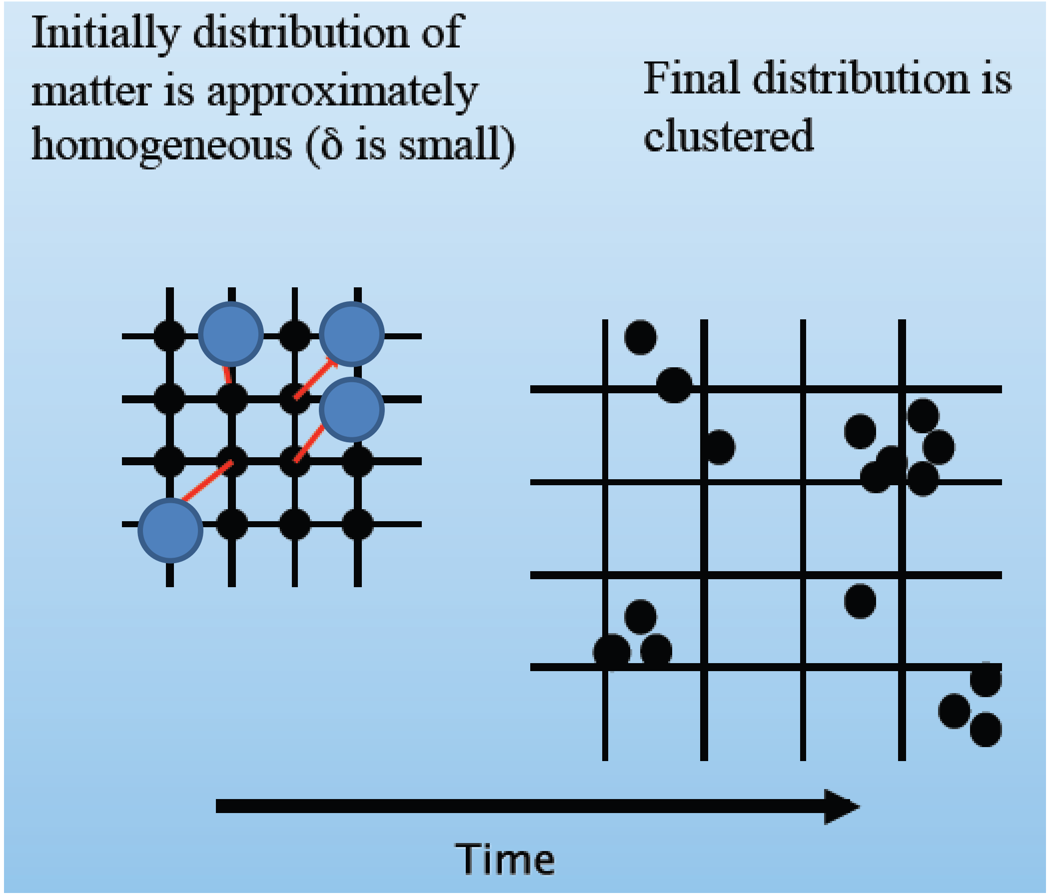
(based on arXiv :1411.7475)

OUTLINE

- Structure Growth
- Large Scale Structure
- What we measure
- Redshift Space Distortions (RSD)
- Measuring Galaxy Power Spectrum
- Bias Factor
- Extract Bias Factor FROM Observation
- CONCLUSION

STRUCTURE GROWTH

- Structure growth happens due to peculiar velocities

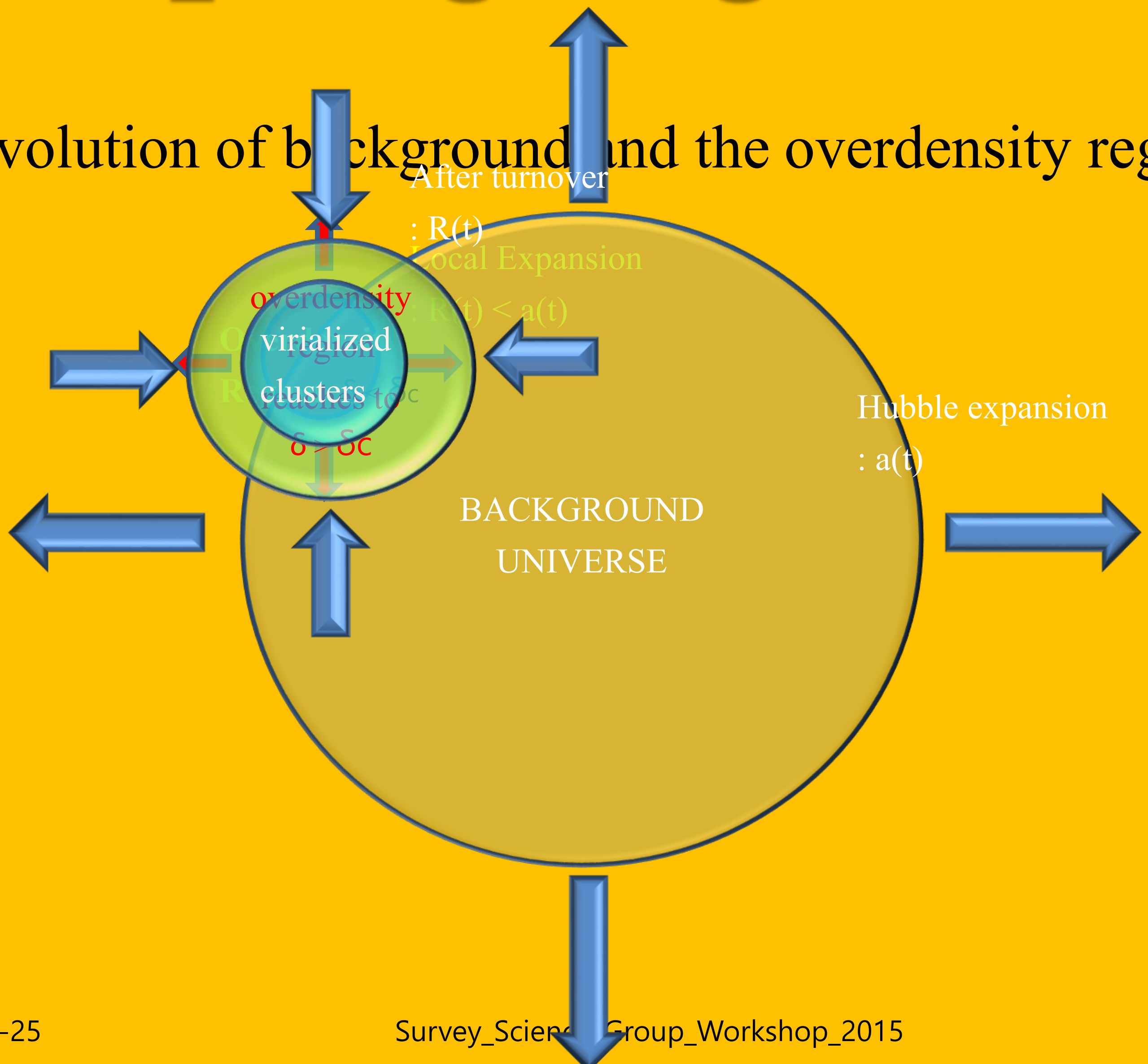


randomly distributed δ

starts from δ < 1 (linear) , then reaches to δ >1 (non-linear)

LARGE SCALE STRUCTURE

- Evolution of background and the overdensity region



WHAT WE MEASURE

- We measure galaxy numbers ≠ We calculate dark matter correlations (need **bias factor**)
- We measure in the redshift space ≠ We calculate in the real space (need **Redshift space distortions** correction = l.o.s peculiar velocity)
- Our measurement also includes non-linear growth : need N-body Simulation or semi-analytic higher order perturbation theory

REDSHIFT SPACE DISTORTIONS

- We measu ... ties cz = Hx)
- Peculiar v ... e shift
  (Hubble f
- Coherent ... Power
  Spectrum)

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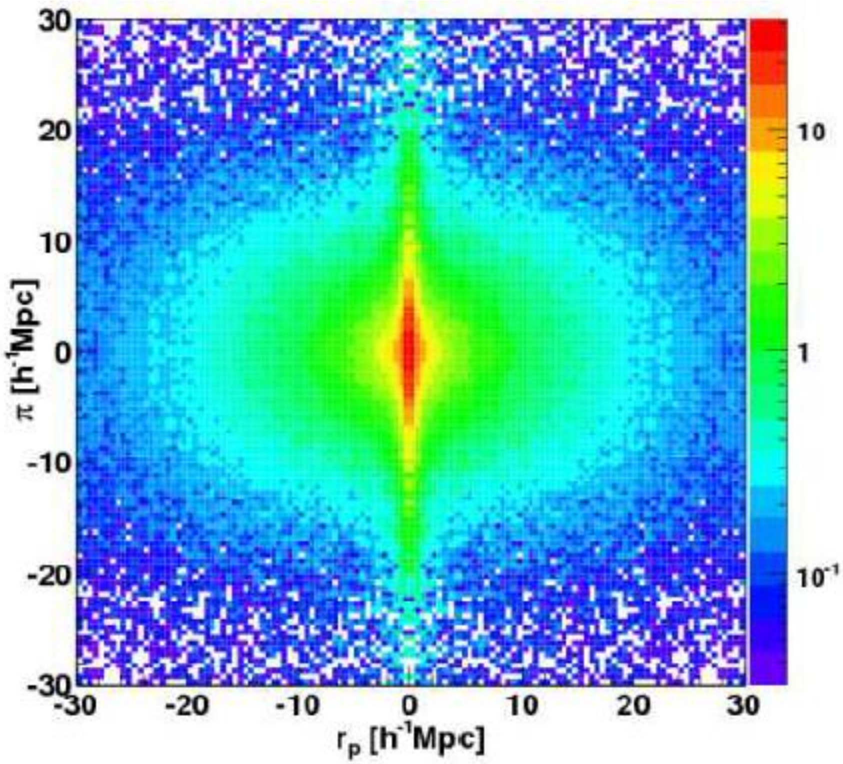


Figure 2. The 2D correlation function of 6dFGS using a density weighting with $P_0 = 1600h^3\,\mathrm{Mpc}^{-3}$. For reasons of presentation we binned the correlation function in $0.5h^{-1}$ Mpc bins, while in the analysis we use larger bins of $2h^{-1}$ Mpc. Both redshift-space distortion effects are visible: the “finger-of-God” effect at small angular separation r_p, and the anisotropic (non-circular) shape of the correlation function at large angular separations.

LINEAR PECULIAR VELOCITIES

- Assume galaxy with physical position x(t)

$$\begin{aligned} \vec{x}(t) &= a(t)\vec{r}(t) \\ \dot{\vec{x}} &\equiv \vec{v}_{\rm tot} = H\vec{x} + a\dot{\vec{r}} \equiv H\vec{x} + \vec{v}_{\rm peculiar} \\ &\equiv H\vec{x} + \vec{u} \end{aligned}$$

- peculiar velocity and gravitational acceleration

$$\dot{u} + 2Hu = -g \qquad \vec{g} = \nabla\Phi/a$$

- continuity (linear approximation) and Poisson equation

$$\boxed{\frac{d\delta}{d\tau} + \nabla\cdot\left[(1+\delta)\vec{u}\right]} \simeq \frac{d\delta}{d\tau} + \nabla\cdot\vec{u} = 0 \qquad \nabla\cdot g = \frac{3}{2}\Omega_m H^2 a^2 \delta$$

Need to be solved by using
1. N-body simulation
2. perturbation theory

- Solution for peculiar velocity & matter fluctuation

$$\vec{u} = \frac{2f}{3H\Omega_m}\vec{g} \text{ where f} \equiv \frac{\mathrm{d}\ln\delta}{\mathrm{d}\ln\mathrm{a}} \qquad \delta = -\frac{\nabla\cdot\vec{u}}{aHf} \rightarrow P_u(k) = \left(\frac{aHf}{k}\right)^2 P(k)$$

MEASURING GALAXY POWER SPECTRUM

- What we measure is in the **redshift space** (denoting with superscript, s) which is different from observable in real space

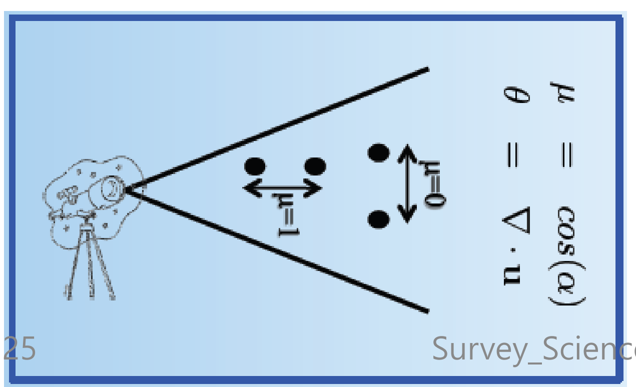
$$\begin{aligned} \delta_g^s(\mu) &= \delta_g + \mu^2\theta \\ P_g^s(\mu) &= \left\langle |\delta_g^s|^2 \right\rangle = P_{gg} + 2\mu^2 P_{g\theta} + \mu^4 P_{\theta\theta} \\ &= P_g \boxed{(1+\beta\mu^2)^2} (1 + k^2\mu^2\sigma_P^2/2)^{-1} \end{aligned}$$

- Also what we observe is galaxy not dark matter, need to introduce **bias factor**, b(z)

$$\theta = -f\delta_m \quad \beta \equiv bf$$

$$b(z) \equiv \delta_g / \delta_m$$

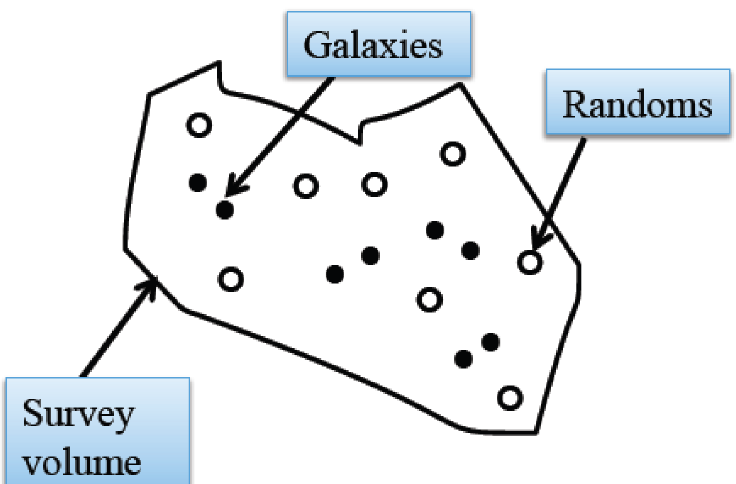
What we measure (galaxies)
is different from
what we calculate (DM)

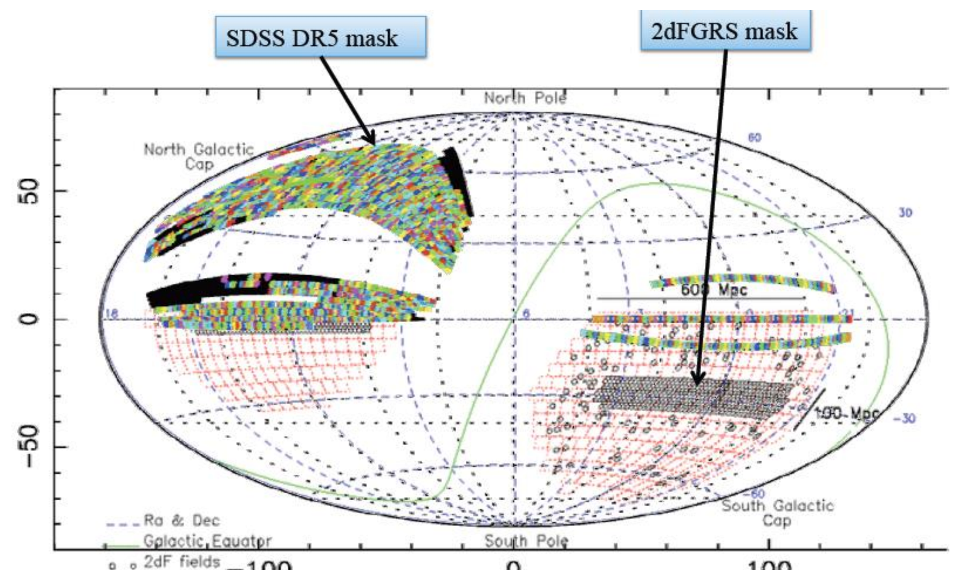


Galaxies = a preferred locations such as peaks in matter distribution (definition for the linear bias, Kaiser 84)

DATA ANALYSIS IN GALAXY SURVEYS : I

- First create random catalogue with same spatial sampling (same number of particles) as galaxies without clustering. define overdensity field as $F(r) = n_g(r) - n_s(r)/\alpha \equiv \frac{\rho - \bar{\rho}}{\bar{\rho}}$
- Modeling the angular galaxy mask & radial galaxy distribution





DATA ANALYSIS IN GALAXY SURVEYS : II

$$\xi_{\rm st}(r_p,\pi) = \int_{-\infty}^{\infty} \xi\left(r_p, \pi - \frac{v}{H(z_{\rm eff})a_{\rm eff}}\right) F(v)dv, \quad F(v) = \frac{1}{\sigma_p\sqrt{2}} \exp\left[\frac{-\sqrt{2}|v|}{\sigma_p}\right]$$

- Change into the redshift distribution in bins (ex : 6dF GRS, arXiv:1204.4725)

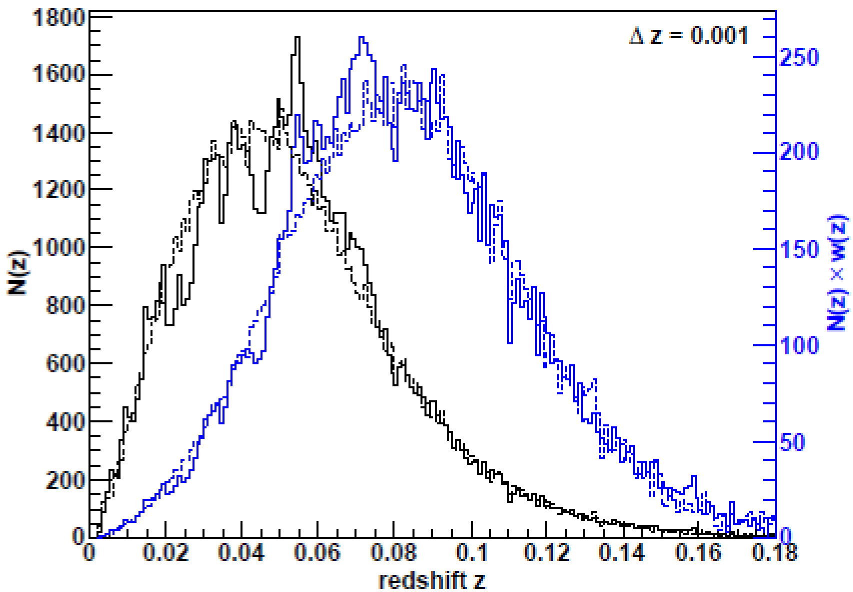


Figure 1. The solid black line shows the 6dFGS redshift distribution, while the dashed black line shows one of the random mock catalogues containing the same number of galaxies. The blue solid and dashed lines show the distribution after weighting with $P_0 = 1600h^3$ Mpc^{-3} (see section 3.1 for more details on the employed weighting scheme).

Fit to the redshift space 2-point correlation function

$$\xi'_{\rm data} = 1 + \frac{DD}{RR}\left(\frac{n_r}{n_d}\right)^2 - 2\frac{DR}{RR}\left(\frac{n_r}{n_d}\right)$$

Compare this with the theoretical 2-point correlation function to obtain $\beta\sigma_{\rm gal}$ $\sigma_{\rm gal}$

$$\begin{aligned}\xi_{\rm Sc}(r_p,\pi) = &\left[g_b^2\xi_{0,\delta\delta}(r) + \frac{2}{3}g_b g_\theta \xi_{0,\delta\theta}(r) + \frac{1}{5}g_\theta^2\xi_{0,\theta\theta}(r)\right]\mathcal{P}_0(\mu) \\ &+ \left[\frac{4}{3}g_b g_\theta \xi_{2,\delta\theta}(r) + \frac{4}{7}g_\theta^2\xi_{2,\theta\theta}(r)\right]\mathcal{P}_2(\mu) \\ &+ \frac{8}{35}g_\theta^2\xi_{4,\theta\theta}(r)\mathcal{P}_4(\mu),\end{aligned}$$

$$g_\theta(z) = f(z)\sigma_8(z) \text{ and } g_b(z) = b\sigma_8(z)$$

BIAS FACTOR

- Definition of (linear) bias

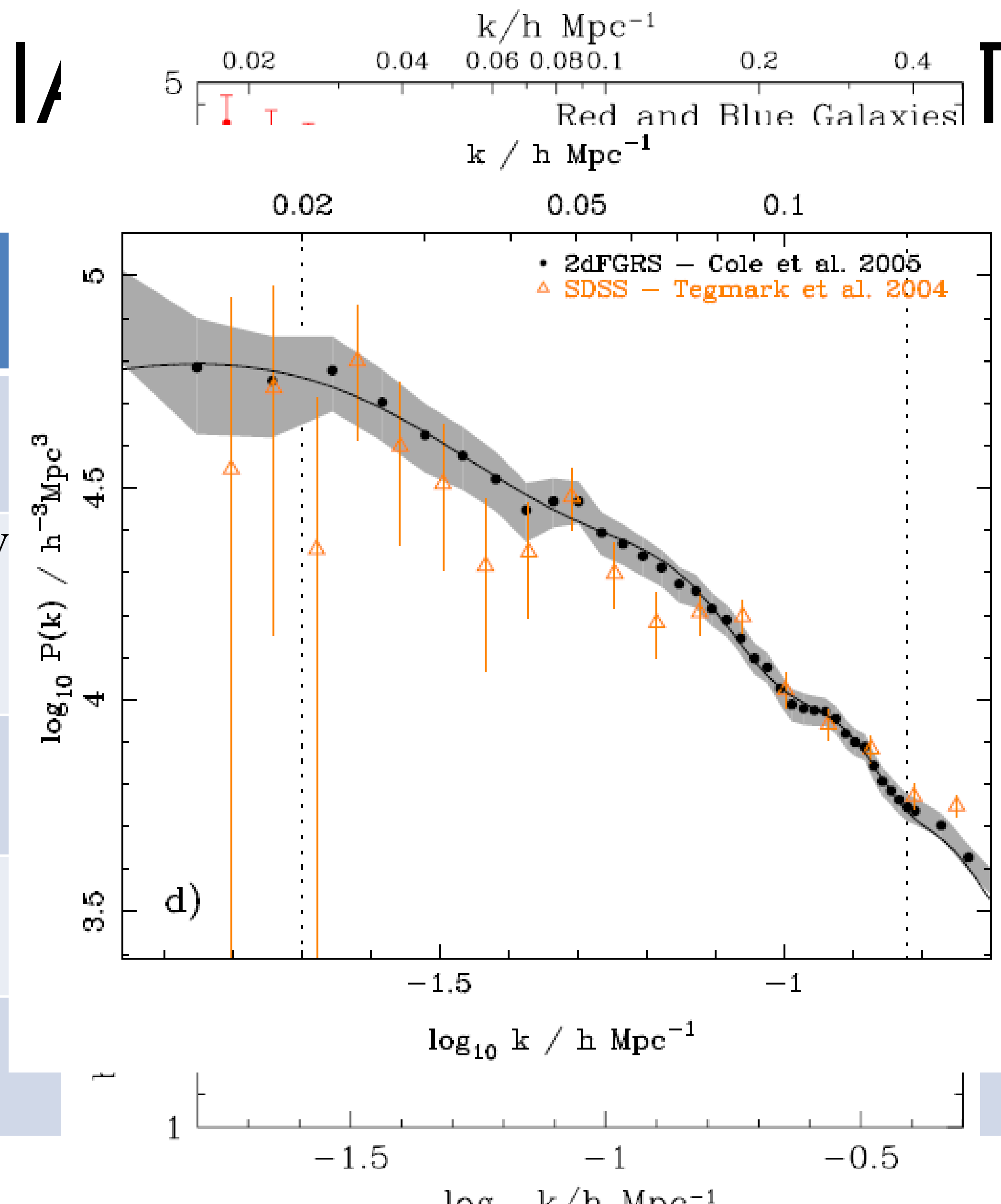
$$\delta_g = b\delta_m \qquad b = \sqrt{\frac{\xi_g}{\xi_m}} = \frac{\sigma_{8,g}}{\sigma_{8,m}}$$

bias : **a statistical in nature**
galaxies & clusters : high peaks of an underlying initially Gaussian random field

- Nuisance parameter because we don't understand δ_{gal}
- There exist several fitting formulae (ref arXiv:1405.5521)

Bias Model	$b(z)$	Source	Fiducial Values	Comments
Constant bias	b_0	-	$b_0 = 1.02$	'Unbiased'
Linear Redshift Evolution	$b_0(1+z)$	-	$b_0 = 0.68$	*Ad hoc*
Constant Galaxy Clustering (CGC)	$b_0/D(z)$	Lahav et al. (2002)	$b_0 = 0.80$	Empirical
Fry	$1+(b_0-1)/(D(z))$	Fry (1996)	$b_0 = 1.03$	Theoretical
Merging	$0.41+(b_0-0.41)/D(z)^\alpha$	Matarrese et al. (1997)	$b_0 = 0.84,\ \alpha = 1.73$	Theoretical
T10	$\nu(z) = \nu_0/D(z)$	Tinker et al. (2010)	$\nu_0 = 0.83$	Fitting function, N body
C05	$b_0(0.53+0.289(1+z)^2$	Croom et al. (2005)	$b_0 = 0.85$	Fitting function, QSO
Generalised Time Dependent (GTD)	$c+[b_0-c]/D(z)^\alpha$	-	$c = 0.57, b_0 = 0.79, \alpha = 2.23$	

BIA… TS



SURVEYS [Reference]	
2dFGRS [0212375]	-0.1
VVDS (VIMOS V… Deep Survey) [0802.1944]	-0.1
SDSSII LRG [1102.1014]	
6dFGRS [1204.4725]	+-0.27
WiggleZ [1302.5178]	1.10

Extract Bias From Observation

- Derive bias factor from its definition

$$\frac{d(f(z)\sigma_8(z))}{dz} = \frac{1}{(1+z)}\left[\left(\frac{1}{2} - \frac{3}{2}w\Omega_{\rm de}(z)\right)f(z)\sigma_8(z) - \frac{3}{2}\Omega_{\rm m}(z)\sigma_8(z)\right]$$

$$\begin{aligned} b(k,z) &= \frac{3}{2}\Omega_{\rm m}(z)\boxed{\sigma_{\rm gal}(z)}\left[\left(\frac{1}{2} - \frac{3}{2}w\Omega_{\rm de}(z)\right)\boxed{f\sigma_8} - (1+z)\boxed{\frac{d(f\sigma_8)}{dz}}\right]^{-1} \\ &= \frac{3}{2}\Omega_{\rm m}(z)\boxed{\sigma_{\rm gal}(z)}\left[\left(\frac{1}{2} - \frac{3}{2}w\Omega_{\rm de}(z)\right)\boxed{\beta\sigma_{\rm gal}} - (1+z)\boxed{\frac{d(\beta\sigma_{\rm gal})}{dz}}\right]^{-1} \end{aligned}$$

From theory
: **Calculable**

From Observation
: **Measurable**

SENSITIVITIES AND FORECAST

(SL. JCAP14)

- b vs w, Omo
- b vs w, Omo, gamma

Survey	z	N	V $(h^{-1}\text{Mpc})^3$	$\Delta(f\sigma_8)/(f\sigma_8)$ (%)
WFMOS	$0.5 \sim 1.3$	2×10^6	4×10^9	4.5
	$2.3 \sim 3.3$	6×10^5	1.2×10^9	8.3
BigBOSS	$0.2 \sim 2$	3×10^7	3×10^{10}	1.2
EUCLID	2	5×10^8	1×10^{11}	0.3
LSST	$0.15 \sim 3$	1×10^{10}	1×10^{11}	0.1

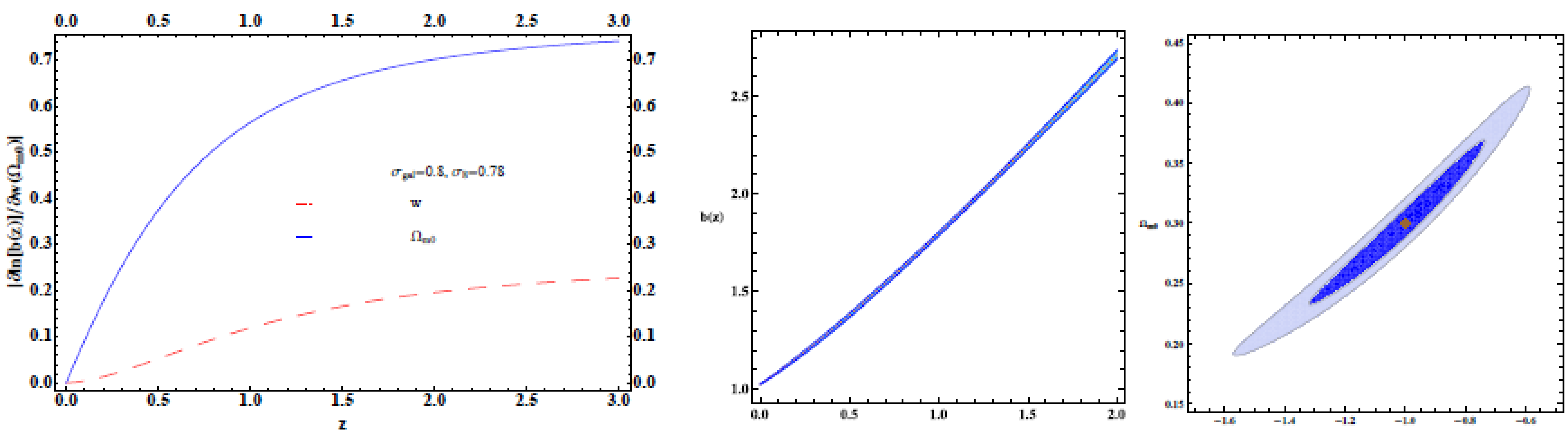


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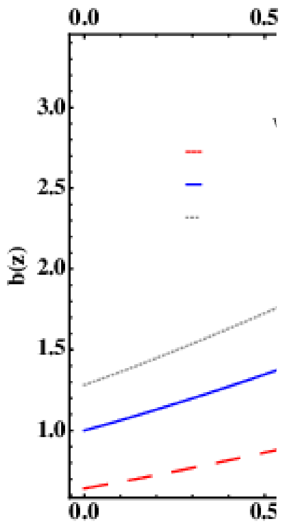
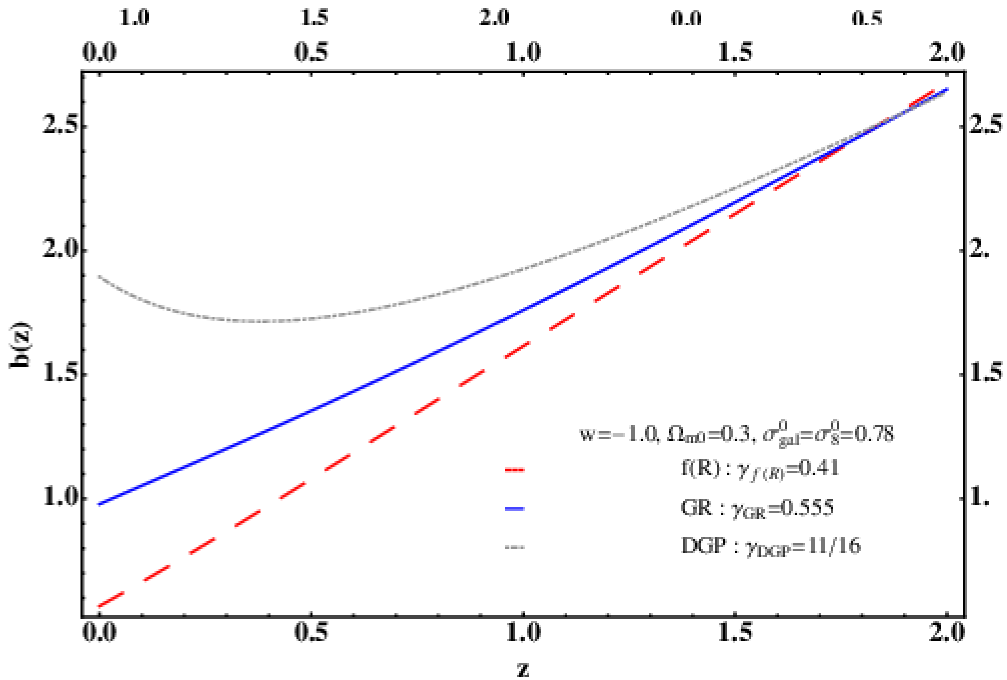
FIG. 3: *Left*) The sensitivity of the $b(z)$ to the cosmological parameters, w and Ω_{m0}. The thick solid line and the dashed line correspond Ω_{m0} and w, respectively. *Middle*) The variation of the $b(z)$ over redshift. The dashed line are the best-fit and the shaded shadow contour represents the 68 % confidence level around the best fit. *Right*) The 1-σ (inner ellipsoid) and 2-σ (outer one) confidence contours in the w-Ω_{m0} plane for the corresponding $b(z)$.

PREDICTION OF b FOR GR & MG

Predictions : break degeneracy btw w and Om0 (Peacock 9010.3834)





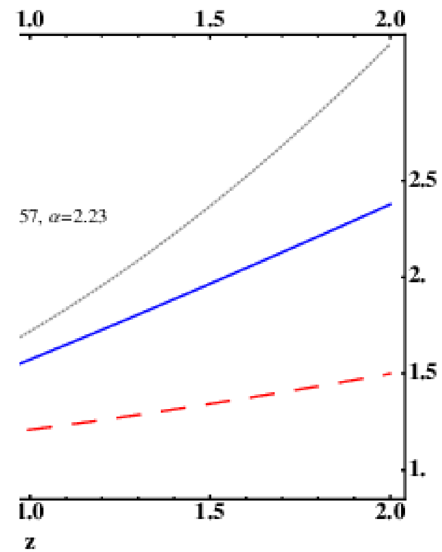


FIG. 2: *Left*) Tim ... $= 0.3$, and $\sigma_8 = 0.78$. $b(z)$ correspond $\sigma_{gal} =$ ... z) for different models. b_{TP} (dashed), b_S (solid ...

0.35 (dashed), respectively.

CONCLUSIONS

- What we see is not what we have due to RSD and b(z)
- Bias was known as a nuisance parameter
- Bias can be obtained both from theory and observation
- One can investigate the cosmology and galaxy dependence on b
- Different gravity theories produce different b(z). Thus, one should consider these difference compared with data (because theory calculate Pm(k) not Pg(k)
- b(z) grows as z increases in GR but not in DGP or (in f(R))